DEENDAYAL PORT AUTHORITY
(Erstwhile: DEENDAYAL PORT TRUST)

Administrative Office Building
Post Box NO. 50
GANDHIDHAM (Kutch).
Gujarat: 370 201.
Fax: (02836) 220050
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www.deendayalport.gov.in

EG/WK/4751/Part (Comp.1)/ 11

Dated: 06 /01/2025

To,
Director (Environment) & Member Secretary,
Gujarat Coastal Zone Management Authority,
Forest & Environment Department,
Govt. of Gujarat,
Block No.14, 8th floor,
Sachivalaya, **Gandhinagar – 382 010.**

Sub: "Development of 7 Integrated facilities (Stage I) within the existing Kandla Port Trust limit at District Kutch (Gujarat) by M/s Kandla Port Trust Limited"– **Pointwise Compliances of the conditions stipulated in CRZ Recommendations reg.**

Ref.: 1) Letter No. ENV-I0-2014-25-E July, 1, 2015 of Director (Environment) & Member Secretary, GCZMA, Forest & Environment Department, GoG
2) Compliance Report (period up to May, 2017) submitted vide letter dated: 12/6/2017.
3) Compliance Report (period up to Nov., 2017) submitted vide letter dated: 15/12/2017.
4) Compliance Report (period up to May, 2018) submitted vide letter dated: 14(21)/06/2018.
5) Compliance Report (period up to March, 2019) submitted vide letter dated: 30(2)/03(04)/2019.
6) Compliance report (period up to October, 2019) submitted vide letter dated: 14/11/2019.
7) Compliance report (period upto Nov., 2020) submitted vide letter dated 29/12/2020.
8) Compliance report (period upto May, 2021) submitted vide letter dated 07/10/2021.
9) Compliance report (period upto May, 2022) submitted vide letter dated 30/01/2023.
10) Compliance report (period upto Nov., 2022) submitted vide letter dated 20/04/2023
11) Compliance report (period upto May, 2023) submitted vide letter dated 12/09/2023.
12) Compliance report (period upto Nov, 2023) submitted vide letter dated 20/2/2024.
13) Compliance report (period upto May, 2024) submitted vide letter dated 25/07/2024.
14) Compliance report (period upto Dec, 2024) submitted vide letter dated 21/01/2025.
15) Compliance report (period upto March, 2025) submitted vide letter dated 02/06/2025.

Sir,

It is requested to kindly refer the above cited references for the said subject.

In this connection, it is to state that, the Gujarat Coastal Zone Management Authority vide above referred letter dated 1/7/2015 had recommended 7 project activities of Deendayal Port Authority. Subsequently, the MoEF&CC, GoI had accorded the Environmental & CRZ Clearance vide letter dated 19/12/2016 for the 7 project activities recommended by the GCZMA.

.....Cont.....

Subsequently, DPA vide above referred letters had regularly submitted compliance report of the stipulated conditions, to the Additional Secretary & Director (Env.), F & E Dept., GoG.

Now, as directed under Specific Condition No. 28 mentioned in the CRZ Clearance letter dated 1/7/2015 i.e. ***A six monthly report on compliance of the conditions mentioned in this letter shall have to be furnished by the DPA on a regular basis to this Department and MoEF&CC, GoI***, please find enclosed herewith compliance report (for the period April, 2025 to September, 2025) of stipulated conditions along with necessary annexures, for kind information & record please **(Annexure I).**

Further, as per the MoEF&CC, Notification S.O.5845 (E) dated 26.11.2018, stated that "***In the said notification, in paragraph 10, in sub-paragraph (ii), for the words "hard and soft copies" the words "soft copy" shall be substituted***". Accordingly, we are submitting herewith soft copy of the same via e-mail ID gczma.crz@gmail.com & direnv@gujarat.gov.in.

This has the approval of Chief Engineer, Deendayal Port Authority.

Thanking you.

Yours faithfully,

Executive Engineer

Deendayal Port Authority

Copy to:

Shri Amardeep Raju,
Scientist E, Ministry of Environment, Forest and Climate Change,
& Member Secretary (EAC-Infra.1),
Indira Paryavaran Bhawan,
3rd Floor, Vayu Wing, Jor Bagh Road, Aliganj,
New Delhi- 110 003;
E-mail: ad.raju@nic.in

COMPLIANCE REPORT (for the period from April, 2025 to September, 2025)

Subject: Status of Compliance with the conditions stipulated By Gujarat State Coastal Zone Management Authority, Gandhinagar, in CRZ Recommendation Letter granted for "**Development of 7 integrated facilities (Stage I) within existing Deendayal Authority at Kandla**".

CRZ Recommendations: Letter No. ENV-I0-2014-25-E dated July 1, 2015, of Director (Environment) & Member Secretary, GCZMA, Forest & Environment Department, GoG.

**Note: Based on the recommendation of* the GCZMA, MoEF&CC, GoI *had accorded Environmental & CRZ Clearance vide letter dated 19/12/2016*

Sr. No.	Conditions in CRZ Recommendation Letter	Compliance
	Specific Conditions	
1	The provisions of the CRZ notification of 2011 and subsequent amendments issued from time to time shall be strictly adhered to by the KPT. No activity in contradiction to the Provisions of the CRZ Notification shall be carried out by the KPT.	a) For Project at Sr. No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A**. b) Further, w.r.t. project at Sr. No. 2 & 4 (construction not yet started), it is assured that no activity in contradiction to the Provisions of the CRZ Notification shall be carried out by DPA. c) Project at Sr no. 3,5,6 and 7 is already completed.
2	The KPT shall have to ensure that there shall not be any damage to the existing mangrove area.	a) For Project at Sr. No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A**. b) Further, w.r.t. project at sr.no. 2 & 4 (construction not yet started), it is assured that due care shall be taken to protect the existing mangrove area.
3	The KPT shall prepare an emergency plan to protect existing mangroves in case of any eventuality/accident.	DPA had already prepared report through Gujarat Institute of Desert Ecology, Bhuj on Study on present Status, Conservation and Management plan for Mangroves of Deendayal Port region.
4	The KPT shall have to make a provision that mangrove areas get proper flushing water and free flow of water shall not be obstructed.	a) For Project at Sr. No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A.** b) Further, w.r.t. project at sr.no. 2 & 4 (construction not yet started), it is assured that provisions shall be made that mangrove areas get proper flushing water and free flow of water shall not be obstructed.
5	The KPT shall have to abide by whatever decision is taken by the GCZMA for violations of CRZ Notification, 2011.	a) Point noted. DPA will abide by whatever decision is taken by the GCZMA for violations of CRZ Notification, 2011. b) For Project at Sr. No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A.**
6	There shall not be violations of the order dated 9/12/2013 passed by the National Green Tribunal; and accordingly, there shall be no mangrove destruction taking place in the KPT area.	a) Point Noted. It is hereby assured that due care shall be taken to protect the existing mangrove area. b) For Project at Sr.No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A.**
7	No dredging, reclamation or any other project-related activities shall be carried out in the CRZ area categorised as CRZ I (i), and it shall have to be ensured that the mangrove habitats and other ecologically important and significant areas, if any, in the region are not affected due to any of the project activity.	a) It is hereby assured that DPA will undertake only such project activities (7 project activities) recommended by the GCZMA vide letter dated 1/7/2015 and EC & CRZ Clearance accorded by the MoEF&CC, GoI vide letter dated 19/12/2016. DPA issued a work order to M/s GUIDE vide its letter no. EG/ WK/ 4751/ Part (Marine Ecology Monitoring) /11

		dated 03/05/2021 for Regular monitoring of Marine Ecology in and around Deendayal Port Authority (Erstwhile Deendayal Port Trust) and continuous Monitoring Program covering all seasons on various aspects of the Coastal Environs for the period 2021-24. Final Reports for the period 2021-22, 2022-23 & 2023-24, have already been submitted along with compliance report submitted from time to time. In continuation of the same, DPA issued a work order to M/s GUIDE vide its letter no. EG/ WK/ 4751/ Part (Marine Ecology Monitoring) /72 dated 10/06/2024 for further period of 2024 – 27. A copy of Annual report (2024 25) is attached herewith as **Annexure B** b) For Project at Sr.No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A.**
8	The KPT shall participate financially in installing and operating the Vessel Traffic Management System in the Gulf of Kachchh and shall also take the lead in preparing and operational sing and updating regularly after getting it vetted by the Indian Coast Guard.	Deendayal Port Authority had already contributed Rs. 41.25 crores, i.e. 25% of the total project cost of 165 crores for installing and operating the VTMS in the Gulf of Kachchh.
9	The KPT shall strictly ensure that no creeks or rivers are blocked due to any activity at Kandla.	a) For Project at Sr.No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A.** b) Further, w.r.t. project at sr.no. 2 & 4 (construction not yet started), it is assured that no creeks or rivers shall be blocked due to any activity at Kandla.
10	Mangrove plantation in an area of 100 ha. Shall be carried out by the KPT within 2 years in time bound manner on Gujarat coastline either within or outside the Kandla port Trust area, and a six-monthly compliance report along with the satellite images shall be submitted to the Ministry of Environment and Forest as well as to this Department without fail.	DPA has undertaken Mangrove Plantation in an area of 1650 Hectares since the year 2005. carried out through various agencies. The copy of the details has already been communicated with the earlier compliance reports submitted. In addition to the above, DPA appointed M/s GUIDE, Bhuj, for "Regular Monitoring of Mangrove Plantation carried out by DPA" (period 15/9/2017 to 14/9/2018 vide work order dated 1/9/2017 and 24/5/2021 to 23/5/2022 vide work order dated 3/5/2021). The final report submitted by M/s GUIDE, Bhuj, for the years 2017 to 2018 as well as for the year 2021 to 2022 has been submitted in the earlier compliance report submitted. Further, vide work order dated 10/06/224 DPA appointed M/s GUIDE, Bhuj, for "Regular Monitoring of Mangrove Plantation carried out by DPA" (Period 10/06/2024 to 09/06/2025). The work has completed and the final report submitted by GUIDE, Bhuj is attached herewith as **Annexure C.**
11	No activities other than those permitted by the competent authority under the CRZ Notification shall be carried out in the CRZ area.	a) Point Noted. It is assured that only activities permitted by the competent authority under the CRZ Notification shall be carried out in the CRZ area. b) For Project at Sr. No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A**.
12	No groundwater shall be tapped for any purpose during the proposed expansion modernization activities.	a) For Project at Sr.No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A**. b) Further, w.r.t. Project at Sr. no.2 & 4 (construction not yet started), Water requirement will be met through procurement from GWSSB or private tankers. No

		ground water shall be tapped.
13	All necessary permissions from different Government Departments/agencies shall be obtained by the KPT before commencing the expansion activities.	DPA had already obtained the necessary Environmental & CRZ Clearance for 7 project activities (dated 19.12.2016). Further, Consent to Establish from GPCB had already been obtained from GPCB for 7 project activities. Moreover, DPA had obtained CTE validity extension (CTE-125870) from GPCB vide Order dated 27/04/2023 with validity up to 15/11/2025.
14	No effluent or sewage shall be discharged into sea/creek or in the CRZ area and it shall be treated to conform to the norms prescribed by the GPCB and would be reused /recycled within the plant premises.	a) For completed projects (modification/ strengthening/ up- gradation of existing facilities), Sewage is being treated in the STP of Kandla (1.5 MLD). The treated sewages from STP of DPA are utilized for plantation / Gardening. For monitoring of environmental parameters, DPA has been appointing NABL Accredited laboratory and reports are being submitted from time to time to the GPCB, IRO, MoEF&CC, GoI, Gandhinagar. Recently, DPA appointed GEMI, Gandhinagar for regular monitoring of environmental parameters vide Work Order dated 15/02/2023. The work is in progress and the latest environmental monitoring report submitted by GEMI, Gandhinagar is attached herewith as **Annexure D**. b) Further, w.r.t. Project at Sr.No.1, kindly refer to the Monitoring reports submitted by M/s KOTPL along with compliance report placed at **Annexure A**.
15	All the recommendations and suggestion given by the MANTEC Consultants Pvt. Ltd. in their Comprehensive Environment Impact Assessment report for conservation / protection and betterment of environment shall be implemented strictly by the KPT.	DPA has installed Mist Canon at the Port area to minimize the dust. DPA has undertaken the project of dust supersession sprinkling system for the 34 hectare coal storage yard Further, DPA has already installed continuous sprinkling system in coal stack yard in DPA (40 ha. area) to prevent dust pollution. Further, to control dust pollution in other area, regular sprinkling through tankers on roads and other staking yards is being done. Regular sweeping of spilled cargo from roads is done by parties on regular basis. For monitoring of environmental parameters, DPA has been appointing NABL Accredited laboratory and reports are being submitted from time to time to the GPCB, IRO, MoEF&CC, GoI, Gandhinagar. Recently, DPA appointed GEMI, Gandhinagar for regular monitoring of environmental parameters vide Work Order dated 15/02/2023. The work is in progress and the latest environmental monitoring report submitted by GEMI, Gandhinagar is attached herewith as **Annexure D**. For ship waste management, DPA issued Grant of License/Permission to carry out the work of collection and disposal of "Hazardous Waste/Sludge/ Waste Oil" and "Dry Solid Waste (Non- Hazardous)" from Vessels calling at Deendayal Port" through DPA contractors. Further, it is to state that, all ships are required to follow DG Shipping circulars regarding the reception facilities at Swachch Sagar portal. Further, DPA has appointed GEMI, Gandhinagar for the work of "Preparation of Plan for Management of Plastic Wastes, Solid Waste, including C&D waste, E-waste, Hazardous waste, including Biomedical and Non-Hazardous Waste in the Deendayal Port Authority" vide Work Order dated 24/01/2023. The work is completed.

		And final report submitted on along with compliance submitted on 21/01/2025 DPA assigned work to M/s GUIDE, Bhuj, for regular monitoring of Marine Ecology since the year 2017 (From 2017 – 2021), and final reports of the same submitted by GUIDE, Bhuj has already been communicated to the Regional Office, MoEF&CC, GoI, Gandhinagar as well as to the MoEF&CC, GoI, New Delhi along with compliance reports submitted. Further, DPA issued a work order to M/s GUIDE vide its letter no. EG/ WK/ 4751/ Part (Marine Ecology Monitoring) /11 dated 03/05/2021 for Regular monitoring of Marine Ecology in and around Deendayal Port Authority (Erstwhile Deendayal Port Trust) and continuous Monitoring Program covering all seasons on various aspects of the Coastal Environs for the period 2021-24. Final Report for the period 2020-21 has already been submitted along with compliance report submitted dated 07/10/2021 In continuation of the same, DPA issued a work order to M/s GUIDE vide its letter no. EG/ WK/ 4751/ Part (Marine Ecology Monitoring) /72 dated 10/06/2024 for further period of 2024 – 27. A copy of Annual report (2024 25) is attached herewith as **Annexure B** As already informed, DPA entrusted work of green belt development in and around the Port area to the Forest Department, Gujarat at Rs. 352 lakhs (Area 32 hectares). The work is completed. Further, DPA has appointed the Gujarat Institute of Desert Ecology (GUIDE) for "Green belt development in Deendayal Port Authority and its Surrounding Areas, Charcoal site' (Phase-I)" vide Work Order No.EG/WK/4757/Part [Greenbelt GUIDE, dated 31st May 2022. The final report submitted by GUIDE, Bhuj is submitted by compliance report submitted on 12/09/2023. Further DPA has accorded the work of "Green belt development in DPA and its surrounding area (Phase II) to Gujarat Institute of Desert Ecology (GUIDE), Bhuj for the plantation of 10000 saplings of suitable species vide work order dated 23/06/2023. The same completed. Final report submitted along with compliance report submitted on 21/01/2025 Further DPA has accorded the work of "Green belt development in DPA and its surrounding area (Phase III) to Gujarat Institute of Desert Ecology (GUIDE), Bhuj for the plantation of 5000 saplings at DPA and 200 saplings at Gopalpuri colony. The inception report is attached herewith as **Annexure E.** For dredged material management, DPA had issued work order to GUIDE, Bhuj for "Study on dredged material for presence of Contaminants for year 2021-2024. The copy final report submitted by M/s GUIDE, Bhuj for the period 2023-2024 has already been communicated with last compliance report submitted on 02/06/2025. In continuation of same DPA issued DPA had issued work order to GUIDE, Bhuj for "Study on dredged material for presence of Contaminants for year 2024-2027 vide work order dated 07/10/2025 A copy of 2nd season report is

		Attached herewith as **Annexure F.** Further, Dredged Material will be disposed of at designated location as identified by the CWPRS, Pune. For energy conservation measures, DPA is already generating 20.7 MW installed capacity of Wind energy. In addition to it, DPA has commissioned a 45 kWP Solar Plant at Gandhidham. Further, it is relevant to mention that, two out of four Nos. of Harbour Mobile Crane (HMC) made electric operated. Balance 02 Nos. shall be made electric operated by 2025 end. Four Nos. of Deisel operated RTGs converted to e-RTGs. Retrofitting of hydrogen fuel cell in Tug Kalinga and Pilot Boat Niharika to be done as a pilot project under the guidance of MoPSW. Also, 14 Nos. of EV cars to be hired in this year and hydrogen Buses to be procured in the year 2025-26. Further, for Oil Spill Management, DPA is already having Oil Spill Contingency Plan in place and Oil Response System as per the NOS-DCP guidelines. A copy of updated oil spill contingency plan has already communicated with last compliance report submitted.
16	The construction and operational activities shall be carried out in such a way that there is no negative impact on mangroves and other coastal /marine habitats. The construction activities and dredging shall be carried out only under the constant supervision and guidelines of the Institute of National repute like NIOT.	a) For Project at Sr. No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A.** b) For the remaining projects Sr. No 2 & 4 (construction not yet started), it is assured that construction activities and dredging shall be carried out only under the constant supervision and guidelines of the Institute of National repute like NIOT.
17	The KPT shall contribute financially for any common study or project that may be proposed by this Department for environmental management / conservation / improvement for the Gulf of Kutch.	Point noted.
18	The construction debris and / or any other of waste shall not be disposed of into the sea, creek or the CRZ areas. The debris shall be removed from the construction site immediately after the construction is over.	a) For Project at Sr.No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A**. b) Further, w.r.t. project at sr.no. 2 & 4 (construction not yet started), it is assured that construction debris and/ or any other of waste shall not be disposed of into the sea, creek or the CRZ areas, and the debris shall be removed from the construction site immediately after the construction is over.
19	The construction camps shall be located outside the CRZ area and the construction labour shall be provided with the necessary amenities, including sanitation, water supply and fuel and it shall be ensured that the environmental conditions are not deteriorated by the construction labours.	a) No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A**. b) Further, w.r.t. project at sr.no. 2 & 4 (construction not yet started), it is assured that, the construction camps shall be located outside the CRZ area, provision of the necessary amenities, including sanitation, water supply and fuel to the construction labour shall be made, and that the environmental conditions are not deteriorated by the construction labours.
20	The KPT shall regularly updates its Local Oil Spill Contingency and Disaster management Plan in accordance with the National Oil Spill and Disaster Contingency Plan and shall submit the same to the MoEF, GoI and this department after having it vetted through the Indian Coast Guard.	▪ Deendayal Port already has an update Disaster Management Plan. A copy has already communicated with the last compliance submitted on 02/06/2025. ▪ Further, the Local Oil Spill Contingency Plan is already available with Deendayal Port Trust. Copy has already communicated with last compliance report. ▪ DPA has also executed MOU with Oil Companies, i.e. IOCL, HPCL, BPCL etc., for combating the Oil Spill at

		Kandla
21	The KPT shall bear the cost of the external agency that may be appointed by this Department for supervision/monitoring of proposed activities and the environmental impacts of the proposed activities.	Point noted.
22	The KPT shall take up massive greenbelt development activities in and around Kandla and also within the KPT limits.	DPA has planted about one lakhs trees in roadside dividers, colony areas at Kandla and Gopalpuri, in the green belt area of Gandhidham & Adipur Township, Sewage Treatment Plants at Gopalpuri & Kandla and some green belt development plans initiated at different locations in Township areas. DPA entrusted work of green belt development in and around the Port area to the Forest Department, Gujarat, at the cost of Rs. 352 lakhs (Area 32 hectares). The plantation is completed. Further, DPA has appointed the Gujarat Institute of Desert Ecology (GUIDE) for "Green belt development in Deendayal Port Authority and its Surrounding Areas, Charcoal site' (Phase-I)" vide Work Order No.EG/WK/4757/Part [Greenbelt GUIDE, dated 31st May 2022. The final report submitted by GUIDE, Bhuj is submitted along with compliance report submitted on 12/09/2023. Further DPA has accorded the work of "Green belt development in DPA and its surrounding area (Phase II) to Gujarat Institute of Desert Ecology (GUIDE), Bhuj for the plantation of 10000 saplings of suitable species vide work order dated 23/06/2023. The same is completed. Final report is submitted along with compliance report submitted on 21/01/2025. Further DPA has accorded the work of "Green belt development in DPA and its surrounding area (Phase III) to Gujarat Institute of Desert Ecology (GUIDE), Bhuj for the plantation of 5000 saplings at DPA and 200 saplings at Gopalpuri colony. The inception report is attached herewith as **Annexure E.**
23	The KPT shall have to contribute financially for taking up the socio- economic upliftment activities in this region in construction with the Forest and Environment Department and the District Collector/District Development Officer.	The details of the fund earmarked under CSR activities and CSR activities undertaken by DPA to date & proposed activities are placed at **Annexure G**.
24	A separate budget shall be earmarked for environmental management and socioeconomic activities and details there of shall be furnished to this Department as well as the MoEF, GOI. The details with respect to the expenditure from this budget head shall also be furnished.	a) The allocation made under the "Environmental Services & Clearance of other related Expenditure" during RBE 2024-25 is Rs. 585 Lakhs. b) The funds earmarked for EMP by the Concessionaire M/s KOTPL w.r.t. project at Sr.No. 1 are delineated in the compliance report submitted (**Annexure A**).
25	A separate environmental management cell with qualified personnel shall be created for environmental monitoring and management during the construction and operational phases of the project.	a) For Project at Sr.No. 1 which is under construction, kindly refer compliance submitted by M/s KOTPL (concessionaire of the project) placed at **Annexure A.** b) DPA is already having Environment Management cell. Further, DPA has also appointed expert agency for providing Environmental Experts from time to time.

		Recently, DPA appointed M/s Precitech Laboratories, Vapi for providing Environmental Experts vide work order dated 04/10/2024. In addition, it is relevant to submit here that, DPA has appointed a Chief Manager (Environment and Safety) and two Managers (Environment and safety) on contractual basis for the period of 3 years and further extendable to 2 years. Copy of the details are attached herewith as **Annexure H**. For monitoring of environmental parameters, DPA has been appointing NABL Accredited laboratory and reports are being submitted from time to time to the GPCB, IRO, MoEF&CC, GoI, Gandhinagar. Recently, DPA appointed GEMI, Gandhinagar for regular monitoring of environmental parameters vide Work Order dated 15/02/2023. The work is in progress and the latest environmental monitoring report submitted by GEMI, Gandhinagar is attached herewith as **Annexure D**.
26	An Environmental report indicating the changes, if any, with respect to the baseline environmental quality in the coastal and marine environment shall be submitted every year by the KPT to this Department as well as to the MoEF&CC, GOI.	For monitoring of environmental parameters, DPA has been appointing NABL Accredited laboratory and reports are being submitted from time to time to the GPCB, IRO, MoEF&CC, GoI, Gandhinagar. Recently, DPA appointed GEMI, Gandhinagar for regular monitoring of environmental parameters vide Work Order dated 15/02/2023. The work is in progress and the latest environmental monitoring report submitted by GEMI, Gandhinagar is attached herewith as **Annexure D**.
27	The KPT shall have to contribute financially to support the National Green Corps Scheme being implemented in Gujarat by the GEER Foundation, Gandhinagar, in construction with Forests and Environment Department.	Point Noted.
28	A six-monthly report on compliance of the conditions mentioned in this letter shall have to be furnished by the KPT on regular basis to this department/MoEF, GOI.	DPA has been submitting the six-monthly compliance report of the conditions stipulated in CRZ recommendation to GCZMA and IRO, MoEF&CC, GoI, Gandhinagar.
29	Any other condition that may be stipulated by this department from time to time for environmental protection/management purpose shall also have to be complied with by the KPT.	Point noted.

Annexure -A

Kandla Oil Terminal Private Limited

Registered Office: "NEELADRI", 3rd Floor, No. 9, Cenotaph Road, Alwarpet, Chennai - 600 018.
Tel: +91-44-4590 2222, 4590 2299, Fax: + 91-44-4590 2200, URL : www.imc.net.in CIN: U60200TN2013PTC092551

Ref: KRO/KOTPL/03102025

Date:03-10-2025

To,

The Executive Engineer(Design)

Deendayal Port Authority

Administrative-Office

Gandhidham -Kutch-370201

Sub: Development of oil jetty to handle Liquid Bulk and Ship bunkering Terminal at Old Kandla (Project)-Half Yearly EC & CRZ Compliance report.

Dear Sir,

The half yearly compliance report for the KOTPL project for the period from April 2025 to Sept 2025 are enclosed herewith (EC, CRZ & CTE)

We would appreciate your acknowledgment of receipt of these documents.

Your sincerely,

For Kandla Oil Terminal Private Limited.

(Authorized Signatory)

CC: independent Engineer, IITM

Encl:

1. EC Compliance report
2. CRZ Compliance report
3. CTE Compliance report
4. Monitoring data sheet
5. Ambient air (Six months).
6. Noise Monitoring (Six months)
7. Drinking water Report (Six Months).

Pertem to XEN (Env)
6/10.

Report Ref. No: EE/ENV/2025/04/127

Report Date: 30/04/2025

TEST REPORT
(For the Month of April - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/AA1	**Sample Location**	Near Jetty Landfall Area
Sampling Date	25/04/2025	**Type of Sample**	Ambient Air
Sample Received Date	25/04/2025	**Sampling Method**	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	26/04/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	28/04/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	65.31	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	18.44	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	12.30	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	15.14	IS 5182 (Part 6) : 2022	80

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ GUJARAT
Authorized Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/04/128

Report Date: 30/04/2025

TEST REPORT
(For the Month of April - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near loc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/AA2	Sample Location	Near Tank Farm Area
Sampling Date	25/04/2025	Type of Sample	Ambient Air
Sample Received Date	25/04/2025	Sampling Method	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	26/04/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	28/04/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	60.25	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	15.58	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	09.39	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	11.62	IS 5182 (Part 6) : 2022	80

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY ★ EARTH ENVIROTECH)

Authorized Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/04/129

Report Date: 30/04/2025

TEST REPORT
(For the Month of April - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near loc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/N1-N4	Sampling Location	As per table
Measurement Start Date	25/04/2025	Type of Sample	Noise Monitoring
Measurement End Date	26/04/2025	Sampling Instrument	Sound Level Meter
Measurement Done By	Earth Envirotech Team	Sampling Method	IS 9989 : 2023

ANALYSIS RESULTS

Sr. No.	Location Name	Unit	Day Time	Night Time
			Spot Noise Level dB(A) Maximum	Spot Noise Level dB(A) Maximum
Standard Limits		dB(A)	75.0	70.0
1.	Near Jetty Landform Area	dB(A)	72.6	66.2
2.	Near Tank Farm Area	dB(A)	65.0	60.6
3.	Near Tank Farm Right Side	dB(A)	69.4	63.9
4.	Near Tank Farm Left Side	dB(A)	62.9	55.8

Day Time: 06:00 AM to 10:00 PM
Night Time: 10:00 PM to 06:00 AM

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ GUJARAT
Authorized Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/04/130

Report Date: 30/04/2025

TEST REPORT
(For the Month of April - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near loc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/DW1	Sample Location	Near Office Area
Sampling Date	25/04/2025	Type of Sample	Drinking Water
Sample Received Date	25/04/2025	Quantity of Sample	2 Liter
Analysis Start Date	26/04/2025	Sampling Method	APHA 24th ED. 1060 B : 2023
Analysis End Date	30/04/2025	Sample Collection By	Earth Envirotech Team

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Acceptable Limit as per (IS 10500 : 2018)
1.	pH	--	7.50	6.5 - 8.5
2.	Temperature	°C	24	--
3.	Electric Conductivity	µS/cm	286.37	--
4.	Total Suspended Solids	mg/L	05	--
5.	Total Dissolved Solids	mg/L	168	500
6.	Total Hardness (as $CaCO_3$)	mg/L	45	200
7.	Calcium (as Ca)	mg/L	37.23	75
8.	Magnesium (as Mg)	mg/L	25	30
9.	Chloride	mg/L	77	250
10.	E. Coli	Per 100 ml	Absent	Absent

Analyzed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ EARTH ENVIROTECH
Authorized Signatory

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/05/132

Report Date: 31/05/2025

TEST REPORT
(For the Month of May - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near loc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/AA1	Sample Location	Near Jetty Landfall Area
Sampling Date	26/05/2025	Type of Sample	Ambient Air
Sample Received Date	26/05/2025	Sampling Method	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	27/05/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	30/05/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	65.10	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	17.27	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	12.68	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	15.34	IS 5182 (Part 6) : 2022	80

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) GUJARAT
Authorized Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/05/133

Report Date: 31/05/2025

TEST REPORT
(For the Month of May - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. **Address:** Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/AA2	**Sample Location**	Near Tank Farm Area
Sampling Date	26/05/2025	**Type of Sample**	Ambient Air
Sample Received Date	26/05/2025	**Sampling Method**	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	27/05/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	30/05/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	67.52	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	23.60	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	16.83	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	20.48	IS 5182 (Part 6) : 2022	80

Hemali

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) GUJARAT

Authorized Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/05/134 Report Date: 31/05/2025

TEST REPORT
(For the Month of May - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/N1-N4	Sampling Location	As per table
Measurement Start Date	26/05/2025	Type of Sample	Noise Monitoring
Measurement End Date	27/05/2025	Sampling Instrument	Sound Level Meter
Measurement Done By	Earth Envirotech Team	Sampling Method	IS 9989 : 2023

ANALYSIS RESULTS

Sr. No.	Location Name	Unit	Day Time	Night Time
			Spot Noise Level dB(A) Maximum	Spot Noise Level dB(A) Maximum
Standard Limits		dB(A)	75.0	70.0
1.	Near Jetty Landform Area	dB(A)	71.0	63.3
2.	Near Tank Farm Area	dB(A)	66.9	61.5
3.	Near Tank Farm Right Side	dB(A)	60.4	55.8
4.	Near Tank Farm Left Side	dB(A)	67.3	61.4

Day Time: 06:00 AM to 10:00 PM
Night Time: 10:00 PM to 06:00 AM

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ GUJARAT
Authorized Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/05/135 Report Date: 31/05/2025

TEST REPORT
(For the Month of May - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near loc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/DW1	Sample Location	Near Office Area
Sampling Date	26/05/2025	Type of Sample	Drinking Water
Sample Received Date	26/05/2025	Quantity of Sample	2 Liter
Analysis Start Date	27/05/2025	Sampling Method	APHA 24th ED. 1060 B : 2023
Analysis End Date	31/05/2025	Sample Collection By	Earth Envirotech Team

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Acceptable Limit as per (IS 10500 : 2018)
1.	pH	--	7.24	6.5 - 8.5
2.	Temperature	°C	25	--
3.	Electric Conductivity	µS/cm	305.62	--
4.	Total Suspended Solids	mg/L	10	--
5.	Total Dissolved Solids	mg/L	190	500
6.	Total Hardness (as $CaCO_3$)	mg/L	52	200
7.	Calcium (as Ca)	mg/L	40.51	75
8.	Magnesium (as Mg)	mg/L	32.77	30
9.	Chloride	mg/L	81	250
10.	E. Coli	Per 100 ml	Absent	Absent

Analyzed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY ★ GUJARAT)
Authorized Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/06/109

Report Date: 27/06/2025

TEST REPORT
(For the Month of June - 2025)

Client Details

Name: M/s. Kandla Oil Terminal Pvt. Ltd.
Address: Opp. Shiva Railway Crossing, Near loc Foreshore Terminals, New Kandla - 370210.

Sample Details

Sample ID	KOTPL/AA1	Sample Location	Near Jetty Landfall Area
Sampling Date	23/06/2025	Type of Sample	Ambient Air
Sample Received Date	23/06/2025	Sampling Method	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	24/06/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	26/06/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	65.82	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	17.95	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	12.70	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	14.44	IS 5182 (Part 6) : 2022	80

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ GUJARAT
Authorised Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/06/111

Report Date: 27/06/2025

TEST REPORT
(For the Month of June - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/N1-N4	Sampling Location	As per table
Measurement Start Date	23/06/2025	Type of Sample	Noise Monitoring
Measurement End Date	24/06/2025	Sampling Instrument	Sound Level Meter
Measurement Done By	Earth Envirotech Team	Sampling Method	IS 9989 : 2023

ANALYSIS RESULTS

Sr. No.	Location Name	Unit	Day Time	Night Time
			Spot Noise Level dB(A) Maximum	Spot Noise Level dB(A) Maximum
Standard Limits		dB(A)	75.0	70.0
1.	Near Jetty Landform Area	dB(A)	73.5	66.4
2.	Near Tank Farm Area	dB(A)	60.9	56.7
3.	Near Tank Farm Right Side	dB(A)	68.2	63.1
4.	Near Tank Farm Left Side	dB(A)	61.8	58.6

Day Time: 06:00 AM to 10:00 PM
Night Time: 10:00 PM to 06:00 AM

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ GUJARAT
Authorized Signatory

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/06/110 Report Date: 27/06/2025

TEST REPORT
(For the Month of June - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/AA2	Sample Location	Near Tank Farm Area
Sampling Date	23/06/2025	Type of Sample	Ambient Air
Sample Received Date	23/06/2025	Sampling Method	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	24/06/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	26/06/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	67.49	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	23.11	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	16.28	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	19.62	IS 5182 (Part 6) : 2022	80

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ EARTH ENVIROTECH
Authorised Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/06/112

Report Date: 27/06/2025

TEST REPORT
(For the Month of June - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/DW1	Sample Location	Near Office Area
Sampling Date	23/06/2025	Type of Sample	Drinking Water
Sample Received Date	23/06/2025	Quantity of Sample	2 Liter
Analysis Start Date	24/06/2025	Sampling Method	APHA 24th ED. 1060 B : 2023
Analysis End Date	27/06/2025	Sample Collection By	Earth Envirotech Team

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Acceptable Limit as per (IS 10500 : 2018)
1.	pH	--	7.35	6.5 - 8.5
2.	Temperature	°C	28	--
3.	Electric Conductivity	µS/cm	289.92	--
4.	Total Suspended Solids	mg/L	04	--
5.	Total Dissolved Solids	mg/L	119	500
6.	Total Hardness (as $CaCO_3$)	mg/L	26.45	200
7.	Calcium (as Ca)	mg/L	18.76	75
8.	Magnesium (as Mg)	mg/L	11.69	30
9.	Chloride	mg/L	52.10	250
10.	E. Coli	Per 100 ml	Absent	Absent

Hemali

Analyzed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) GUJARAT

Authorised Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/07/214

Report Date: 19/07/2025

TEST REPORT
(For the Month of July - 2025)

Client Details

Name: M/s. Kandla Oil Terminal Pvt. Ltd.
Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details

Sample ID	KOTPL/AA1	Sample Location	Near Jetty Landfall Area
Sampling Date	14/07/2025	Type of Sample	Ambient Air
Sample Received Date	14/07/2025	Sampling Method	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	15/07/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	18/07/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	62.18	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	16.44	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	12.75	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	13.98	IS 5182 (Part 6) : 2022	80

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY ★ EARTH ENVIROTECH)
Authorised Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/07/215

Report Date: 19/07/2025

TEST REPORT
(For the Month of July - 2025)

Client Details

Name: M/s. Kandla Oil Terminal Pvt. Ltd.
Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details

Sample ID	KOTPL/AA2	Sample Location	Near Tank Farm Area
Sampling Date	14/07/2025	Type of Sample	Ambient Air
Sample Received Date	14/07/2025	Sampling Method	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	15/07/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	18/07/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	67.29	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	23.64	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	15.82	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	20.41	IS 5182 (Part 6) : 2022	80

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) GUJARAT

Authorized Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/07/216

Report Date: 19/07/2025

TEST REPORT
(For the Month of July - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/N1-N4	Sampling Location	As per table
Measurement Start Date	14/07/2025	Type of Sample	Noise Monitoring
Measurement End Date	15/07/2025	Sampling Instrument	Sound Level Meter
Measurement Done By	Earth Envirotech Team	Sampling Method	IS 9989 : 2023

ANALYSIS RESULTS

Sr. No.	Location Name	Unit	Day Time	Night Time
			Spot Noise Level dB(A) Maximum	Spot Noise Level dB(A) Maximum
Standard Limits		dB(A)	75.0	70.0
1.	Near Jetty Landform Area	dB(A)	65.7	61.2
2.	Near Tank Farm Area	dB(A)	60.6	55.9
3.	Near Tank Farm Right Side	dB(A)	66.8	61.6
4.	Near Tank Farm Left Side	dB(A)	62.5	58.6

Day Time: 06:00 AM to 10:00 PM
Night Time: 10:00 PM to 06:00 AM

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ GUJARAT
Authorized Signatory

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/07/217

Report Date: 19/07/2025

TEST REPORT
(For the Month of July - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near loc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/DW1	Sample Location	Near Office Area
Sampling Date	14/07/2025	Type of Sample	Drinking Water
Sample Received Date	14/07/2025	Quantity of Sample	2 Liter
Analysis Start Date	15/07/2025	Sampling Method	APHA 24th ED. 1060 B : 2023
Analysis End Date	20/09/2025	Sample Collection By	Earth Envirotech Team

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Acceptable Limit as per (IS 10500 : 2018)
1.	pH	--	7.50	6.5 - 8.5
2.	Temperature	°C	25	--
3.	Electric Conductivity	µS/cm	330.76	--
4.	Total Suspended Solids	mg/L	03	--
5.	Total Dissolved Solids	mg/L	122	500
6.	Total Hardness (as $CaCO_3$)	mg/L	27.65	200
7.	Calcium (as Ca)	mg/L	19.42	75
8.	Magnesium (as Mg)	mg/L	12.30	30
9.	Chloride	mg/L	50	250
10.	E. Coli	Per 100 ml	Absent	Absent

Hemali

Analyzed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ EARTH ENVIROTECH

Authorized Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/08/122 Report Date: 29/08/2025

TEST REPORT
(For the Month of August - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near loc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/AA1	Sample Location	Near Jetty Landfall Area
Sampling Date	25/08/2025	Type of Sample	Ambient Air
Sample Received Date	25/08/2025	Sampling Method	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	26/08/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	28/08/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	61.18	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	16.27	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	10.91	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	13.86	IS 5182 (Part 6) : 2022	80

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ EARTH ENVIROTECH
Authorized Signatory

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/08/123

Report Date: 29/08/2025

TEST REPORT

(For the Month of August - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/AA2	Sample Location	Near Tank Farm Area
Sampling Date	25/08/2025	Type of Sample	Ambient Air
Sample Received Date	25/08/2025	Sampling Method	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	26/08/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	28/08/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	67.59	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	22.33	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	14.78	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	18.90	IS 5182 (Part 6) : 2022	80

Analysed By:

EARTH ENVIROTECH ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY
Authorised Signatory
GUJARAT

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/08/124

Report Date: 29/08/2025

TEST REPORT
(For the Month of August - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/N1-N4	Sampling Location	As per table
Measurement Start Date	25/08/2025	Type of Sample	Noise Monitoring
Measurement End Date	26/08/2025	Sampling Instrument	Sound Level Meter
Measurement Done By	Earth Envirotech Team	Sampling Method	IS 9989 : 2023

ANALYSIS RESULTS

Sr. No.	Location Name	Unit	Day Time	Night Time
			Spot Noise Level dB(A) Maximum	Spot Noise Level dB(A) Maximum
Standard Limits		dB(A)	75.0	70.0
1.	Near Jetty Landform Area	dB(A)	70.6	63.7
2.	Near Tank Farm Area	dB(A)	64.9	59.2
3.	Near Tank Farm Right Side	dB(A)	61.4	55.7
4.	Near Tank Farm Left Side	dB(A)	58.5	52.1

Day Time: 06:00 AM to 10:00 PM
Night Time: 10:00 PM to 06:00 AM

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) GUJARAT Authorised Signatory

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/08/125

Report Date: 29/08/2025

TEST REPORT
(For the Month of August - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. **Address:** Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/DW1	**Sample Location**	Near Office Area
Sampling Date	25/08/2025	**Type of Sample**	Drinking Water
Sample Received Date	25/08/2025	**Quantity of Sample**	2 Liter
Analysis Start Date	26/08/2025	**Sampling Method**	APHA 24th ED. 1060 B : 2023
Analysis End Date	29/08/2025	**Sample Collection By**	Earth Envirotech Team

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Acceptable Limit as per (IS 10500 : 2018)
1.	pH	--	7.24	6.5 - 8.5
2.	Temperature	°C	27	--
3.	Electric Conductivity	µS/cm	330.68	--
4.	Total Suspended Solids	mg/L	03	--
5.	Total Dissolved Solids	mg/L	110	500
6.	Total Hardness (as $CaCO_3$)	mg/L	28.19	200
7.	Calcium (as Ca)	mg/L	22.40	75
8.	Magnesium (as Mg)	mg/L	14.82	30
9.	Chloride	mg/L	45	250
10.	E. Coli	Per 100 ml	Absent	Absent

Analyzed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ Authorized Signatory

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/09/189 Report Date: 20/09/2025

TEST REPORT
(For the Month of September - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/AA1	Sample Location	Near Jetty Landfall Area
Sampling Date	15/09/2025	Type of Sample	Ambient Air
Sample Received Date	15/09/2025	Sampling Method	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	16/09/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	18/09/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	68.21	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	21.33	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	16.52	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	19.23	IS 5182 (Part 6) : 2022	80

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ GUJARAT
Authorized Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/09/190 Report Date: 20/09/2025

TEST REPORT
(For the Month of September - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. **Address:** Opp. Shiva Railway Crossing, Near loc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/AA2	**Sample Location**	Near Tank Farm Area
Sampling Date	15/09/2025	**Type of Sample**	Ambient Air
Sample Received Date	15/09/2025	**Sampling Method**	IS 5182 (Part 23) : 2022 - PM_{10}
Analysis Start Date	16/09/2025		EE-WI-7.3.2-A1 - $PM_{2.5}$
Analysis End Date	18/09/2025		IS 5182 (Part 5) : 2020 - Gaseous Pollutant
Sample Collection By	Earth Envirotech Team		

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Reference Method	National Ambient Air Quality Standards
1.	Particulate Matter PM_{10}	$\mu g/m^3$	73.94	IS 5182 (Part 23) : 2022	100
2.	Particulate Matter $PM_{2.5}$	$\mu g/m^3$	27.60	EE-WI-7.2.2A	60
3.	Sulphur Dioxide (SO_2)	$\mu g/m^3$	21.45	IS 5182 (Part 2/Sec 1) : 2023	80
4.	Nitrogen Dioxide (NO_2)	$\mu g/m^3$	23.63	IS 5182 (Part 6) : 2022	80

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ EARTH ENVIROTECH
Authorised Signatory

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

Report Ref. No: EE/ENV/2025/09/191 Report Date: 20/09/2025

TEST REPORT
(For the Month of September - 2025)

Client Details
Name: M/s. Kandla Oil Terminal Pvt. Ltd. Address: Opp. Shiva Railway Crossing, Near Ioc Foreshore Terminals, New Kandla - 370210.

Sample Details			
Sample ID	KOTPL/N1-N4	Sampling Location	As per table
Measurement Start Date	15/09/2025	Type of Sample	Noise Monitoring
Measurement End Date	16/09/2025	Sampling Instrument	Sound Level Meter
Measurement Done By	Earth Envirotech Team	Sampling Method	IS 9989 : 2023

ANALYSIS RESULTS

Sr. No.	Location Name	Unit	Day Time	Night Time
			Spot Noise Level dB(A) Maximum	Spot Noise Level dB(A) Maximum
Standard Limits		dB(A)	75.0	70.0
1.	Near Jetty Landform Area	dB(A)	68.5	59.1
2.	Near Tank Farm Area	dB(A)	62.8	58.6
3.	Near Tank Farm Right Side	dB(A)	65.3	52.4
4.	Near Tank Farm Left Side	dB(A)	63.2	53.5

Day Time: 06:00 AM to 10:00 PM
Night Time: 10:00 PM to 06:00 AM

Analysed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ EARTH ENVIROTECH
Authorized Signatory:

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

EARTH envirotech
ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY
GPCB Approved Environmental Auditor

Report Ref. No: EE/ENV/2025/09/192

Report Date: 20/09/2025

TEST REPORT

(For the Month of September - 2025)

Client Details

Name: M/s. Kandla Oil Terminal Pvt. Ltd.
Address: Opp. Shiva Railway Crossing, Near loc Foreshore Terminals, New Kandla - 370210.

Sample Details

Sample ID	KOTPL/DW1	Sample Location	Near Office Area
Sampling Date	15/09/2025	Type of Sample	Drinking Water
Sample Received Date	15/09/2025	Quantity of Sample	2 Liter
Analysis Start Date	16/09/2025	Sampling Method	APHA 24th ED. 1060 B : 2023
Analysis End Date	20/09/2025	Sample Collection By	Earth Envirotech Team

ANALYSIS RESULTS

Sr. No.	Parameters	Unit	Results	Acceptable Limit as per (IS 10500 : 2018)
1.	pH	--	7.16	6.5 - 8.5
2.	Temperature	°C	26	--
3.	Electric Conductivity	µS/cm	318.22	--
4.	Total Suspended Solids	mg/L	07	--
5.	Total Dissolved Solids	mg/L	135	500
6.	Total Hardness (as $CaCO_3$)	mg/L	31	200
7.	Calcium (as Ca)	mg/L	26.24	75
8.	Magnesium (as Mg)	mg/L	17.30	30
9.	Chloride	mg/L	58	250
10.	E. Coli	Per 100 ml	Absent	Absent

Hemali

Analyzed By:

EARTH ENVIROTECH (ANALYTICAL & ENVIRONMENTAL ENGINEERING LABORATORY) ★ GUJARAT

Authorised Signatory

- Analysis is subject to the condition in which the sample is received at laboratory.
- Report cannot be used as evidence anywhere including judiciary purpose without our prior permission.
- Sample will be retained till 15 days from the date of sampling.

CRZ Compliance Report for September 2025

Subject: Point-wise Compliance Status Report for CRZ clearance for Developing integrated facility within the existing Kandla Port at Kandla, Dist: Kutch by M/s. Kandla Port Trust Limited – Reg.

Ref No: - GCZMA CRZ recommendation vide Letter No – ENV-10-2014-25-E Cell dated 01.07.2015

S. No.	CRZ Conditions	Compliance Status
	SPECIFIC CONDITIONS	
1.	The provisions of the CRZ notification of 2011 shall be strictly adhered to by the KPT. No activity in contradiction to the provisions of the CRZ Notification shall be carried out by the KPT.	It is assured that no activity contradicting the Provisions of the CRZ Notification shall be carried out.
2.	The KPT shall have to ensure that there shall not be any damage to the existing mangrove area.	It is ensured that due care shall be taken to protect the existing mangrove area.
3.	The KPT shall prepare an emergency plan to protect existing mangroves in case of any eventuality/accident	Not Applicable
4.	The KPT shall have to make a provision that mangrove areas get proper flushing water and free flow of water shall not be obstructed.	It is assured that provisions are being made that mangrove areas get proper flushing water and free flow of water shall not be obstructed.
5.	The KPT shall have to abide by whatever decision taken by the GCZMA for violations of CRZ notification 2011	Decisions taken by the GCZMA for violations of CRZ Notification, 2011, will be abided by.
6.	There shall not be violations of the order dated 9-12-2013 passed by the National Green Tribunal, and accordingly, there shall be no mangrove destruction taking place in the KPT area.	It is assured that due care shall be taken to protect the existing mangrove area.
7.	No dredging, reclamation or any other project-related activities shall be carried out in the CRZ area categorized as CRZ I (i), and it shall have to be ensured that the mangrove habitats and other ecologically important and significant areas, if any, in the region are not affected due to any of the project activities.	Noted
8.	The KPT shall participate financially in installing and operating the Vessel Traffic Management System in the Gulf of Kachchh and shall also take the lead in preparing and operational sing the Regional Oil Spill Contingency plan in the Gulf of Kachchh.	Not Applicable
9.	The KPT shall strictly ensure that no creeks or rivers are blocked due to any activity at Kandla.	It is assured that no creeks or rivers shall be blocked due to any activity at Kandla.

KANDLA

S. No.	CRZ Conditions	Compliance Status
10.	Mangrove plantation in an area of 100 ha. shall be carried out by the KPT within 2 years in a time-bound manner on the Gujarat coastline either within or outside the Kandla Port Trust area, and a six-monthly compliance report along with the satellite images shall be submitted to the Ministry of Environment and Forests as well as to this Department without fail.	Not Applicable
11.	No activities other than those permitted by the competent authority under the CRZ Notification shall be carried out in the CRZ area.	It is assured that only activities permitted by the competent authority under the CRZ Notification shall be carried out in the CRZ area.
12.	No groundwater shall be tapped for any purpose during the proposed expansion/modernization activities.	Water requirements will be met through GWSSB or private tankers. No groundwater shall be tapped.
13.	All necessary permissions from different Government Departments/agencies shall be obtained by the KPT before commencing the expansion activities.	Noted
14.	No effluent or sewage shall be discharged into the sea/creek or in the CRZ area, and it shall be treated to conform to the norms prescribed by the Gujarat Pollution Control Board and would be reused/recycled within the plant premises.	No waste water generation during the construction phase
15.	All the recommendations and suggestions given by Mantec Consultants Pvt. Ltd. New Delhi in their Comprehensive Environment Impact Assessment report for conservation/protection and betterment of the environment shall be implemented strictly by the KPT.	Noted
16.	The construction and operational activities shall be carried out in such a way that there is no negative impact on mangroves and other coastal/marine habitats. The construction activities and dredging shall be carried out only under the constant supervision and guidelines of the Institute of National repute like NIOT.	It is assured that construction activities being carried out under constant supervision.
17.	The KPT shall contribute financially to any common study or project that may be proposed by this Department for environmental management/conservation /improvement for the Gulf of Kutch.	Not applicable
18.	The construction debris and/or any other type of waste shall not be disposed of into the sea, creek, or in CRZ areas. The debris shall be removed from	It is assured that the construction activities are being carried out, with due care, and that the construction material /debris does not

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S. No.	CRZ Conditions	Compliance Status
	the construction site immediately after the construction is over.	fall into the water. Further, it is also assured that construction waste will be being collected at a designated location before being sent to the disposal site.
19.	The construction camps shall be located outside the CRZ area, and the construction labour shall be provided with the necessary amenities, including sanitation, water supply and fuel, and it shall be ensured that the environmental conditions are not deteriorated by the construction labours.	No construction camps on the site. Only Local laborers are involved.
20.	The KPT shall regularly update their Local Oil Spill Contingency and Disaster Management plan in consonance with the National Oil Spill and Disaster Contingency Plan and shall submit the same to this Department after having it vetted through the Indian Coast Guard.	Project is in construction phase.
21.	The KPT shall bear the cost of the external agency that may be appointed by this Department for supervision/ monitoring of proposed activities and the environmental impacts of the proposed activities.	Not applicable
22.	The KPT shall take up massive greenbelt development activities in and around Kandla and also within the KPT limits.	Not applicable
23.	The KPT shall have to contribute financially for taking up the socio-economic upliftment activities in this region in consultation with the Forests and Environment Department and the District Collector/ District Development officer.	Not applicable
24.	A separate budget shall be earmarked for environmental management and socio-economic activities, and details thereof shall be furnished to this Department as well as MoEF, GOI. The details with respect to the expenditure from this budget head shall also be furnished.	Noted
25.	A separate environmental management cell with qualified personnel shall be created for environmental monitoring and management during the construction and operational phases of the project.	A MoEFCC & NABL-accredited laboratory with expert manpower has assigned the work of monitoring. The Environmental Monitoring Reports are enclosed herewith as **Annexure**.
26.	An environmental report indicating the changes, if any, with respect to the baseline environmental quality in the coastal and marine environment shall be submitted every year by the KPT to this Department as well as to the MoEF&CC, GOI.	Noted. The Environmental Monitoring Reports following CPCB guidelines and as submitted by MoEFCC & NABL accredited laboratory enclosed as **Annexure**.

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S. No.	CRZ Conditions	Compliance Status
27.	The KPT shall have to contribute financially to support the National Green Corps Scheme being implemented in Gujarat by the GEER Foundation, Gandhinagar, in consultation with the Forests and Environment Department	Not applicable
28.	A six-monthly report on compliance with the conditions mentioned in this letter shall have to be furnished by the KPT on a regular basis to this Department/ MoEF&CC, GOI	Noted
29.	Any other conditions that may be stipulated by this Department/ MoEF&CC, GOI from time to time for environmental protection/management purposes shall also have to be complied with by the KPT.	Noted.

Consent Compliance Report for September 2025

Subject: Point-wise Compliance Status Report for Consent to Establish for Developing Integrated Facility within the existing Kandla Port at Kandla, Dist: Kutch by M/s. Kandla Port Trust Limited – Reg.

Ref No: - PC/CCA-KUTCH-1231/GPCB ID 44000 dated 22.12.2015 and Amendment of Consent to Establish dated 04.12.2017

Sr. No.	Condition	Compliance Status
2.	**SPECIFIC CONDITIONS:**	
	1. Kandla Port Trust shall strictly adhere to all conditions of CRZ Clearance issued by the Forest & Environment Department vide order no. ENV-10-2014-25-E dated 01/07/2015.	All conditions of CRZ Clearance issued vide order no. ENV-10-2014-25-E dated 01/07/2015 will be strictly adhered to. The CRZ compliance report is attached.
	2. CTE is granted conditionally that Kandla Port Trust shall not install & commission, including the construction activity of seven activities mentioned above, without obtaining environmental clearance from MoEF&CC, New Delhi.	The construction activity was commissioned after due agreement and as per Environment Clearance was issued in the year 2016 by MoEF&CC, New Delhi.
	3. Kandla Port Trust shall strictly adhere to all conditions of the Terms of Reference (ToR) (vide letter no. F. No. 11-82/2011-IA.III) by MoEF&CC, New Delhi.	Noted
3.	**CONDITION UNDER THE WATER ACT 1974:**	
	3.1 There shall be no industrial effluent generation from the loading and unloading activities at the port and other ancillary operations.	Not applicable
	3.2 The quantity of Domestic wastewater (Sewage) shall not exceed 6.4 KL/Day.	The project is under the construction stage
	3.3 The quality of the sewage shall conform to the following standards:	The project is under the construction stage

PARAMETERS	GPCB NORMS
BOD (5 days at 20 °C)	20 mg/L

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	Suspended solids: 30 mg/L Residual Chlorine: Minimum 0.5 mg/L	
	3.4 Sewage shall be disposed of through a septic tank/soak pit system.	Noted
	3.5 The unit shall install meters at utilities for measuring category-wise (Category as given in Schedule II of "Water (Prevention & Control of Pollution) Cess Act-1977") consumption of water.	Noted
4.	**CONDITION UNDER THE AIR ACT 1981:** 4.1 There shall be no use of fuel hence there shall be no flue and process gas emission from storage handling activity and other ancillary operations.	Not Applicable
	4.2 The applicant shall provide portholes, ladder, platform, etc at chimney(s) for monitoring the air emissions and the same shall be open for inspection. The chimney(s) vents attached to various sources of emission shall be designed by numbers such as S-1, S-2, etc. and these shall be painted/ displayed to facilitate identification.	Not Applicable
	4.3 The concentration of the following parameters in the ambient air within the premises of the industry shall not exceed the limits specified hereunder as per National Ambient Air Quality Standards issued by MoEF&CC dated 16th November-2009.	The environment monitoring is being done through a MoEFCC & NABL accredited laboratory, and the data is being submitted along with compliance reports. The latest environmental monitoring reports are enclosed as **Annexure**.

Sr. No.	Pollutant	Time Weighted Average	Concentration in Ambient air in µg/m³
1.	Sulphur Dioxide (SO_2)	Annual 24Hours	50 80
2.	Nitrogen Dioxide (NO_2)	Annual 24Hours	40 80
3.	Particulate Matter (Size <10 µm) OR	Annual 24Hours	60 100

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		PM10		
	4.	Particulate Matter (Size <2.5µm) OR PM2.5	Annual 24Hours	40 60
	4.4 The level of Noise in ambient air within the premises of the industrial unit shall not exceed the following levels: Between 6 A.M. to 10 P.M.:75 dB(A) Between 10 P.M. to 6 A.M.:70 dB(A)			The latest environmental monitoring reports are enclosed as **Annexure**.
5.	**CONDITIONS UNDER HAZARDOUS WASTE:**			
	5.1 The applicant shall provide temporary storage facilities for each type of Hazardous Waste as per Hazardous Waste (Management, Handling & Transboundary Movement) Rules, 2008, as amended from time to time.			Noted, the Project is under construction stage.
	5.2 The applicant shall obtain membership of a common TSDF site for the disposal Hazardous. Waste as categorized in Hazardous Waste (Management, Handling & Transboundary Movement) Rules, 2008, as amended from time to time.			Noted, the Project is under construction stage.
6.	**GENERAL CONDITIONS**			
	6.1 Any change in personnel, equipment, or working conditions as mentioned in the consent form/order should immediately be intimated to this Board.			Noted
	6.2 The waste generator shall be totally responsible for (i.e. Collection, storage, transportation and ultimate disposal) the wastes generated.			Noted
	6.3 Records of waste generation, its management, and annual return shall be submitted to the Gujarat Pollution Control Board in Form- 4 by 31st January of every year.			Noted
	6.4 In case of any accident, details of the same shall be submitted in Form- 5 to the Gujarat Pollution Control Board.			Noted

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	6.5 Applicant shall comply with the relevant provision of "Public Liability Insurance Act-91".	Noted
	6.6 Unit shall take all concrete measures to show tangible results in waste generation reduction, avoidance, reuse, and recycling. Action taken in this regard shall be submitted within 03 months and also along with Form 4.	Noted, the project is under the construction stage
	6.7 Industry shall have to display online data outside the main factory gate with regard to the quantity and nature of hazardous chemicals being handled in the plant, including wastewater and air emissions and solid hazardous waste generated within the factory premises.	Noted, the project is under the construction stage
	6.8 Adequate plantation shall be carried out all along the periphery of the industrial premises in such a way that the density of plantation is at least 1000 trees per acre of land and a green belt of 10 meters width is developed.	Noted.
	6.9 The applicant shall have to submit the returns in the prescribed form regarding water consumption and shall have to make payment of water cess to the Board under the Water (Prevention and Control of Pollution) Cess Act 1977.	Noted, the project is under the construction stage

KANDLA OIL TERMINAL PVT. LTD.

EC Compliance Report for September 2025

Subject: Point-wise Compliance Status Report for Environmental clearance for Developing Integrated Facility within the existing Kandla Port at Kandla, Dist: Kutch by M/s. Kandla Port Trust Limited – Reg.

Ref No: - Environmental Clearance vide Letter No- F. No. 11-82/2011-IA III dated 19.12.2016

Sr. No.	EC Conditions	Compliance Status
PART A – SPECIFIC CONDITIONS		
I	Construction activity shall be carried out strictly according to the provisions of CRZ Notification 2011 No. construction work other than those permitted in coastal Regulation Zone Notification Shall be carried out in Coastal Regulation Zone area	It is assured that no activity other than those permissible in the Coastal Regulation Notification shall be carried out in the CRZ area.
ii	The project proponent shall ensure that there shall be no damage to the existing mangrove patches near the site and also ensure the free flow of water to avoid damage to the mangroves.	It is assured that due care shall be taken to protect existing mangrove patches near the site and the free flow of water to avoid damage to the mangroves.
iii	The project proponent shall ensure that no creeks or rivers are blocked due to any activities at the project site, and free flow of water is maintained.	It is assured that no creeks or rivers shall be blocked due to any activities at the project site, and the free flow of water shall be maintained.
iv	The shoreline should not be disturbed due to dumping. Periodical study on shoreline changes shall be conducted, and mitigation carried out, if necessary. The details shall be submitted along with the six-monthly monitoring reports.	No shoreline is disturbed due to dumping.
v	The foreshore facilities shall be set up in the stable/low or medium eroding site as demarcated in the shoreline change map by NCSCM. Further, NCSCM shall be authorized to monitor the project during the construction and operation phases so as to ensure that the foreshore facilities cause minimum or	Ongoing construction is in line with and strictly adhering to EC-CRZ conditions issued about this project.

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Sr. No.	EC Conditions	Compliance Status
	no impact to the geomorphological systems.	
vi	The PP should take measures to ensure that construction materials/debris (mortar, cementing material, etc.) do not fall into the water. Construction materials including labor camps should be located at an adequate distance from CRZ areas.	It is assured that the construction activities are being carried out, with due care, and that the construction material /debris does not fall into the water. Further, it is also assured that construction waste will be collected at a designated location before being sent to the disposal site.
vii	Dredged materials should be analyzed for the presence of contaminants and also to decide the disposal options. Monitoring of dredging activities should be conducted, and the findings should be shared with the Gujarat SPCB and the Regional office of the Ministry.	The project is under construction stage, and no dredging activity has been carried out to date.
viii	PP in consultation with GCZMA should prepare a regional strategic impact assessment report with a special focus on the region where the PP started construction without permission. The cost towards this study should be borne by the PP	Not Applicable
ix	A comprehensive and integrated conservation plan including a detailed bathymetry study and protection of creeks/mangrove area including buffer zone, mapping of coordinates, running length, HTL, and CRZ boundary should be put in the palace. The plan should take note of all the conditions of approvals granted to all the project proponents in this area, and the reported cases of the disappearance of mangroves near the project site. The preservation of the entire area to maintain the fragile ecological conditions should be a part of the plan in relation to the creek and mangrove conservation.	DPA has appointed the Gujrat Institute of Desert Ecology, Bhuj, for the work.
x	The commitments made during the Public Hearing and recorded in the	Not Applicable

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Sr. No.	EC Conditions	Compliance Status
	minutes shall comply with by letter and spirit. A hard copy of the action taken shall be submitted to the ministry.	
xi	All the conditions stipulated in the earlier clearance including the recommendations of the Environment Management Plan, and Disaster Management Plan shall be strictly complied with.	Noted
xii	Disposal sites for excavated material should be so designed that the revised land use after dumping and changes in the land use pattern does not interfere with the natural drainage.	It is assured that; construction waste will be collected at a designated location before sending to the disposal site. Also, the land use pattern will not interfere with the natural drainage.
xiii	PP shall install a continuous automatic ambient air quality monitoring system (24x7) for all relevant parameters at two locations to monitor the ambient air quality status of the project area. Data should be transferred online to CPCB and SPCB websites.	The Environmental Monitoring Reports following CPCB guidelines and as submitted by MoEFCC & NABL accredited laboratory is enclosed as **Annexure**.
xiv	The groundwater shall not be tapped within the CRZ areas by the PP to meet the water requirement in any case.	Water requirements will be met through GWSSB or private tankers. No groundwater shall be tapped.
xv	Necessary arrangements for the treatment of the effluents and solid wastes must be made and it must be ensured that they conform to the standards laid down by the competent authorities including the Central or State Pollution Control Board and under the Environment (Protection) Act, 1986.	Noted, the project is under the construction stage.
xvi	All the operational areas will be connected with the network of liquid waste collection corridors comprising of stormwater, oily waste and sewage collection pipelines.	Noted, the project is under the construction stage.

Sr. No.	EC Conditions	Compliance Status
xvii	Automatic /online monitoring system (24x7) monitoring devices) for water pollution in respect of flow measurement and relevant pollutants in the treatment system to be installed. The data to be made available to the respective SPCB and in the Company's website.	Noted
xviii	Marine ecology shall be monitored regularly also in terms of seaweeds, sea grasses, mudflats, sand dunes, fisheries, echinoderms, shrimps, turtles, corals, coastal vegetation, mangroves, and other marine biodiversity components as part of the management plan. Marine ecology shall be monitored regularly also in terms of all micro, macro, and mega floral and faunal components of marine biodiversity.	DPA appointed the Gujarat Institute of Desert Ecology, Bhuj for Regular Monitoring of Marine Ecology.
xix	Measures should be taken to contain, control, and recover the accidental spills of fuel and cargo handles.	Noted, the project is under the construction stage.
xx	All the mitigation measures submitted in the EIA report shall be prepared in a matrix format and the compliance for each mitigation plan shall be submitted to the RO, MoEF&CC along with half yearly compliance report.	Noted
xxi	Ships/barges shall not be allowed to release any oily bilge waste or ballast water in the sea. Any effluents from the Jetty which have leachable characteristics shall be segregated and recycled/disposed of as per SPCB guidelines.	Noted, the project is under the construction stage.
xxii	The location of DG sets and other emission-generating equipment shall be decided keeping in view the predominant wind direction so that emissions do not affect nearby	Not Applicable

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Sr. No.	EC Conditions	Compliance Status
	residential areas. Installation and operation of DG sets shall comply with the guidelines of CPCB.	
xxiii	All the mechanized handling systems and other associated equipment such as hoppers, belt conveyors, stackers cum reclaimers shall have integrated dust suppression systems. Dust suppression systems shall be provided at all transfer points.	Not applicable, as this project is for the handling of liquid cargo.
xxiv	No product other than permitted under the CRZ notification, 2011 shall be stored in the CRZ area.	It is hereby assured that only products permitted under the CRZ Notification, 2011 shall be stored in the CRZ area.
xxv	It shall be ensured by the Project Proponent that the activities do not cause disturbance to the fishing activity, movements of fishing boats and destruction of mangroves during the construction and operation phase.	It is assured that, due care will be taken so that the activities do not cause disturbance to the fishing activity, movement of fishing boats and destruction to mangroves.
xxvi	As proposed, a green belt over an area of 36.8 ha shall be developed with at least 10-meter-wide green belt on all sides along the periphery of the project area, in the downward direction, and along roadsides etc. Selection of plant species shall be as per the CPCB guidelines in consultation with the DFO.	Noted.
xxvii	Mangrove plantation in an area of 100 ha. shall be carried out by KPT within 2 years in a time bound manner. Action taken report shall be submitted to the Regional Office of MoEF &CC.	Not Applicable
xxviii	Municipal solid wastes and hazardous wastes shall be managed as per the Municipal Solid Waste Rule, 2016 and Hazardous Waste Management Rule, 2016.	Noted.
xxix	The Project Proponent shall take up and earmark adequate funds for socio-economic development and welfare measures as proposed under the CSR program. This shall be taken up on	Noted, the project is under the construction stage.

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Sr. No.	EC Conditions	Compliance Status
	priority.	
xxx	The project proponent shall set up a separate environmental management cell for the effective implementation of the stipulated environmental safeguards under the supervision of a Senior Executive.	A MoEFCC & NABL-accredited laboratory with expert manpower has assigned the work of monitoring. The Environmental Monitoring Reports are enclosed herewith as **Annexure**.
xxxi	The funds earmarked for the environment management plan shall be included in the budget, and this shall not be diverted for any other purposes.	Noted
xxxii	The proponent shall abide by all the commitments and recommendations made in the EIA/EMP report and also during their presentation to the EAC.	Noted, the project is under the construction stage.
xxxiii	The company shall prepare an operating manual in respect of all activities. It shall cover all safety & environmental related issues and systems. Measures to be taken for protection. One set of the environmental manual shall be made available at the project site. Awareness shall be created at each level of management. All the schedules and results of environmental monitoring shall be available at the project site office.	Noted, the project is under the construction stage.
xxxiv	Corporate Social Responsibility.	
	a. The Company shall have a well-laid-down Environment Policy approved by the Board of Directors. b. The Environment Policy shall prescribe standard operating processes/procedures to bring into focus any infringements/deviations/ violations of the environmental or forest norms/ conditions. c. The hierarchical system or Administrative Order of the company to deal with environmental issues and for	Noted. Noted. Noted.

Sr. No.	EC Conditions	Compliance Status
	ensuring compliance with the environmental clearance conditions shall be furnished. d. To have proper checks and balances, the company shall have a well-laid-down system of reporting non-compliances/ violations of environmental norms to the board of Directors of the company and/or shareholders or stakeholders at large.	Noted
B.	**GENERAL CONDITIONS:**	
(i)	The project authorities must strictly adhere to the stipulations made by the State Pollution Control Board (SPCB), State Government, and any other statutory authority.	The project authorities assure to strictly adhere to the stipulations
(ii)	Full support shall be extended to the officers of this Ministry/ Regional Office at Bhopal by the project proponent during the inspection of the project for monitoring purposes by furnishing full details and an action plan including action is taken reports in respect of mitigation measures and other environmental protection activities.	Full support shall be extended to the regulatory officers during the inspection and furnishing required project details.
(iii)	A six-Monthly monitoring report shall need to be submitted by the project proponents to the Regional Office of this Ministry at Bhopal regarding the implementation of the stipulated conditions.	Noted.
(iv)	Ministry of Environment, Forest and Climate Change or any other competent authority may stipulate any additional conditions or modify the existing ones, if necessary, in the interest of the environment and the same shall be complied with.	Noted.
(v)	The Ministry reserves the right to revoke this clearance if any of the conditions stipulated have not complied	Noted.

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Sr. No.	EC Conditions	Compliance Status
	with the satisfaction of the Ministry.	
(vi)	In the event of a change in the project profile or change in the implementation agency, a fresh reference shall be made to the Ministry of Environment, Forest and Climate Change.	Noted.
(vii)	The project proponents shall inform the Regional Office as well as the Ministry, of the date of financial closure and final approval of the project by the concerned authorities and the date of start of land development work.	Noted.
(viii)	A copy of the clearance letter shall be marked to the concerned Panchayat/local NGO, if any, from whom any suggestion/ representation has been made or received while processing the proposal.	Complied.
(ix)	A copy of the environmental clearance letter shall also be displayed on the website of the concerned State Pollution Control Board. The EC letter shall also be displayed at the Regional Office, District Industries centre and Collector's Office/Tehsildar's office for 30 days.	Complied.
11	These stipulations would be enforced among others under the provisions of the Water (Prevention and Control of Pollution) Act 1974, the Air (Prevention and Control of Pollution) Act 1981, the Environment (Protection) Act 1986, the Public Liability (Insurance) Act, 1991 and EIA Notification 1994, including the amendments and rules made thereafter.	Noted. The Environmental Monitoring Reports following CPCB guidelines and as submitted by MoEFCC & NABL accredited laboratory enclosed as **Annexure**.
12	All other statutory clearances such as the approvals for storage of diesel from Chief Controller of Explosives, Fire Department, Civil Aviation Department, Forest Conservation Act, 1980 and Wildlife (Protection) Act, 1972 etc. shall be obtained, as applicable by project	Noted, the project is under the construction stage. Due statutory clearances applicable, will be taken during the course of respective project stages as per the condition stipulated.

Sr. No.	EC Conditions	Compliance Status
	proponents from the respective competent authorities.	
13	The project proponent shall advertise in at least two local Newspapers widely circulated in the region, one of which shall be in the vernacular language informing that the project has been accorded Environmental and CRZ Clearance and copies of clearance letters are available with the State Pollution Control Board and may also be seen on the website of the Ministry of Environment, Forest and Climate Change at http://www.envfor.nic.in. The advertisement should be made within Seven days from the date of receipt of the Clearance letter and a copy of the same should be forwarded to the Regional office of this Ministry at Bhopal.	Complied
14	This Clearance is subject to a final order of the Hon'ble Supreme Court of India in the matter of Goa Foundation Vs Union of India in Writ Petition (Civil) No. 460 of 2004 as may be applicable to this product.	Noted.
15	The status of compliance with the various stipulated environmental conditions and environmental safeguards will be uploaded by the project proponent on its website.	Noted.
16	Any appeal against this Clearance shall lie with the National Green Tribunal, if preferred, within a period of 30 days as prescribed under Section 16 of the National Green Tribunal Act, 2010.	Noted.
17	A copy of the clearance letter shall be sent by the proponent to the concerned Panchayat, Zilla Parishad/Municipal Corporation, Urban Local Body and the Local NGO, if any, from whom suggestions/ representations, if any,	Complied.

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Sr. No.	EC Conditions	Compliance Status
	were received while processing the proposal. The clearance letter shall also be put on the website of the company by the proponent.	
18	The proponent shall upload the status of compliance with the stipulated EC conditions, including results of monitored data on their website and shall update the same periodically. It shall simultaneously be sent to the Regional Office of MoEFCC, the respective Zonal Office of CPCB and the SPCB.	Noted.
19	The environmental statement for each financial year ending 31st March in Form-V as is mandated to be submitted by the project proponent to the concerned State Pollution Control Board as prescribed under the Environment (Protection) Rules, 1986, as amended subsequently, shall also be put on the website of the company along with the status of compliance of EC conditions and shall also be sent to the respective Regional Offices of MoEFCC by e-mail.	Noted.

Monitoring Report (for September 2025 submission)

DATA SHEET

Sr. No.	Particulars	Reply
1.	Project type: River valley/ Mining/Industry/ thermal/nuclear/Other (specify)	Development of Oil Jetty to handle Liquid Bulk and Ship bunkering Terminal at Old Kandla
2.	Name of the project	Development of Oil Jetty to handle Liquid Bulk and Ship bunkering Terminal at Old Kandla
3.	Clearance Letter (s). OM no and date	MoEF&CC File No. F.No.11-82/2011-IA-III Proposal No. IA/GJ/MIS/28772/2011 Dated 16th May 2016
4.	Location a) District (s) b) State (s)	Location: a) Kutch b) Gujarat
5.	Address for Correspondence a) address of Concerned Project Chief Engineer (with pin code & telephone/telex/fax numbers b) Address of Executive project Engineer/manager/ (with pin code fax numbers)	Regional Head (IMCL) Near IOCL foreshore Terminal, Kandla Gandhidham, Kutch 370 201 Dy. General Manager Near IOCL foreshore Terminal, Kandla Gandhidham, Kutch 370 201
6.	Salient features a) Of the Project b) Of the Environmental Management Plan	Jetty: 3.39 MMTPA Tank farm: About 1,37,000 KL & Allied Facilities
7.	Production Details during compliance period and (or) during the previous financial year	The project is under the construction stage.
8.	Breakup of the project area a) Submergence area: forest & non-forest b) Others	N/A
9.	Breakup of the project affected population with enumeration of those loing houses/dwelling units only agricultural land & landless laborer's/artisan	Not Applicable

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	a) SC. ST/Adivasis b) Others (please indicate whether these figures are based on any scientific and systematic survey carried out of only provisional figures, if a survey is carried out give details and years of survey).	
10.	Financial details a) Project cost as originally planned and subsequent revised estimates and the year of prices reference b) Allocation made for environmental management plans with item wise and year wise break-up c) Benefit cost ratio/Internal rate of Return and the year of assessment Whether (c) includes the cost of environmental management plans so far. d) Actual expenditure incurred on the project (Up to Sept-25) e) Actual expenditure incurred on the environmental management plans so far.	Estimated Project cost: Rs. 233.50 Cr. Revised project cost: Rs. 343 Cr. (Estimated) Rs. 5.5 Lakhs Rs. 126.30 Cr. Rs. 04 Lakhs
11.	Forest land requirement a) The status of approval for diversion of forest land for non-forestry use b) The status of clear felling c) The status of compensatory a forestation, if any d) Comments on the viability & sustainability of compensatory a forestation programmed in the light of actual field experience so far	Nil N/A. N/A N/A N/A

12.	The status of clear felling in non-forest areas (such as the submergence area of the reservoir, approach roads), if any, with quantitative information.	N/A
13.	Status of construction a) Date of commencement (Actual and/or planned) b) Date of completion (Actual and/or planned)	The project is under the construction stage. Award of concession: December 2020 Planned date of Completion: August 2026
14.	Reasons for the delay if the Project is yet to start	The project is under construction stage, and delayed because of the Pandemic & Local hindrances.
15.	Date of site visited a) The dates on which the project was monitored by the regional office on pervious occasion. if any b) The date site visit for this monitoring report	No
16.	Details of the correspondence with project authorities for obtaining action plans/information on status of compliance to safeguard other than the routine letters for logistic support for site visit. (The first monitoring report may contain the details of all the letters issued so far but the later reports may cover only the letters issued subsequently.)	Noted.

Annexure -B

First Year - Annual Report
(2024-2025)

Regular Monitoring of Marine Ecology in and around the Deendayal Port Authority and Continuous Monitoring Programme

Submitted to

DEENDAYAL PORT AUTHORITY

DEENDAYAL PORT AUTHORITY
Administrative Office Building
Post Box No. 60, Gandhidham (Kuchchh)
Gujarat-370201

Submitted by

Gujarat Institute of Desert Ecology
P.O Box No. #83, Opp. Changleshwar Temple,
Mundra Road Bhuj - 370001
Gujarat - India

May 2025

First Year - Annual Report
(2024-2025)

Regular Monitoring of Marine Ecology in and around the Deendayal Port Authority and Continuous Monitoring Programme

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May 2025

Gujarat Institute
of Desert Ecology

Dr. V. Vijay Kumar
Director

CERTIFICATE

This is to state that this final report of work entitled "**Regular monitoring of Marine ecology in and around the Deendayal Port Authority and Continuous Monitoring Programme**" has been prepared as per the work order issued by DPA vide no :EG/WK/4751/Part (Marine Ecology Monitoring)/72 dt.10.06.2024 for the period 2024-2025 as per EC and CRZ clearance accorded by the MOEF& CC, GOI dated 19.12.2016,18.2 2020.19.2.2022 and 20.11.2020 with specific conditions xviii, xxiii, xv iv and xxv respectively.

Authorized signatory

Gujarat Institute of Desert Ecology Bhuj

Institute seal

P.O. Box No. 83, Opp. Omnageshwar Temple, Mundra Road, Bhuj (Kachchh) - 370 001, Gujarat (India)
Tel : 02832 - 235025-29
www.gujaratdesertecology.com, E-mail : desert_ecology@yahoo.com

Project Coordinator

Dr. V. Vijay Kumar, Director

Principal Investigator		
Dr. Durga Prasad Behera	Scientist	Phytoplankton & Zooplankton, Physico-chemical parameters, Seaweed, Seagrass , halophytes, Marine Fisheries and Intertidal fauna
Co-Principal Investigator		
Dr. Kapilkumar Ingle	Project Scientist	Mangrove Ecology
Dr. Dhara Dixit	Project Scientist	Physico-chemical
Team Member		
Dr. L. Prabha Devi	Advisor	Management Plan
Dr.S.K Sajan	Scientist	Avifauna
Mr. Viral. D. Vadodariya	Project Fellow	Avifauna
Mr. Dayesh Parmar	Project officer	GIS & Remote sensing
Mr. Rupak Kumar Dey	Project Scientist	GIS & Remote sensing
Mr. Samir Mashru	Project assistant	Physico-chemical& Macrobenthos
Ms, Shivani Singh	Project assistant	Physico-chemical& Biological

Abstract May-2024 to May 2025

S. No	Components of the Study	Remarks
1	**MoEF & CC Sanction Letter and Details**	• EC & CRZ clearance granted by the MoEF &CC, GoI dated 19/12/16 Dev. Of 7 integrated facilities – specific condition no. xviii. • EC & CRZ clearance granted by the MoEF &CC, GoI dated 18/2/2020 Dev. Remaining 3 integrated facilities – specific condition no. xxiii. • EC & CRZ clearance granted by the MoEF &CC, GoI dated 19/2/2020 Dev. integrated facilities (Stage II-5 -specific condition no. xv. • EC & CRZ clearance granted by the MoEF &CC, GoI dated 20/11/20 – Creation of waterfront facilities (OJ 8 to 11- Para VIII Marine Ecology, specific condition iv. • EC& CRZ clearance granted by MoEF CC , GOI dated 1/1/2024 augmentation of iquid cargo handling facility specific condition no XXV.
2	Deendayal Port letter Sanctioning the Project	DPA work Order: WK/4751/Part/ (Marine Ecology Monitoring)/72
3	Duration of theProject	Three years-from 24.05.2021 to 23.05.2024
4	Period Of Survey Carried out	Three years-from 2024-2027
5	Survey Area Within the Port limit	All major and minor creek systems from Tuna to Surajbari and Vira coastal area.
6	Number of sampling locations	Fifteen sampling locations in and around DPA port jurisdiction
7	**Components of the report**	
7a	**Mangroves**	During the monsoon 2024, the overall average tree density recorded was 2,189 trees/ha, with Tuna Creek exhibiting the highest mean density (2,535 trees/ha) and S-6 having the highest individual density (3,673 trees/ha). During post-monsoon 2024-2025, the overall tree density recorded as 1,986 trees/ha, with Kharo Creek leading at 2,788 trees/ha and S-6 remaining the densest (3,156 trees/ha). During pre-monsoon 2025, the overall tree density recorded was 1,907 trees/ha and S-6 continued to show the highest density (3,113 trees/ha), with an impressive 6,774 trees per hectare

7b	**Mudflats**	The sediment organic carbon of DPA varied from may 2024 to May 2025 was 0.5% to 3.2 % with average variation of 1.8% to 2.5%. Through out season the highest percentage of organic carbon was observed in post-monsoon followed by monsoon and pre-monsoon. The sediment bulk density varied from 1.10 gm/cm3 to 1.89 gm/cm3 with overall average variation of 1.21 gm/cm3 to 1.68 gm/cm3 . Highest bulk density was observed in Pre-monsoon followed by post-monsoon and post-monsoon

	Phytoplankton	The density of different phytoplankton group varied from 4000 No/L to 24320 No/L with average variation of 7,627 No/L to 24, 320. Highest phytoplankton density was observed in post-monsoon followed by Pre-monsoon and Monsoon. During monsoon 15 genera such as *Cheatoceros, Coscinodiscus, Dictylum, Eucampia, GyrosigmaMelosira, Navicula, Nitzschia, Odontella, Pleurosigma, Pseudonitzschia, Rhizosolenia, Synedra, Thalassionema, Thalassiothrix* represent 100% of occurrence. But in Post-monsoon and pre monsoon represent less number i.e 8 and 5 number of genera represent 100% of occurrence.
7c	**Zooplankton**	The density of zooplankton from May 2024 to May 2025was 8,000 No/L to 20,000 No/L with average variation of 7,653 No/L to 17,660 No/ L. Highest Zooplankton density was observed in Post-mon soon followed by pre-monsoon and Monsoon. 12 genera such as *Acartia, Acrocalanus, Bivalve larvae, Brachyuran larvae, Calanus, Cirripede nauplius, Codonellopsis, Eucalanus, Gastropod larvae,Globigerina, Microsetella, Tintinnopsis* occurred 100% of occurrence.
7d	**Intertidal Fauna**	The survey of the intertidal Fauna of DPA Kandla area recorded the presence of 4 phyla (Arthropoda, Chordata, Mollusca). The faunal diversity was the highest for phylum Mollusca followed by Arthropoda and Chordata respectively. The organism such as Austruca iranica, Austruca sindensis, and Austruca variegata contribute highest percentage of composition. The density of Intertidal organism among different station was varied from 17No/m2 to 133 No/m2 with overall variation in 3 season was 18 No/m2 to 97No/m2. Monsoon contribute highest density of organism followed by Pre- and Post-Monsoon.
7e	**Sub-tidal Macrobenths**	The number of macro benthic fauna of the various groups from the DPA port environment includes Annelida, Arthropoda, Mollusca and Nematoda. The average density and population of subtidal macrobenthos from May 2024 to May 2025 varied from 307 N0/m2 to 507 No./m 2 and 12 to 20 in number. In station wise density of subtidal macrobenthos varied from 25 no/m2 to 1150 no /m2 with average variation of 100 no/m2 to 754 no/m2 . Highest dinsith was observed in Pre-monsoon and lowest was observed during post-monsoon. The species such as *Mysis larvae, Nereis sp, Glauconome angulata* and *Pirenella cingulata* was dominated

7f	Seaweeds and Seagrasses	No species of sea weeds and sea grass was recorded from the the stations sampled.
7g	Halophytes	During the period of May 2024 to May 2025 four major halophytes were recorded along the selected study stations of Deendayal Port Authority sites during the 3 seasons, were Salicornia brachiata, Aeluropus lagopoides, Salvadora persica and Sesuvium portulacastrum. Maximum percentage coverage of halophytes belongs to species Salicornia brachiate shared highest percentage of coverage in all season (100%) followed Sesuviumportulacastrum (30-45%)
7h	**Mammals**	No species of mammals was recorded from the stations sampled
7i	**Reptiles**	During the Monsoon AND Post- period of 2024-2025 field surveys it was encounter at S-10 located in the Southern part of Sat Saida bet
7j	**Fisheries**	The major fish catch activity is carried out in extensive creek systems of Khari creek, Tuna creek, Navalakhi creek and Jhangi creek. For the period of period 2024-2025, cast net was operated in different creek system of Kandla and major fish catch was include during monsoon Mugil cephalus, is major catch within 10 minutes around 1 km of distance.
7k	**Avifauna**	A total of 64 species (34 species terrestrial and 30 aquatic bird) representing 11 order, 26 families and 46 genera were recorded during the study period. Among 64 species, only five species viz. Painted Stork Mycteria leucocephala (Pennant, 1769), Black-headed Ibis Threskiornis melanocephalus (Latham, 1790), Glossy Ibis Plegadis falcinellus (Linnaeus, 1766), Black-tailed Godwit Limosa limosa (Linnaeus, 1758) and Eurasian curlew Numenius arquata (Linnaeus, 1758) are under the Near Threatened

Comparison Study of Marine Biodiversity of Deendayal Port Authority (DPA) Since 2019-2025

Habitat/ Groups	Major Taxa/Genera/Species	Year		Year		Year			Year		
		2019-2020		2020-2021		May 2021- May 2022			May 2022- May 2023		
		Pre Monsoon	Post monsoon	Pre monsoon	Post monsoon	Monsoon	Post monsoon	Pre monsoon	Monsoon	Post monsoon	Pre monsoon
Mangroves	*Avicennia marina*, *Ceriops tagal*, *Rhizophora mucronata, Aegiceras corniculatum*	4	4	4	4	4	4	4	4	4	4
Intertidal Habitat	Gastropods, Bivalves, Crustaceans Polychaetes, fishes, amphipods and Isopods	19	10	10	12	21	16	16	14	14	13
Subtidal Habitat	Polychaetes, molluscs, crustaceans,echinoderms	26	28	30	48	22	22	11	14	21	32
Phytoplankton	*Bacillaria, Navicula, Nitzschia, Chaetoceros, Coscinodiscus, Triceratium, Bidulphia, Melosira, Thassiosira*	32	26	23	19	35	23	23	24-33	22-26	21-26
Zooplankton	Copepods, Harpacticoids, Cyclopoids. brachyurans, cirripedes, Bivalve veligers	33	36	29	27	42	35	42	41	45	40
Seaweeds	Nil (Drifted tufts only)	Nil	Nil	drifted	drifted	drifted	drifted	drifted	NIL	NIL	NIL

Habitat/ Groups	Major Taxa/Genera/Species	Year		Year		Year			Year		
		2019-2020		2020-2021		May 2021- May 2022			May 2022- May 2023		
		Pre-M	Post-M	Pre-M	Post-M	Monsoon	Post-M	Pre-M	Monsoon	Post-M	Pre-M
Sea grasses	Nil (Drifted tufts only)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Halophytes	*Sesuvium portulacastrum, Salvadora persica, Aeluropus*	3	4	4	4	4	4	4	4 Salicrnia dominance	4 Salicrnia dominance	5 Salicrnia dominance
Avifauna	Charadriiformes, Phoenicopteriformes, Pelecaniformes, Passeriformes	49	89	49	69	62	84	52	49	79	53
Fishes	*Mugil cephalus, Harpodon nehereus, Pampus argenteus, Hilsa, Engraulis, Coilia* sp. *Peneaus,Portunus,lobester*	10	8	5	4	7	5	7		160 kg	50 kg
Marine Mammals	Dolphin, *Sousa plumbea*	1	1	Nil	Nil	1	Nil	Nil	1	1	Nil
Reptiles in the	The saw-scaled viper, *Echis*	1	1	Nil	1	Nil	Nil	1	1	1	Nil

For the period May 2023 to May 2024

Habitat/ Groups	Major Taxa/Genera/Species	Year		
		May 2023- May 2024		
		Monsoon	Post monsoon	Pre monsoon
Mangroves	*Avicennia marina*, *Ceriops tagal*, *Rhizophora mucronata, Aegiceras corniculatum*	4	4	4
Intertidal Habitat	Annelida, Arthropoda, Chordata Mollusca	15	15	14
Subtidal Habitat	Annelida,Arthropoda,Mollusca Chordata	26	21	15
Phytoplankton	*Coscinodiscus* dominance in all season	20-25	8-27	11-20
Zooplankton	The phylum Arthropoda was the predominant represented 16 groups in monsoon and post-monsoon (9) and pre-monsoon it contain 6 group which mainly include Copepoda, Harpacticoida, Cyclopoida, Decapoda, Crab larvae and Malacostrac	29-36	15-36	15-31
Seaweeds	No observation of seaweed during the study period	NIL	NIL	NIL

Habitat/ Groups	Major Taxa/Genera/Species	Year		
		May 2023- May 2024		
		Monsoon	**Post monsoon**	**Pre monsoon**
Sea grasses		NIL	NIL	NIL
Halophytes	*Sesuvium portulacastrum*, , Aeluropus lagopoides, *Salicornia brachiata*, *Suaeda nudiflora*	Present	Present	Present
Avifauna	55 species, 71 species , 68 species	55 species 8 order,24 families 23 genera	71 species 9 orders 29 families 55 genera	68 species 8 orders 28 families 53 genera
Marine Mammals	*Sousa plumbea*	No observation	S-6 and S-11	No observation
Fishes	*Mugil cephalus, Planiliza klunzingeri, Planiliza planiceps, Planiliza macrolepis*	*Mugil cephalus* More catch	*Mugil cephalus* More catch	Mugil cephalus
Reptiles	*Echis carinatus sochureki*	No observation	S-10	No observation

For the period May 2024 to May 2025

Habitat/ Groups	Major Taxa/Genera/Species	Year		
		May 2024- May 2025		
		Monsoon	Post monsoon	Pre monsoon
Mangroves	*Avicennia marina*, *Ceriops tagal*, *Rhizophora mucronata, Aegiceras corniculatum*	4	4	4
Intertidal Habitat	Arthropoda ,Chordata, Mollusca	Total density 53	Total density 42	Total density 45
Subtidal Habitat	Annelida,Arthropoda, Mollusca, Nematoda 307, 412,508	Total density 307	Total density 42 412	Total density 42 548
Phytoplankton	*Pennales, Centrales* dominated	65.1% 54.55	59.4% 33.9%	42.4% 33.1%
Zooplankton	The phylum Arthropoda was the predominant represented include Copepoda, Harpacticoida, Cyclopoida, Decapoda, Crab larvae and Malacostrac	14420	20000	18560
Seaweeds	No observation of seaweed during the study period	Nil	Nil	Nil

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Habitat/ Groups	Major Taxa/Genera/Species	Year		
		May 2024- May 2025		
		Monsoon	**Post monsoon**	**Pre monsoon**
Sea grasses		NIL	NIL	NIL
Halophytes	*Sesuvium portulacastrum*, , Aeluropus lagopoides, *Salicornia brachiata*, *Suaeda nudiflora*	Present	Present	Present
Avifauna	A total of 64 species (34 species terrestrial and 30 aquatic bird) representing 11 order, 26 families and 46 genera were recorded during the study period.	53	64	60
Marine Mammals	*Sousa plumbea*	no	no	no
Fishes	*Mugil cephalus, Planiliza klunzingeri, Planiliza planiceps, Planiliza macrolepis*	*Mugil cephalus*	*Mugil cephalus*	Mugil cephalus
Reptiles	*Echis carinatus sochureki*	S-10	S-10	NO

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1. Introduction

Deendayal Port is located at Kandla in the Kachchh district of Gujarat state, operated by Deendayal Port Authority (DPA) (constituted under the major port Authority Act and the administrative control of the Ministry of ports shipping & water way (GOI) is India's busiest major port in recent years and is gearing to add substantial cargo handling capacity with private participation. DPA being one of the 12 major ports in India is situated at latitude 22°59'4.93N and longitude 70°13'22.59 E on the Kandla creek at the inner end of Gulf of Kachchh (GoK). Since its formation in the 1950s, the Deendayal Port provides the maritime trade requirements of states such as Rajasthan, Madhya Pradesh, Uttar Pradesh, Haryana and Gujarat. Because of its proximity to the Gulf countries, large quantities of crude petroleum are imported through this port. About 35% of the country's total export takes place through the ports of Gujarat in which the Deendayal port has a considerable contribution. Assortments of liquid and dry cargo are being handled at DPA Port. The dry cargo includes fertilizers, iron and steel, food grains, metal products, ores, cement, coal, machinery, sugar, wooden logs, etc. The liquid cargo viz. chemicals, edible oil, crude oil and other petroleum products etc. DPA has handled 132.3 MMTPA during the year 2023-2024. Presently, the Port has total 1-16 dry cargo berths, 7 oil jetties, and one barge jetty at Bunder basin, dry bulk terminal at Tuna Tekra, barge jetty at Tuna and two SPMs (2 local & 1 Nayara energy Limited and two product berths-Nayara energy Limited) at Vadinar for handling crude oil and petroleum products. Regular expansion or developmental activities such as the addition of jetties, allied SIPC and ship bunkering facilities oil jetty No 8 and container terminal at Tuna Tekra are underway in order to cope with the increasing demand for cargo handling during the recent times. A developmental initiative of this magnitude is going on since the past 7 decades, which will have its own environmental repercussions. Being located at the inner end of Gulf of Kachchh, Deendayal Port Authority encompasses a number of fragile marine ecosystems that includes a vast expanse of mangroves, mudflats, creek systems and associated biota. Deendayal Port is a natural harbour located on the eastern bank of North-South trending Kandla creek at an aerial distance of 90 km from the mouth of Gulf of Kachchh. The Port's location is marked by a network of major and minor mangrove lined creek systems with a vast extent of mudflats. The coastal belt in and around the port has an irregular and dissected configuration. Due to its location at the inner end of the Gulf, the tidal amplitude

is elevated, experiencing 6.66 m during mean high-water spring (MHWS) and 0.78 m during mean low water spring (MLWS) with MSL of 3.88 m. Commensurate with the increasing tidal amplitude, vast intertidal expanse is present in and around the port environment. Thus, the occurrence of mudflats on the intertidal zone enables mangrove formation to an extensive area. Contrary to the southern coast of Gulf of Kachchh, the coral formations, seaweed and seagrass beds are absent in the northern coast due to high turbulence induced suspended sediment load in the water column, a factor again induced due to the conical Gulf geomorphology and surging tides towards its inner end.

1.1. Rationale of the present study

The ongoing developmental activities at Deendayal Port Authority has been intended for the following.

(i) The development of the 3 remaining integrated facilities (Stage 1) within the existing Port at Kandla which includes development of a container terminal at Tuna off Tekra on BOT base T shape jetty, construction of port craft jetty and shifting of SNA section of Deendayal port and railway line from NH-8A to Tuna port.

(ii) EC & CRZ clearance granted by the MoEF &CC, GoI dated 18/2/2020 Dev. Remaining 3 integrated facilities (Stage I) within the existing Kandla port – specific condition no. xxiii.

(iii) EC & CRZ clearance granted by the MoEF &CC, GoI dated 19/2/2020 Dev. integrated facilities (Stage II-5 (1) Setting of oil jetty No7 (2) Setting up barrage jetty at Jafar wadi (3) Setting up barrage port at Veera (4) Administrative office building at Tuna Tekra (5) Road connecting from Veera barrage jetty to Tuna gate by M/s DPA -specific condition no. xv.

(iv) EC & CRZ clearance granted by the MoEF &CC, GoI dated 20/11/20 – expansion of port by creation of water front facilities (Oil jetty 8,9,10 and 11) and development of land area 554 acres for associated facilities for storage at old Kandla, Gandhidham, Kachchh by Ms. PA Para VIII Marine Ecology, specific condition iv.

(v)Development of 7 integrated facilities (Stage I) within the existing Kandala port CRZ clearance MoEFcc , GOI dated 19/12/2016-Specific condition (ii),(iii) and (iv) the project proponent ensure that, no damage to the mangrove patch without

disturbing creek water circulation ,there is no blocking of creek or rivers of project area and shoreline also not damaged and it periodically monitored .

(vi) EC& CRZ clearance granted by MoEF &CC , GOI dated 1/1/2024 augmentation of liquid cargo handling facility specific condition no XXV.

As per the environmental clearance requirements to these developmental initiatives, by MoEF & CC, among other conditions, has specified to conduct the continuous monitoring of the coastal environment on various aspects covering all the seasons. The regular monitoring shall include physico-chemical parameters coupled with biological indices such as mangroves, seagrasses, macrophytes and plankton on a periodic basis during the construction and operation phase of the project. Besides, the monitoring study also includes an assessment of Mudflats, Fisheries, and Intertidal fauna including the macrobenthos as components of the management plan. The regular marine ecology monitoring includes Micro, Macro and Mega floral and faunal components of marine biodiversity of the major intertidal ecosystems, the water and sediment characteristics. In accord with MoEF&CC directive, DPA has consigned the project on 'Regular Monitoring of Marine Ecology in and around the Deendayal Port Authority and Continuous Monitoring Programme" to Gujarat Institute of Desert Ecology (GUIDE), Bhuj during May, 2021. Further, Deendayal Port authorities has entrusted Gujarat Institute of Desert Ecology (GUIDE) to continue the study for another three years, i.e., 2021 – 2024 and further extended to another 3 years i.e from May 2024 to May 2027 with specific condition XXV for augmentation of liquid cargo handling facility . The study covers all the seasons as specified by specific condition of the Ministry of Environment, Forest and Climate Change (MoEF&CC). The present study is designed considering the scope of work given in the EC conditions

1.2 Scope of work

The scope of the present investigation includes physico-chemical and marine biological components as mentioned in the specific conditions of MoEF&CC, EC & CRZ clearance dated 19.12.2016,18.2.2020,19.2.2022 and 20.11.2020 & 1.1.2024 with specific conditions xviii, xxiii, xv, iv and xxv respectively. A detailed holistic approach to different components of marine physico-chemical parameters of water and sediment and marine biodiversity within the Deendayal Port area will be carried out. Based on the results obtained during the project period, a detailed management plan will be drawn at the end of the project period. The biological and physico-chemical variables will be investigated

during the present study on a seasonal basis i.e., monsoon, post-monsoon and pre-monsoon as the period May 2024 to May 2025 as follows:

- Physico-chemical characteristics of water and sediment will be analysed.
- Detailed assessment of mangrove vegetation structure including density, diversity, height, canopy and other vegetation characteristics.
- GIS and RS studies to assess different ecologically sensitive land use and land cover categories within the Port area such as the extent of dense and sparse mangroves, mudflats, creek systems and other land cover categories within the port limits.
- To study the intertidal faunal composition, distribution, diversity, density and other characteristics, other mega faunal components such as mammals, reptiles and amphibians.
- To investigate the species composition, distribution, diversity, density of sub-tidal benthic fauna.
- To estimate the primary productivity of the selected sampling sites located in around DPA area.
- ToInvestigate the species composition, distribution, density and diversity of phytoplankton and zooplankton.
- To study the distribution of halophytes, sea grasses, seaweeds and other coastal flora, their occurrence, distribution, abundance and diversity.
- To study the Avifaunal density, diversity, composition, habitat, threatened and endangered species and characters.
- Fishery Resources - Common fishes available, composition, diversity, Catch Per Unit Effort (CPUE) and other socio-economic information.

This study in short attempts the following, to i) developing a strong long-term monitoring of the port marine environment from the biological perspective which could be used to monitor changes in the future, and ii) formulating a management plan based on the baseline data in order to ensure long-term ecological health of the port environment. A better understanding of the marine ecology of the port and its processes has been attempted in this study which will assist in better management and conservation decisions to promote marine environmental health within the port limits.

1.2.1. Study Area

The coastal belt in and around Deendayal Port Authority jurisdiction is characterized by a network of creek systems and mudflats which are covered by sparse halophytic vegetation like scrubby to dense mangroves, creeks and salt-encrusted landmass which form the major land components (Table1) .The surrounding environment in 10 km radius from the port includes built-up areas, salt pans, human habitations and port related structures on the west and north creek system, mangrove formations and mudflats in the east and south (Fig1). The nearest major habitation is Gandhidham town located about 12 km away on the western part with population of 2,48,705 (as per 2011 census).

Table 1 . Sampling locations of study area (2024-2025)

Locations	GPS coordination	
	Latitude	Longitude
S-1	22.9410	70.1358
S-2	22.9616	70.1244
S-3	22.9876	70.2345
S-4	23.0285	70.2331
S-5	23.0804	70.2245
S-6	23 9'19.99	7024'1.47
S-7	22.9771	70.2125
S-8	23.0378	70.4070
S-9	22.9960	70.3932
S-10	23.1007	70.2961
S-11	23.1608	70.4948
S-12	22.9446	70.1062
S-13	23° 6'58.69"	70°21'8.77"
S-14	22.89590	70.07450
S-15	23.0654	70.2172

2.Sampling of water and sediment samples

Sampling was carried out for the coastal water (surface) and sediment to determine physical and chemical characteristics from the prefixed sampling sites. The biological parameters (benthic and pelagic fauna, flora and productivity) were also estimated (Table.2). The water samples were collected from each pre-designated site in pre-clean polyethylene bottles. Prior to sampling, the bottles were rinsed with sample water to be collected and stored in an ice box for

transportation to the laboratory and refrigerated at 4°C till further analysis. The analysis of the water quality parameters was carried out by following standard methods (APHA, 2017). All extracting reagents were prepared using metal-free, AnalaR grade chemicals (Qualigens Fine Chemicals Division of Glaxo SmithKline Pharmaceuticals Limited, Mumbai) and double distilled water prepared from quartz double distillation unit.

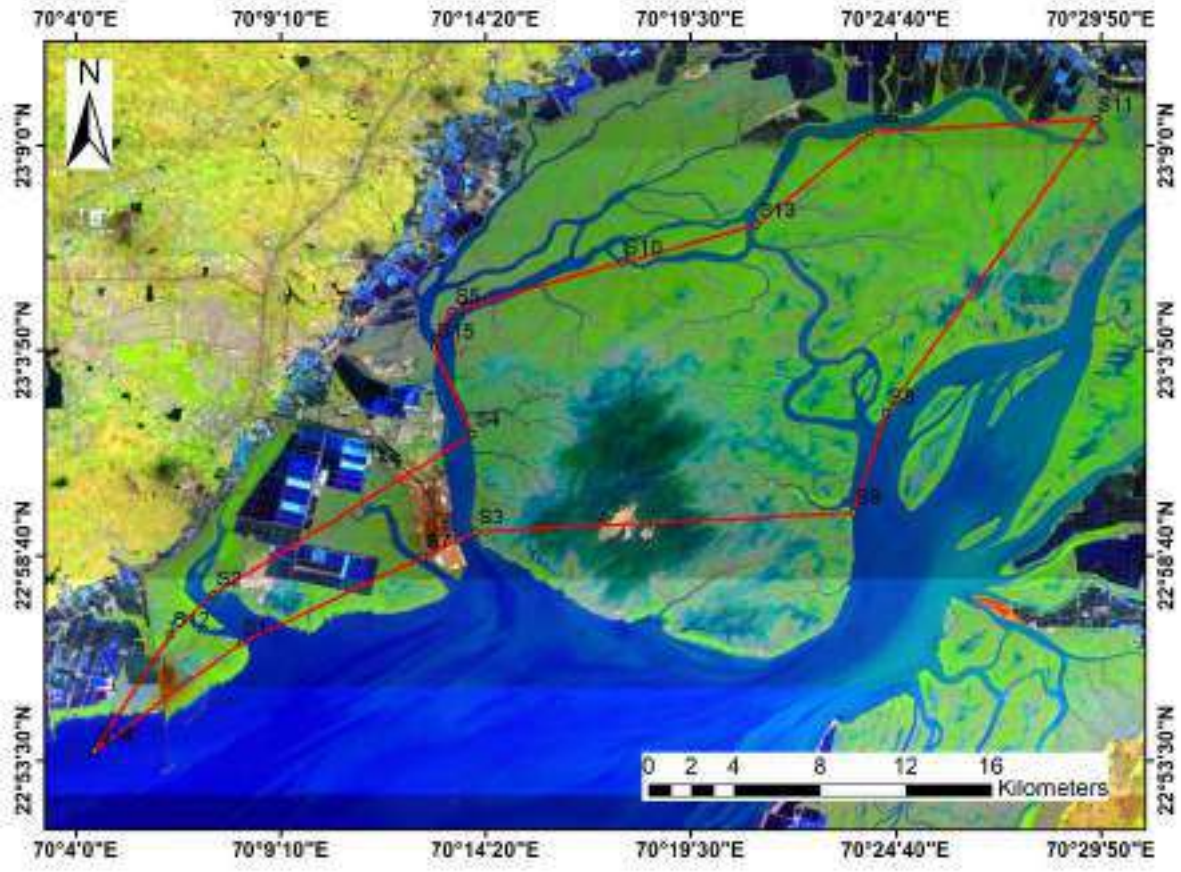


Figure 1. Sampling locations of Study area

2, Land use Land Cover Changes

In order to understand the spatial and temporal changes in the vicinity of the Deendayal port jurisdiction area, Remote Sensing and GIS technique has been employed. Land cover classification was carried out using digital satellite imageries. Images for the Deendayal Port area were acquired for the period of April 2017, December 2019 and March 2020, November 2020, April 2021, March 2022 and March 2023 were used for the study. These were brought to UTM projection with spheroid and datum named WGS 84 in UTM zone 42 north.

Table 2 Satellite Imagery Used for Land Use Land Cover Map

Image use	Satellite name	Sensor	Spatial Resolution	Date acquired
2017	IRS-R2A	LISS IV	5.8m	26 April- 2017
2019	IRS-R2A	LISS IV	5.8m	24-DEC-2019
2020	IRS-R2A	LISS IV	5.8m	29-March-2020
2020	IRS-R2	LISS IV	5.8m	17-Nov-2020
2021	IRS-R2	LISS IV	5.8m	10-APR-2021
2022	IRS-R2	LISS IV	5.8m	12-March-2022
2023	IRS-R2	LISS IV	5.8m	31-March-2023

2.1 Methodology

Training samples were collected from these imageries. Selecting training samples from these cloud-free mosaics was straightforward due to the very distinctive signature of mangrove area. High contrast with open water, saltpan and mudflat helped in selecting the training data successfully. Same training samples with slight modifications in each imageries mosaic (addition and removal of few training samples) were used for the classification of all different date images. Six major classes viz., mangrove, water, mudflat, other vegetation, salt pan and port were delineated. For the tonal variation and pixel values in the imageries, NDVI (Normalised Differential Vegetative Index) and a supervised Maximum Likelihood Classification (MLC) methods were used for the classification. ERDAS Imagine 9.3 was used for satellite image processing, classification and data transformation whereas ARC GIS 10.3 was used for the map formation. Forgraphs and databases processing, MS WORD and MS EXCEL were used.Ground truth study comprises data collection of ground features along with the respectivegeographical positions in

terms of latitudes and longitudes with Garmin e-Trex Vista GPS. Thus, the data were interpreted using all the collected information.

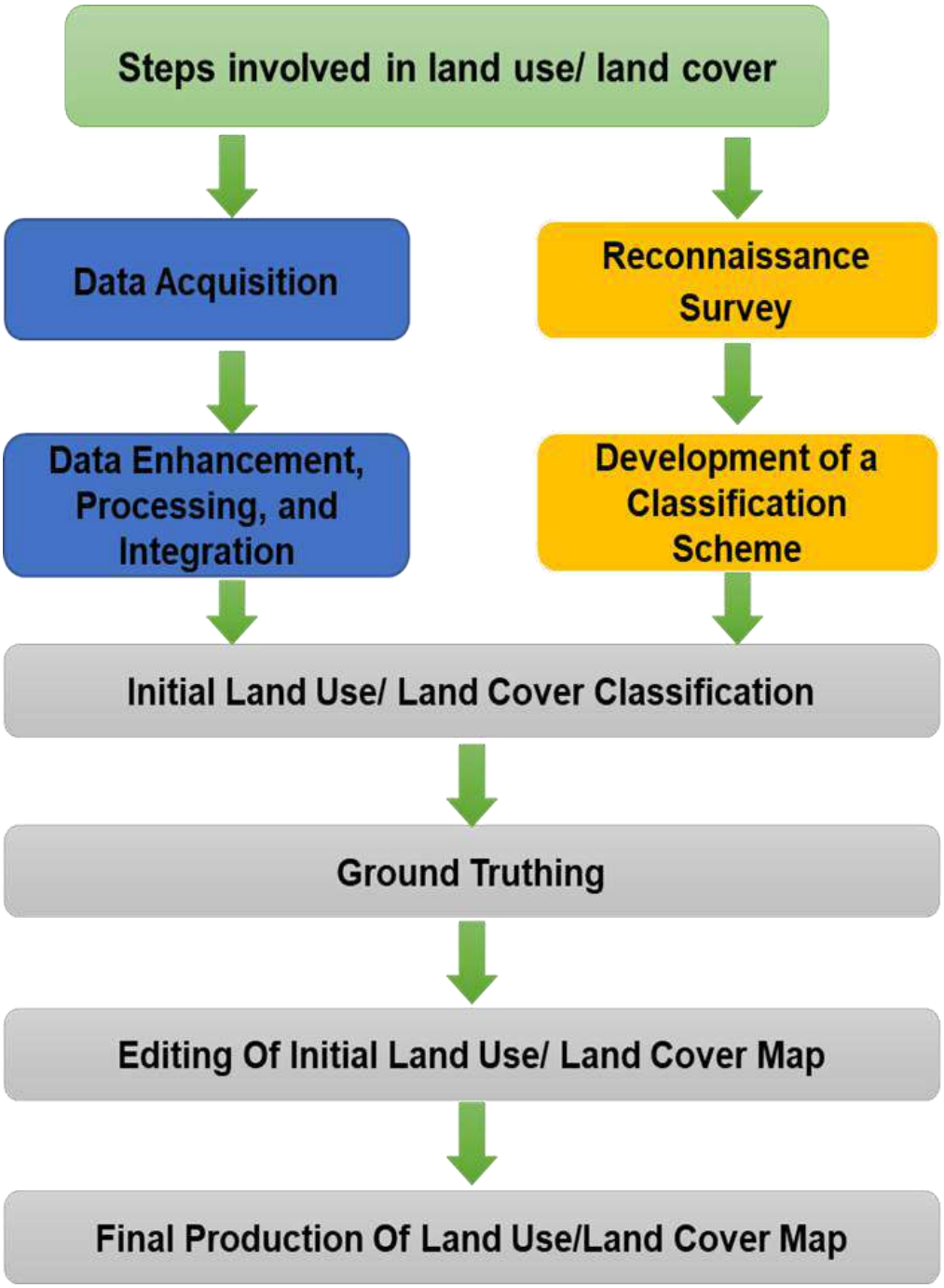


Figure 2. Methodology for land use Land cover

2.2.1Land use Land Cover

Classified imageries are presented in Fig 3 to Fig 4 and detailed presented in table 2 and 3.

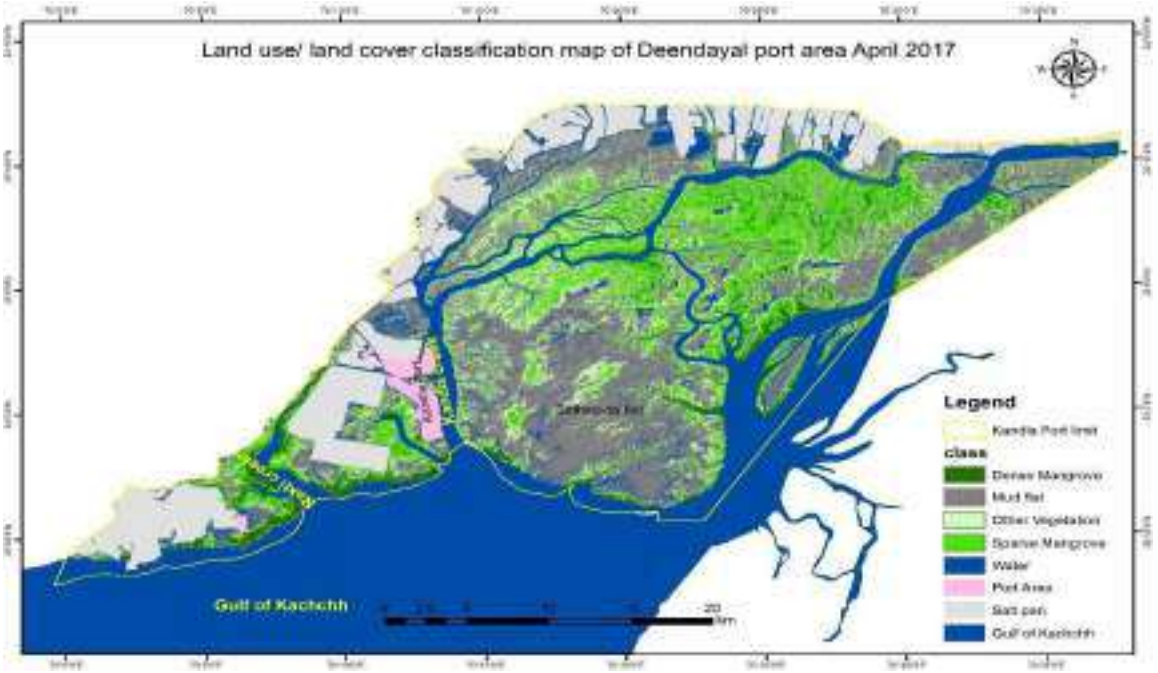


Figure 3. Land use/ Land cover classification in DPA area- April-2017

Figure 4. Land use/ land cover classification in DPA area December-2019

Table 3. Land use /Land cover statistics in the DPA area - April-2017

Class Name	Area (ha)	Percentage
Mangrove (Dense + Sparse)	19319.71	19.32
Mudflat	31293.43	31.3
Other veg	12438.8	12.44
Port Area	1243.67	1.24
Salt pan	15016.1	15.02
Water	20674.3	20.68
Total	**99986.01**	**100**

Table 4. Land use /Land cover statistics in the DPA area - December-2019

Class Name	Area (ha)	Percentage
Mangrove	23060.04	23.06
Mudflat	31179.87	31.18
Other vegetation	12333.21	12.33
Water	16953.68	16.96
Port area	1346.21	1.35
Salt pan	15113	15.12
Total	**99986.01**	**100**

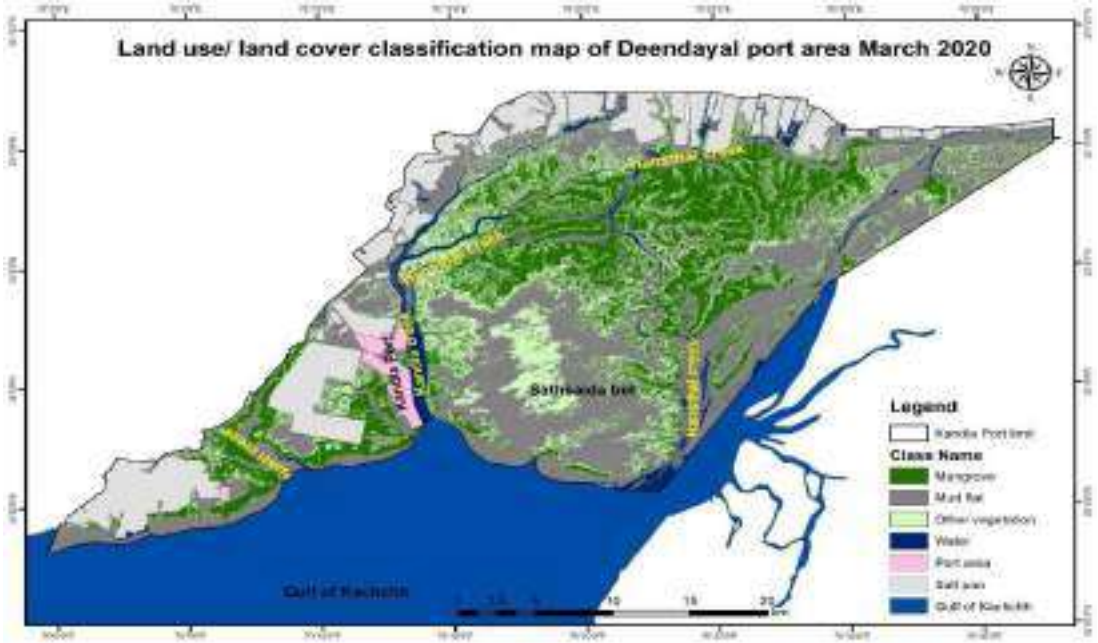


Figure 5. Land use/ land cover classification in DPA area March-2020

Table 5. Land use /land cover statistics in the DPA area- March-2020

Class name	Area (ha)	Percentage
Mangrove	23168.4	23.17
Mudflat	40714.6	40.72
Other vegetation	15991.69	15.99
Port area	1346.21	1.35
Salt pan	15054.5	15.06
Water	3710.61	3.71
Total	**99986.01**	**100**

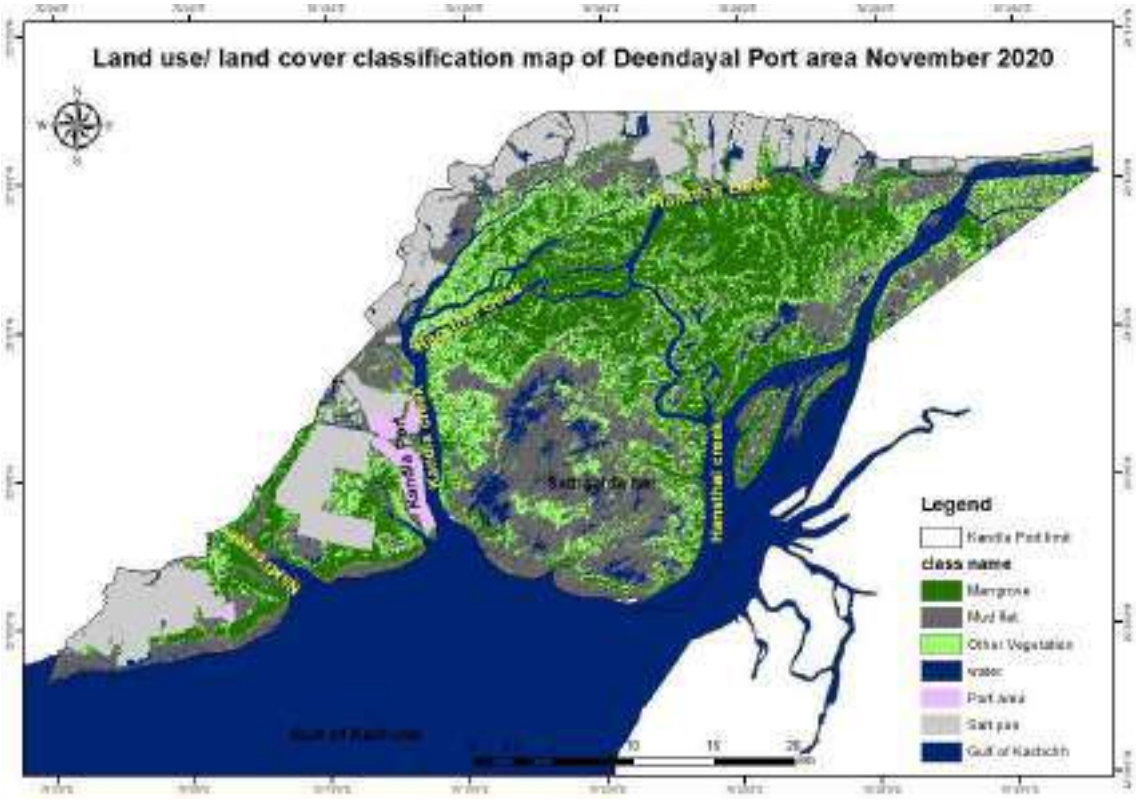


Figure 6. Land use/ land cover classification in Deendayal port area November 2020

Table 6. Land use /land cover statistics in the DPA area- November2020

Class	Area (ha)	Percentage
Mangrove	23856.8	23.86
Mudflat	28764.6	28.77
Other Vegetation	16346.1	16.35
Port area	1346.21	1.35
Salt pan	15193.5	15.2
water	14478.8	14.48
Total	99986.01	100

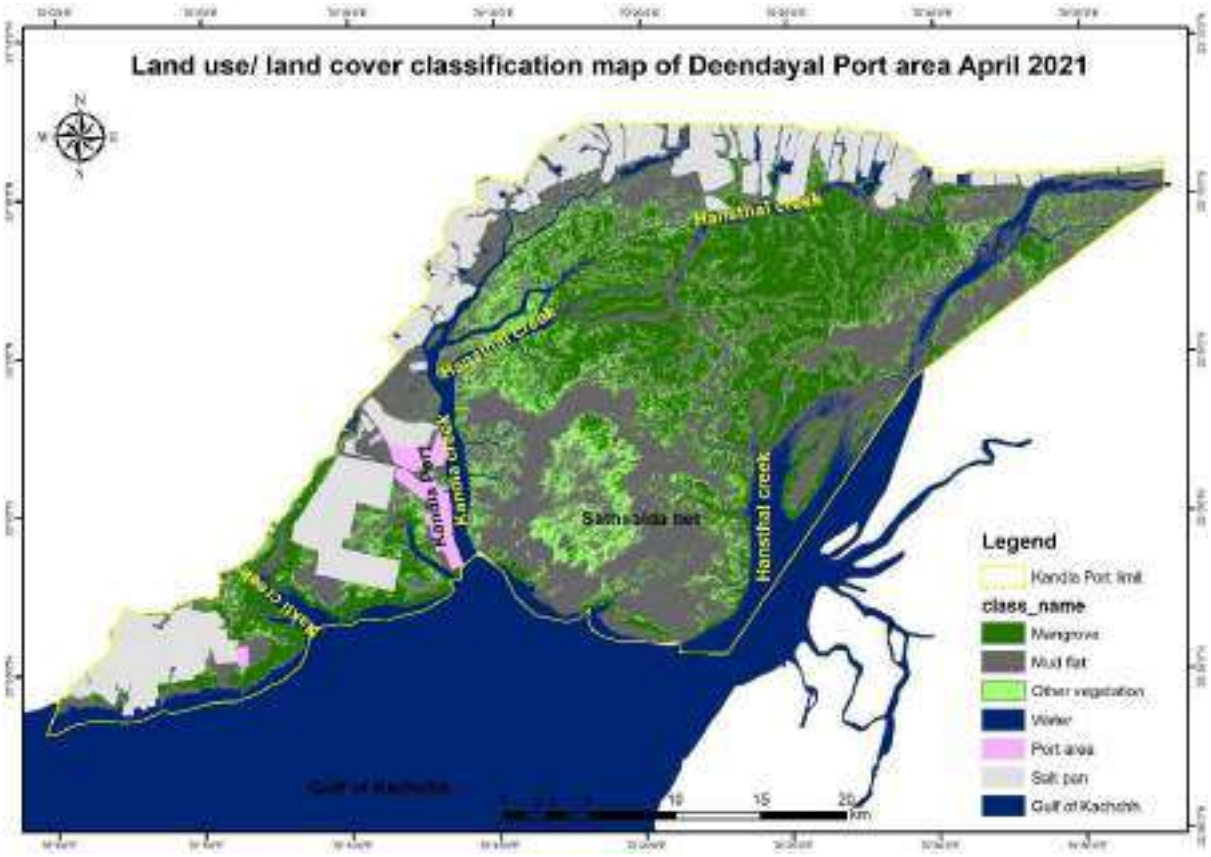


Figure 7. Land use/ land cover classification in Deendayal port area April-2021

Table 7. Land use /land cover statistics in the DPA area April-2021

class name	Area (ha)	Percentage
Mangrove	23967.4	23.97
Mudflat	36909.3	36.91
Other vegetation	11230.4	11.23
Port area	1346.21	1.35
Salt pan	15236.6	15.24
Water	11296.1	11.3
total	**99986.01**	**100**

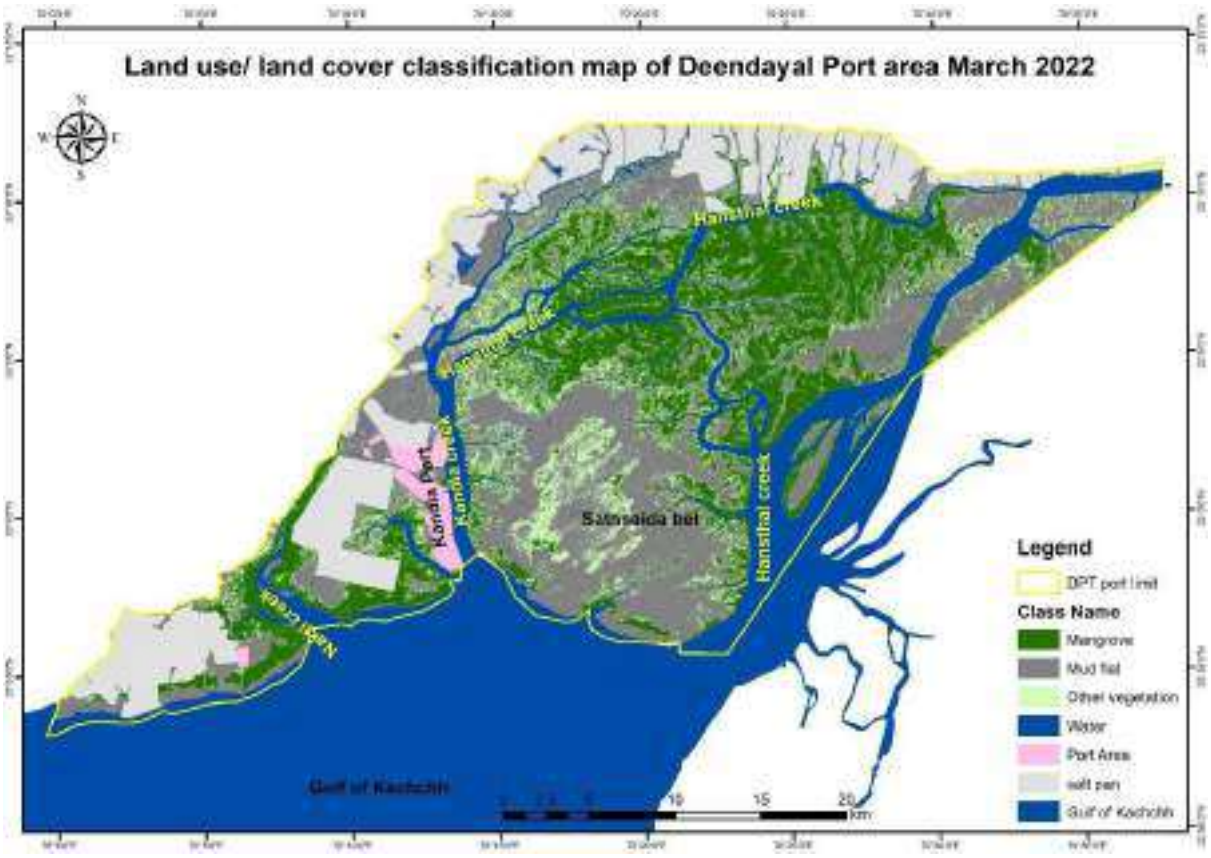


Figure 8.Land use/ land cover classification in Deendayal port area March-2022

Table 8. Land use /land cover statistics in the DPA area March-2022

class name	Area (ha)	Percentage
Mangrove	24328.7	24.33
Mudflat	31089.06	31.09
Other vegetation	11561.2	11.56
Port Area	1436.75	1.44
salt pan	15545.7	15.55
Water	16024.6	16.03
Total	**99986.01**	**100**

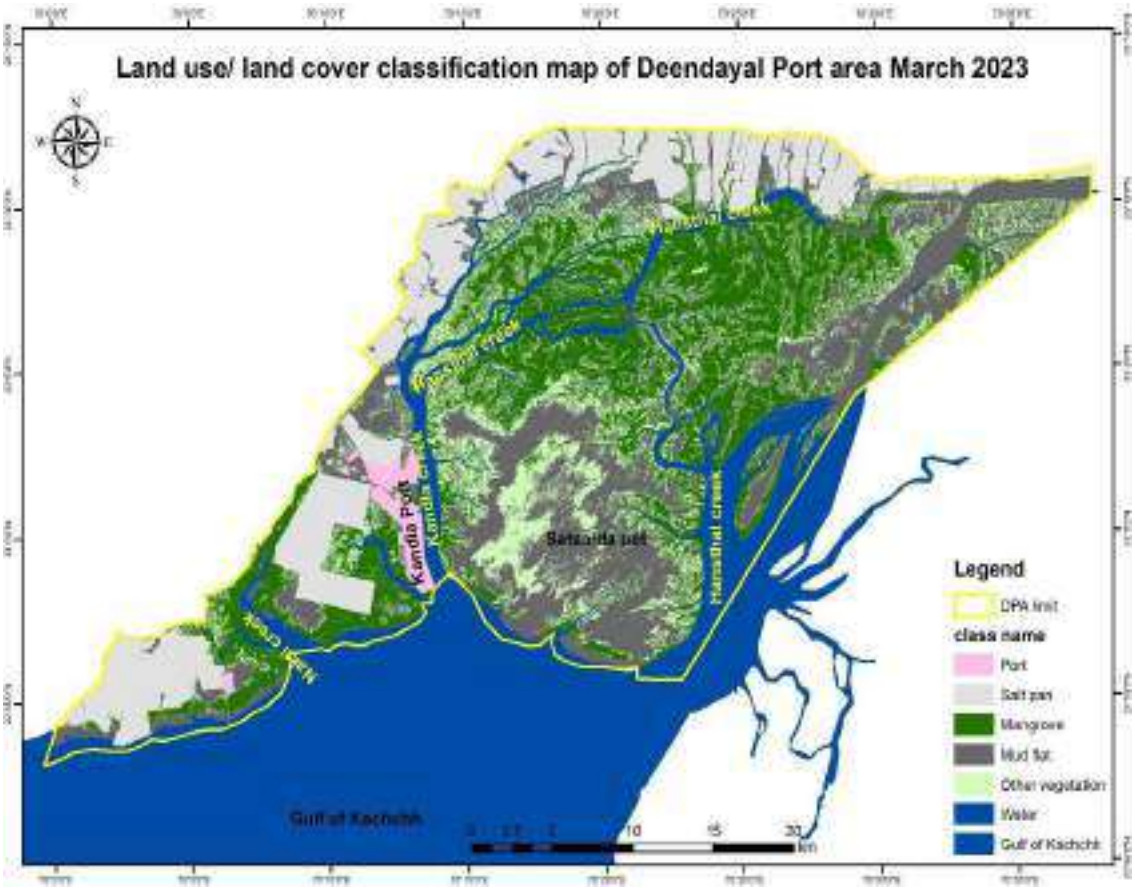


Figure 9. Land use/ land cover classification in Deendayal port area March-2023

Table 9. Land use /land cover statistics in the DPT area for March-2023

class name	Area (ha)	Percentage
Mangrove	26520.56	26.52
Mud flat	27547.90	27.55
Other vegetation	15969.90	15.97
Port	1436.75	1.44
Salt pan	16094.80	16.10
Water	12416.10	12.42
Total	**99986.01**	**100.00**

2.2.2. Comparative Analysis of Land use Land Cover Study

From April 2017 to March 2023 the overall mangrove area increased from 19319 ha to 26520.5 ha, i.e. 7 % of the total area of DPA. Mangrove area is replacing on the mostly on mudflat, hence there is a decreasing trend of the mudflat is clearly seen. Since this area comes under the influence of the tidal time mudflat area comes high value in that case water area decrease. But overall trends show mudflat is replaced by mangroves. (Fig 3.9). Good monsoon and favorable environment have positively impacted the mangroves to flourish. The below graph shows clearly, year on year mangrove area in DPA vicinity is increasing, currently, around 26.5% of the total area of DPT is covered by mangroves.

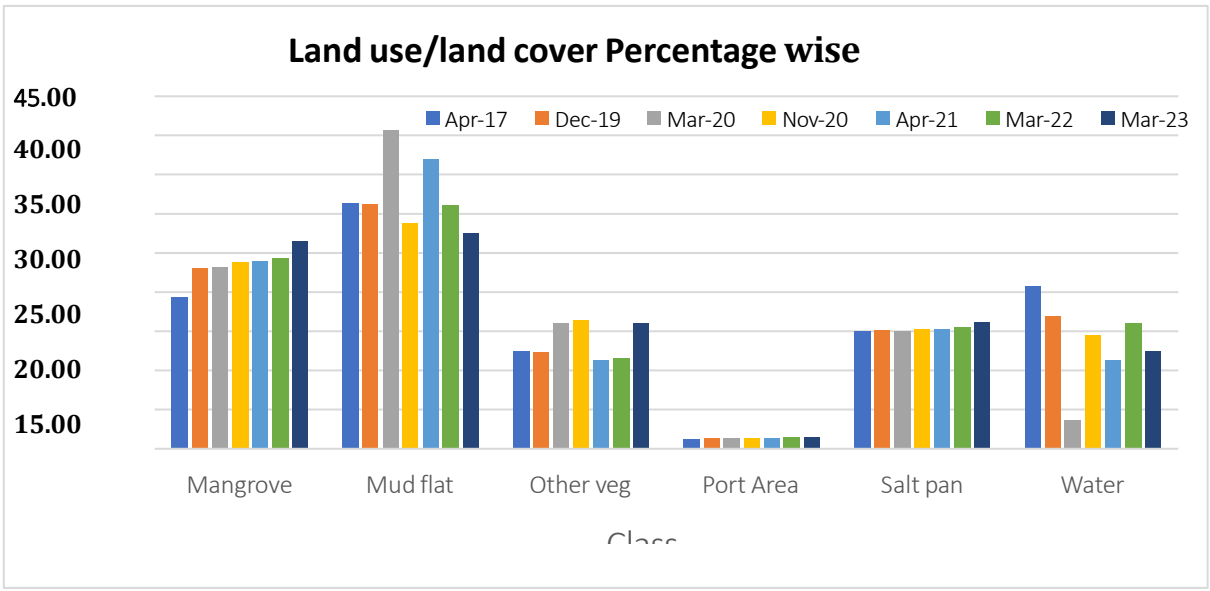
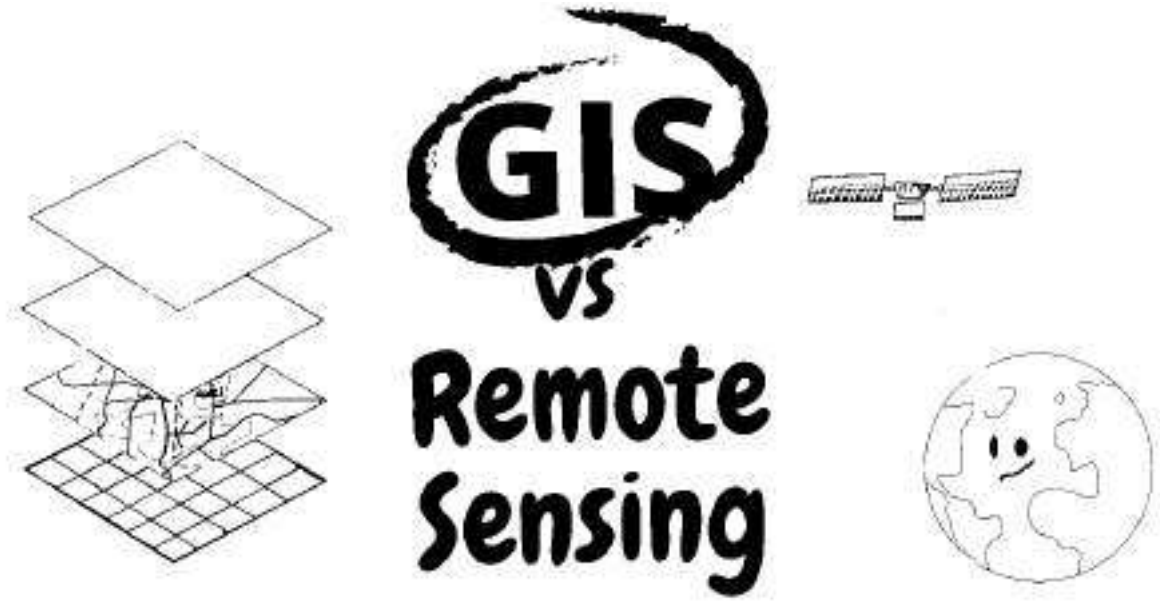


Figure 10. LU/LC Percentage area for the period 2017 to 2023 in Deendayal Port Authority

Table 10. Land use /land cover Percentage wise in the vicinity of DPA area for the study period 2017-2023

Month-Year	Apr-17	Dec-19	Mar-20	Nov-20	Apr-21	Mar-22	Mar-23
Class Name	Area (ha)						
Mangrove	19.32	23.06	23.17	23.86	23.97	24.33	26.52
Mudflat	31.30	31.18	40.72	28.77	36.91	31.09	27.55
Other veg	12.44	12.33	15.99	16.35	11.23	11.56	15.97
Port Area	1.24	1.35	1.35	1.35	1.35	1.44	1.44
Salt pan	15.02	15.12	15.06	15.20	15.24	15.55	16.10
Water	20.68	16.96	3.71	14.48	11.30	16.03	12.42
Total	100	100	100	100	100	100	100



3. Methodology

3.1.Physico-chemical Parameters, Water and Sediment

A port is a location on a coast or shore containing one or more harbors where ships can dock and transfer people or cargo to or from land. Port locations are selected to optimize access to land and navigable water, for commercial demand, and for shelter from wind and waves. Harbors can be natural or artificial. An artificial harbor has deliberately constructed breakwaters, sea walls, or jetties, or otherwise, they could have been constructed by dredging, and these require maintenance by further periodic dredging.Ports are economic instruments for trade and a vital component in the nation's economy. Nevertheless, port activities such as land reclamation, dredging and large-scale construction and its continuous expansion negatively affect the marine ecosystems in its vicinity.

In a port environment, activities like dredging, continuous movement of vessels and humans create major impacts at the marine/coastal environment and the living resources. This will have several impacts on the coastal environmental health which can be reflected by the nature of the physico-chemical characteristics of water which in turn indicates in its productivity. The change in productivity pattern of the marine environment is highly influenced by the flow of nutrients which generally originates from natural and anthropogenic sources. This change in quality of marine water, impacts the composition and availability of aquatic organisms directly and also affects the natural process in the marine ecosystem biological component, coral reefs and seagrass habitats etc. Similar to water, marine sediments also receive pollutants / such as heavy metals, petroleum hydrocarbons, polyaromatic hydrocarbons, polychlorinated biphenyls etc as contaminants from various activities, both off shore and on shore near ports and harbours. Hence assessing the water and sediment characteristics is imperative to understand the environmental changes and to suggest scientific interventions to restore the ecosystem integrity

3.1.1. Sampling Parameters & Water sample collection

Sampling was carried out for the coastal water (surface) and sediment for the determination of physical and chemical characteristics from the prefixed sampling sites. The biological parameters (benthic and pelagic fauna, flora and productivity) were also estimated (Table 11).

Table 11: Physico-chemical and biological parameters analysed

Parameters	
Water	**Mangrove & Other Flora**
pH	**Mangrove**
Temperature	Vegetation structure, density
Salinity (ppt)	Diversity
Dissolved oxygen	Height
Total Suspended Solids (TSS)	Canopy and other vegetation characteristics
Total Dissolved solids (TDS	**Halophytes:**
Turbidity	Percentage of distribution and cover
Nutrients	Diversity
Nitrate (NO_3)	**Seagrass and Seaweed**
Nitrite (NO_2)	Occurrence, distribution, and diversity
Phosphate	**Intertidal fauna**
Silicate	Composition, distribution, diversity, density and other characteristics
Petroleum Hydrocarbon (PHs)	**Mammals**
Sediment	**Avifauna**
Texture	Density, diversity, composition, habitat,
Bulk density	Threatened and endangered species and characters
Total organic carbon (TOC)	
Biological Parameters	
Phytoplankton- Genera, abundance, diversity and biomass	
Productivity-Chlorophyll a	
Zooplankton – Species, abundance, diversity	
Macrobenthos - genera, abundance, diversity	
Fishery Resources	
Common fishes available	
composition, diversity	
Catch Per Unit Effort (CPUE)	

The water samples were collected from each pre-designated sites in pre-cleaned polyethylene bottles. Prior to sampling, the bottles were rinsed with sample water to be collected and stored in an ice box for transportation to laboratory and refrigerated at 4°C till further analysis. The analysis of the water quality parameters was carried out by following standard methods (APHA, 2017). All extracting reagents were prepared using metal-free, AnalaR grade chemicals (Qualigens Fine Chemicals Division of Glaxo SmithKline Pharmaceuticals Limited, Mumbai) and double distilled water prepared from quartz double distillation assembly. There is one water sample will be collect from each designated sampling locations and period of survey will be carried out June to September as Monsoon, October to January will be designated as Post-monsoon and February to May will be designated as Pre-monsoon.

3.1.2.pH and Temperature

A Thermo fisher pH / EC / Temperature meter was used for pH and temperature measurements. The instrument was calibrated with standard buffers just before use.

3.1.3.Salinity

A suitable volume of the sample was titrated against silver nitrate (20 g/l) with Potassium chromate as an indicator. The chlorinity was estimated, and from that, salinity values were derived using a formula (Strickland and Parsons,1972).

3.1.4.Total Suspended Solids (TSS)

About 100 ml of the water sample was filtered through pre-weighed filter paper and placed in the Hot Air Oven at a specified temperature as per the protocol for 1 hour. The filter paper was allowed to cool in a desiccator to obtain a constant weight by repeating the drying and desiccation steps.

3.1.5. Total Dissolved Solids (TDS)

The water samples were subjected for gravimetric procedure for confirmation of the readings obtained from the hand -held meter. About 100 ml of the water sample was taken in a beaker and filtered, which was then dried totally in a Hot Air Oven (105°C). The TDS values were calculated using the difference in the initial and final weight of the container.

3.1.6.Turbidity

The sample tube (Nephelometric cuvette) was filled with distilled water and placed in the sample holder. The lid of the sample compartment was closed. By adjusting the' SET ZERO' knob, the meter reading was adjusted to read zero. The distilled water was removed, the 40 NTU standard solutions were filled in the tube, and the meter reading was set to read 100. Other standards were also run. The turbidity of the marine water sample was then found by filling the sample tube with the sample, and the reading was noted.

3.1.7. Dissolved Oxygen (DO)

The amount of dissolved oxygen (DO) was determined by Winkler's method (Strickland and Parsons,1972).

3.1.8.Phosphate

Acidified Molybdate reagent was added to the sample to yield a phosphomolybdate complex that is reduced with Ascorbic acid to a highly coloured blue compound, which is measured at the wavelength of 690 nm in a Spectrophotometer (Shimadzu UV 5040). The Phosphorus compounds in the sample were oxidized to phosphate with alkaline Potassium per sulphate at high temperature and pressure. The resulting phosphate was analyzed and described as total phosphorous (APHA,2017).

3.1.9. Silicate

The determination of dissolved silicon compounds in natural waters is based on the formation of a yellow silicomolybdic acid when an acid sample is treated with a molybdate solution. It is Spectrophotometrically measured by absorbance (810 nm for maximum absorbance and 660 for about 40% by adopting method of Grasshoff et.al. (1999).

3.1.10.Nitrite

Nitrite in the water sample was allowed to react with Sulphanilamide in acid solution. The resulting diazo compound was reacted with N-1-Naphthyl ethylenediamine dihydrochloride to form a highly coloured azo-dye. The light absorbance was measured at the wavelength of 543 nm in Spectrophotometer (Shimadzu UV 5040).

3.1.11.Nitrate

The Nitrate content was determined as nitrite (as mentioned above) after its reduction by passing the sample through a column packed with amalgamated Cadmium.

3.1.12.Petroleum Hydrocarbon (PHs)

The water sample (1liter) was extracted with Hexane and the organic layer was separated, dried over anhydrous sulphate and reduced to 10 ml at 30°C under low pressure. Fluorescence of the extract was measured at 360 nm (excitation at 310 nm) with Saudi Arabian crude residue as a standard. The residue was obtained by evaporating lighter fractions of the crude oil at 120°C.

3.2 Sediment Characteristic (Sediment sampling)

Sediment samples were collected from the prefixed stations by using a Van Veen grab having a mouth area of 0.04m^2 or by a non-metallic plastic spatula. Sediment analysis was carried out by using standard methodologies. In each location (grid), sediment samples were collected from three different spots and pooled together to make a composite sample, representative of a particular site. The collected samples were air dried and used for further analysis.

3.2.1.Sediment Texture

For texture analysis, specified unit of sediment sample was passed through sieves of different mesh size as per Unified Soil Classification System (USCS). Cumulative weight of the fraction retained in each sieve was calculated starting from the largest sieve size and adding subsequent sediment weights from the smaller size sieves (USDA,1951). The percentage of the various fractions was calculated from the weight retained and the total weight of the sample. The cumulative percentage was calculated by sequentially subtracting percent retained from the 100%.

3.2.2.Total Organic carbon

Percentage of organic carbon in the dry sediment was determined by oxidizing the organic matter in the sample by Chromic acid and estimating the excess Chromic acid by titrating against Ferrous ammonium sulphate with Ferroin as an indicator (Walkley and Black, 1934).

3.3. Biological Characteristics of water and Sediment

3.1.1.Primary productivity

Phytoplankton possess the plant pigment chlorophyll 'a' which is responsible for synthesizing the energy for metabolic activities through the process of photosynthesis in which CO_2 is used and O_2 is released. It is an essential component to understand the consequences of pollutants on the photosynthetic efficiency of phytoplankton in the system. To estimate this, a known volume of water (500 ml) was filtered through a 0.45 µm Millipore Glass filter paper and the pigments retained on the filter paper were extracted in 90% Acetone. For the estimation of chlorophyll 'a' and pheophytin pigments the fluorescence of the Acetone extract was measured using Fluorometer before and after treatment with dilute acid (0.1N HCL) (Strickland and Parsons,1972).

3.1.2.Phytoplankton

Phytoplankton samples were collected from the prefixed 15 sampling sites from the coastal water in and around DPA location using standard plankton net with a mesh size of 25µm and a mouth area of 0.1256 m^2 (20 cm radius). The net fitted with a flow meter (Hydrobios) was towed from a motorized boat moving at a speed of 2 nautical miles/hr. The Plankton adhering to the net was concentrated in the net bucket by splashing seawater transferred to a pre-cleaned and rinsed container and preserved with 5% neutralized formaldehyde and appropriately labelled indicating the details of the collection, and stored for further analysis. The Quantitative analysis of phytoplankton (cell count) was carried out using a Sedgewick-Rafter counting chamber. The density (No/l) was calculated using the formula: N=n ×v/V (Where, N is the total No/liter, n is the average number of cells in 1 ml, v is the volume of concentrate; V is the total volume of water filtered. The identification was done by following the standard literature of Desikachary, (1987), Santhanam *et.al*. (2019) and Kamboj *et.al*. (2018).

3.1.3.Zooplankton

Zooplankton samples were collected using a standard zooplankton net made of bolting silk having 50µm with mouth area of 0.25 m^2 fitted with a flow meter. The net was towed from a boat for 5 minutes with a constant boat speed of 2 nautical miles/hr. The initial and final reading in the flow meter was noted down and the plankton concentrate collected in the bucket was transferred to appropriately labelled container and preserved with 5% neutralized formaldehyde. One ml of the zooplankton concentrate was added to a Sedgwick counting chamber and observed under a compound microscope and

identified by following standard literature. The group/taxa were identified using standard identification keys and their number was recorded. Random cells in the counting chamber were taken for consideration and the number of zooplankton was noted down along with their binomial name. This process was repeated for five times with 1 ml sample and the average value was considered for the final calculation. For greater accuracy, the final density values were counter-checked and compared with the data collected by the settlement method.

3.1.4.Intertidal Fauna

The Intertidal faunal assemblages were studied for their density, abundance and frequency of occurrence during Pre-monsoon 2025 at the pre-fixed 15 sampling locations within the DPA jurisdiction. Sample collection and assessment of intertidal communities were done in the intertidal zone during the low tide period. At each site, 1 x1m^2quadrates were placed randomly and all visible macrofaunal organisms encountered inside the quadrate were identified, counted and recorded. At each site, along the transects which run perpendicular to the waterfront, three to six replicate quadrate samples were assessed for the variability in macro-faunal population structure and the density was averaged for the entire intertidal belt. Organisms, which could not be identified in the field, were preserved in 5% formaldehyde, brought to the laboratory and identified using standard identification keys (Abott, 1954; Vine, 1986; Rao, 2003; 2017; Psomadakis *et al.,* 2015; Naderloo 2017; Ravinesh *et al.* 2021; Edward *et al.,* 2022). Average data at each site were used to calculate the mean density (No/m^2).

3.1.5.Sub tidal macro benthic Fauna

The sampling methods and procedures were designed in such a way to obtain specimens in the best possible condition as to maximize the usefulness of the data obtained. For studying the benthic organisms, triplicate samples were collected at each station using Van Veen grab, which covered an area of 0.04m^2. The wet sediment was passed through a sieve of mesh size 0.5 mm for segregating the organisms. The organisms retained in the sieve were fixed in 5-7% formalin and stained further with Rose Bengal dye for ease of spotting at the time of sorting. The number of organisms in each grab sample was expressed as No. /10cm^2. All the species were sorted, enumerated and identified by following the available literature. The works of Day (1967), Hartman (1968), Rouse and Pleijel (2001), Robin *et al*., (2003), Amr (2021), were referred for polychaetes; Crane (1975), Holthuis (1993), Naderloo (2017). Xavier *et al*., (2020) for crustaceans; Subba

Rao (2017), Ravinesh *et al*. (2021) and Edward *et al*, (2022) for molluscs. Statistical analyses such as diversity indices and Univariate measures such as Shannon-Wiener diversity index (H'), Margalef's species richness (d), Simpson's dominance (D) were determined using Paleontological Statistics Software Package for Education and Data (PAST) version 3.2.1 (Hammer et al., 2001).

Plate 1: Estimation of intertidal fauna by the quadrate method

Plate 2a: Collection of Plankton

2 b. Collection macrobenthos in subtidal habitat

3.4. Mudflats

Mudflats are ecologically and socio-economically vital ecosystems that bring benefits to human populations around the globe. These soft-sediment intertidal habitats, with >10% silt and clay (Dyer, 1979), sustain global fisheries through the establishment of food and habitat (including important nursery habitats), support resident and migratory populations of birds, provide coastal defences, and have aesthetic value. Mudflats are intimately linked by physical processes and dependent on coastal habitats, and they commonly appear in the natural sequence of habitats between subtidal channels and vegetated salt marshes. In some coastal areas, which may be several kilometres wide and commonly form the largest part of the intertidal area. Mudflats are characterized by high biological productivity and abundance of organisms but low in species diversity with few rare species. The mudflat biota reflects the prevailing physical conditions of the region. Intertidal mudflats can be separated into three distinct zones such as the lower tidal, middle and upper mudflats. The lower mudflats lie between mean low water neap and mean low water spring tide levels, and are often subjected to strong tidal currents. The middle mudflats are located between mean low water neaps and mean high water springs. The upper mudflats lie between the mean high-water neap and mean high water springs. The upper mudflats are the least inundated part and are only submerged at high water by spring tides (Klein, 1985). Salt marsh vegetation may colonize as far seaward as mean high water neaps. Mudflats will often continue below the level of low water spring tides and form sub-tidal mudflats (McCann, 1980). The upper parts of mudflats are generally characterized by coarse clays, the middle parts by silts, and the lower region by sandy mud (Dyer *et al*., 2000). The intertidal mudflats are prominent sub-environments that occurred on the margin of the estuaries and low relief sheltered coastal environments. The fine-grained sediments of intertidal mudflats (70%-90%) are derived from terrestrial and marine regions (Lesuerd *et.al*.,2003). Estuarine mudflats are potential sites for deposition of organic matter derived from terrigenous, marine, atmospheric and anthropogenic sources and are mainly associated with fine grained particles (Wang *et.al*., 2006).

Plate 3. Sediment sample collection at mangrove and mudflat areas

Sampling locations

The Sediment samples were collected from 15 sampling locations by using sediment corer. From each site triplicate samples were collected from up to 100 cm depth with four intervals (0-25cm, 25-50cm, 50-75cm & 75-100cm) and made into composite sample for analysis. The samples were packed in zip lock bags, stored in icebox and shifted to the laboratory for subsequent analysis.

Total Organic Carbon

The organic carbon content of the mudflat sediment was estimated to assess the biological productivity of the sediment. Soil Organic Carbon (SOC) was estimated following the method of Walkley and Black (1934). In this method, organic matter (humus) in the soil gets oxidized by Chromic acid (Potassium dichromate plus concentrated H2SO4) by utilizing the heat evolved with the addition of H_2SO4. The unreacted dichromate is determined by back titration with Ferrous ammonium sulphate (redox titration). Organic carbon was determined by following the below given formula:

$$\text{Oxidizable organic carbon (\%)} = \frac{10\ (B\ -\ T)}{B} \times\ 0.003\ \times\ \frac{100}{\text{wt. of soil}}$$

Where B = volume (mL) of Ferrous ammonium sulfate required for blank titration.T = volume of Ferrous ammonium sulfate needed for soil sample. Wt. =weight of soil (g).

Estimation of Bulk Density (BD)

The soil under field condition exists as a three-phase system viz. solid (soil particles), liquid (water) and gas (mostly air). The soil organic matter contained in a unit volume of the soil sample is called its bulk density. The amount of bulk density depends on the texture, structure and organic matter status of the soil. High organic matter content lowers the bulk density, whereas compaction increases the bulk density. To determine the bulk density of the sediment samples collected during the present study, the oven-dry weight of a known sediment volume was considered, and mass per unit volume was calculated (Maiti, 2012).

3.5. Mangrove assessment

Mangroves are widely distributed on the Deendayal Port Authority jurisdiction area along the Kandla coast. The 15 sites were selected at the different creeks belong to Deendayal Port Authority jurisdiction to represent the mangroves status in Kandla. The mangrove

stations in this study were named Tuna, Jangi, Kandla, Phan and Navlakhi based on the closeness of the location to the respective creek system. The Point Centered Quadrate Method (PCQM) was used for the collection of data of the mangrove vegetation structure. The data included, measurements of density of plants, height variations, canopy and basal girth of mangrove trees as per the method of Cintron and Novelli (1984). For this method, a transect of a maximum of 200 m was applied mostly perpendicular or occasionally parallel to the creek. The sampling points were considered at an interval of every 10 m and the vegetation structure of the that area were recorded. As the orientation of the transect line was already fixed, it was easy for movements within the station area for data recording. The distance between trees from the centre of the sampling point to the nearest 4 trees of four different directions, height of trees from the ground level, canopy length and canopy width were measured to determine the canopy cover in this study. The equipments utilized in the field were handy, and easy to use such as ranging rods, pipes and for measurement of girth at root collar above the ground (GRC), a measuring tape was used. The plants with a height <50 cm was considered as regeneration class and >50 cm but <100 cm was considered as recruitment class. Along the transects, sub-plots of 1×1 m^2 for regeneration and 2×2 m^2 were laid randomly for recruitment class of the mangrove sites.

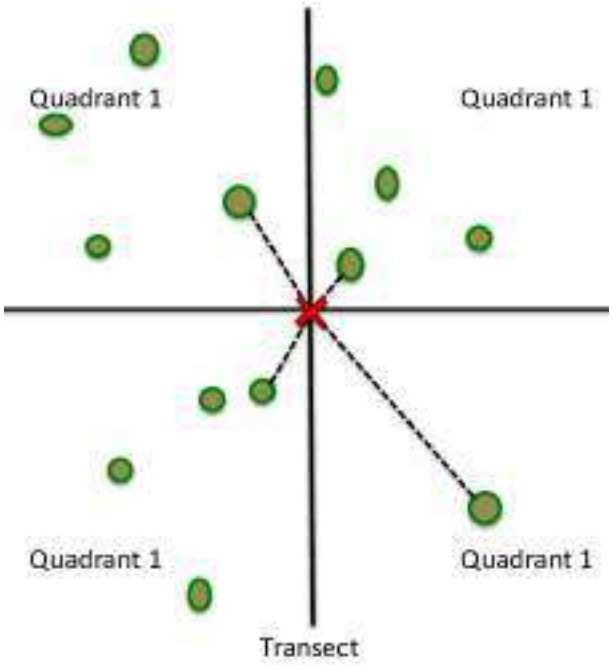


Figure 11 . Point Centred Quadrate Method

Plate 4: Assessment of mangrove density, height, canopy cover and girth

3.6. Halophytes

To quantify and document the halophytes at Deendayal Port Authority region, quadrate method was followed. At each sampling location quadrates of various sizes have been laid during every seasonal sampling. For recording the plant density at each transect, a quadrate 1 x 1m^2 has been laid within the site each tree quadrates were used randomly (Mishra,1968; Bonham, 1989). Four quadrates each for shrubs and herbs were laid in each tree quadrate to assess the halophytes and the percentage cover in the study area. To enrich the species inventory, areas falling outside the quadrates were also explored and the observed species were recorded and photographed and identified using standard keys. Specimens of the various species were collected to know more information on habitat and for the preparation of herbarium.

Plate 5: Assessment and percentage cover of halophyte

3.7. Marine Fishery

Fishery resources and the diversity were assessed from the selected sampling sites. Finfish and shellfish samples were collected using a gill net with a 10 mm mesh size. The net was operated onto the water from a canoe or by a person standing in waist deep water during the high tide using a cast net (Plate 6). For effective sampling, points were fixed at distances within the offshore sites for deploying fishing nets to calculate the Catch per Unit effort estimated per hour. The collected specimens were segregated into groups, weighed and preserved in 10% neutralized formalin solution. Finfishes were identified following Fischer and Bianchi (1984), Masuda *et al*. (1984), de Bruin et al. (1995) and Mohsin and Ambiak (1996). Relevant secondary information pertaining to fishery resources of Deendayal Port creek systems were gathered through technical reports, the District Fisheries department, Government gazette and other research publications.

Plate 6: Fisheries Information from DPA environment

3.8. Avifauna

The Avifauna population was determined along DPA mangrove stands for which the area was demarcated into fifteen major stations. In each station, creeks of varying lengths from 2 to 5 km are available. These creeks were surveyed by using boat and adopting "line transect" method. A total of fifteen boat transect (one in each site) survey was conducted in the Monsoon, Post -Monsoon and Pre-monsoon season (May 2024- May 2025. Survey was done in terrestrial habitats like mangrove plantations adjoining the mudflats, waste land, and aquatic habitats, like creek area, rivers and wetland.

Boat Surveys

Mangrove bird diversity was calculated by using Boat Survey method. Birds were observed from an observation post on board the boat which has given the greatest angle of clear view. Birds within a 100 meter transect on one side of the boat were counted in 10-minute blocks of time (Briggs *et al.* 1985; van Franeker, 1994). Detection of birds was done with a binocular (10 x 40) and counts were made: (1) continuously of all stationary birds (swimming, sitting on mangrove, or actively feeding) within the transect limits and (2) in a snap-shot fashion for all flying birds within the transect limits. The speed of the boat determines the forward limit of the snapshot area within a range of 100 meters. Longer or shorter forward distances were avoided by adapting the frequency of the snapshot counts. Birds that following and circling the boat were omitted from both snapshot and continuous counts. If birds arrive and then follow the boat, they were included in the count only if their first sighting falls within a normal snapshot or continuous count of the transect area. For each bird observation species, number of individuals and activity at the time of sighting, were recorded. Species richness and diversity index were calculated for different mangrove patches (i.e. fifteen station) of the study station in the Deendayal port Authority.Data collected in- situ and through laboratory analysis of samples were subjected to descriptive statistical analysis (PAST and Primer 7.0) for the mean, range and distribution of different variables from the selected 15 study stations.

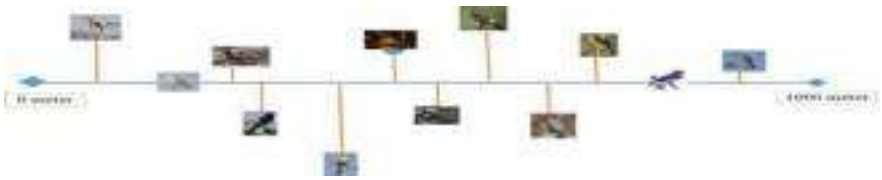


Figure .12 Line transect method for Avifauna survey

3.9 Data analysis

Data collected in situ and through laboratory analysis of samples were subjected to descriptive statistical analysis (PAST) for the mean, range and distribution of different variables from the selected 15 study stations.

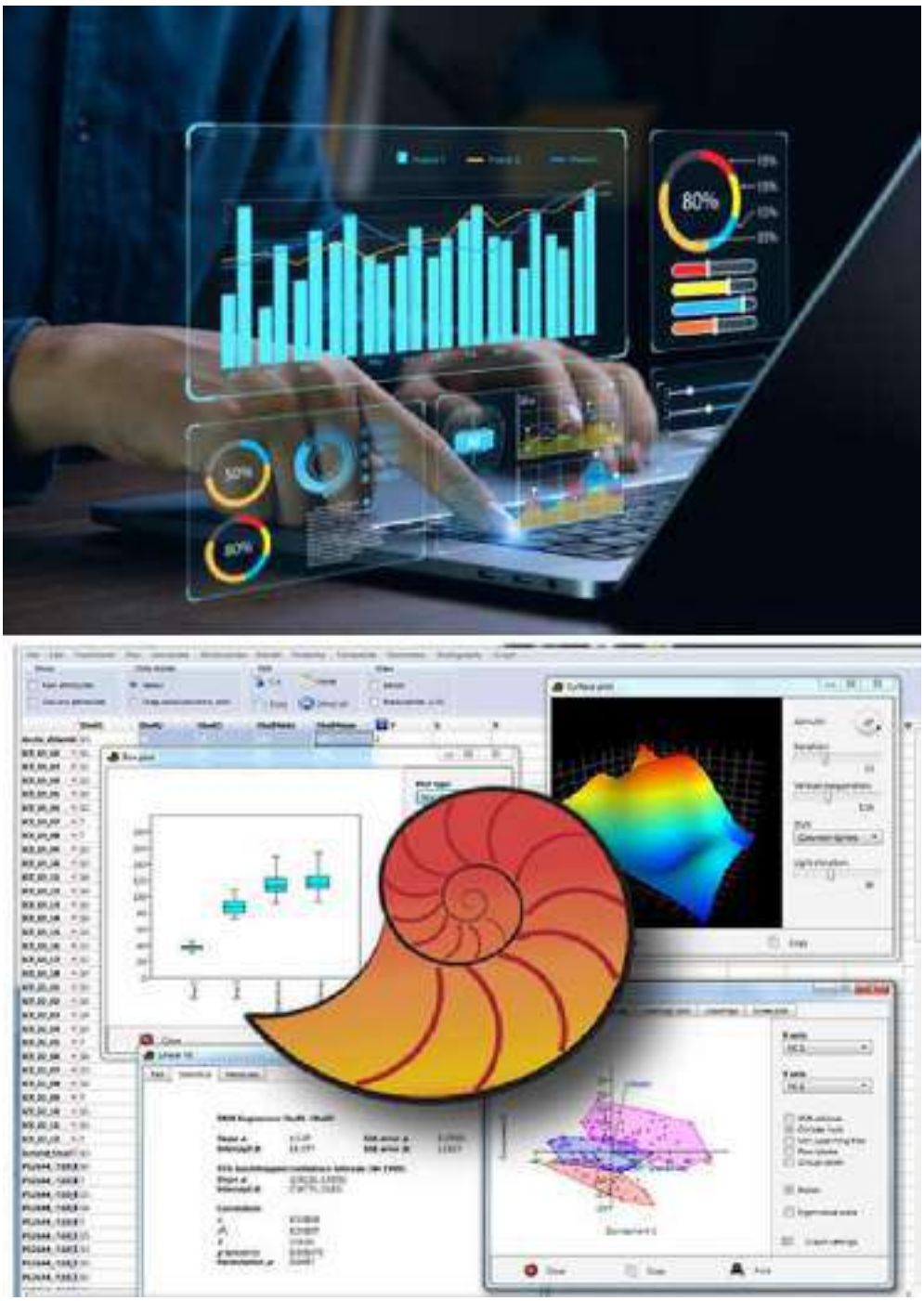


Plate 7 Statistical Data analysis methods

4.Results

4.1. Physico-Chemical Characteristics of water and Sediment

4.1.1.Water quality assessment

The data on the mean water quality parameters measured at the time of sampling of the biological components from the 15 study sites are presented in Table12.

Table-12 Physico-chemical characteristics of the DPA Jurisdiction From May 2024- May 2025

Parameter		Monsoon 2024	Post Monsoon 2024-25	Pre Monsoon 2025
Temperature (°C)	max	30	27	29
	min	23	12	25
pH	max	8.1	8.5	8.3
	min	7.7	7.3	7.8
Salinity	max	42	42	41
	min	34	32	32
Dissolved oxygen (mg/L)	max	8.2	7.7	5.3
	min	2.9	3.9	3.2
Total Suspended Solids (TSS) (mg/L	max	729	579	722
	min	205	222	253
Total Dissolved solids (TDS) (mg/L)	max	139862	95571	41300
	min	26876	9829	3035
Turbidity (NTU)	max	160	133	489
	min	20	38	61.4
Nitrate (NO3) (mg/L)	max	0.003	0.140	0.019
	min	0.001	0.020	0.009
Nitrite (NO2) (mg/L)	max	0.173	0.003	0.128
	min	0.001	0.001	0.003
Total Phosphorus (mg/L)	max	73.24	65.90	27.12
	min	36.18	30.60	3.16
Total silicate	max	0.058	0.07	4.48
	min	0.012	0.01	1.02
PHs (µg/L)	max	10.10	70.80	8.32
	min	1.20	2.50	0.19
Chlorophyll a (mg/L)	max	0.89	0.65	2.98
	min	0.04	0.04	0.12

Temperature (°C)

The values for the Temperature obtained from 15 different sampling station for all the three seasons (Monsoon, post monsoon and pre monsoon) have been represented in Figure 13. During monsoon, the value ranged from 23°C to 30°C while in post monsoon observation, the value ranged from 12°C to 27°C. However, in pre monsoon the values were noted in the range of 25°C to 29°C. During monsoon, the highest temperature was noted at station S-7 while the lowest temperature was noted at S-6 and S-15. In post-monsoon maximum temperature was recorded at S-2 and S-4 and lowest at S-15 while in pre-monsoon highest temperature exhibited at S-2 & S-8 and lowest temperature observed at S-10.

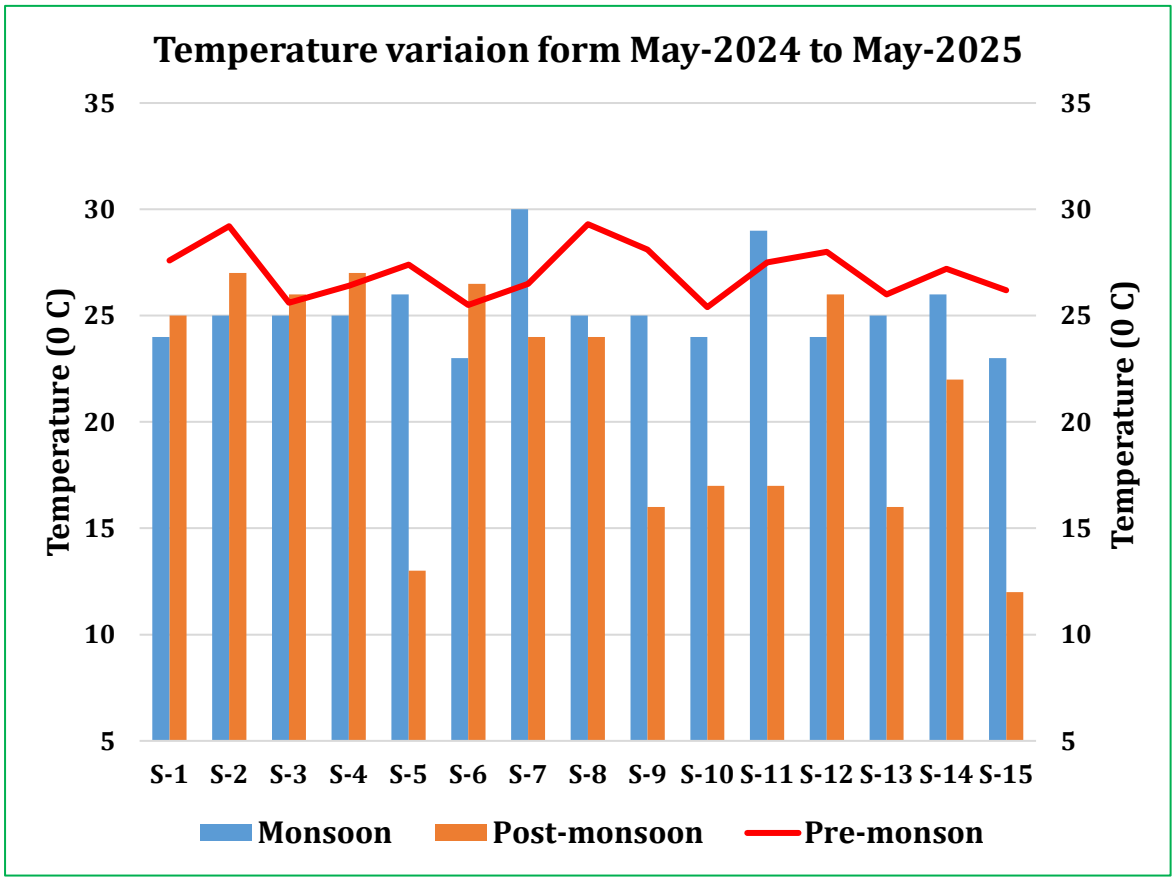


Figure 13. Temperature variation in DPA study sites during 2024-2025

The average temperature in Deendayal port authority jurisdiction varied from 21° C to 27°C in 3 seasons throughout the year.

pH

The pH obtained from 15 different sampling station for all the three seasons (Monsoon, post monsoon and pre monsoon) have been represented in Figure 12. During monsoon, the value ranged from 7.7 to 8.1 while in post monsoon observation, the value ranged from 7.3 to 8.5. However, in pre monsoon the values were noted in the range of 7.8 to 8.3. During monsoon, the highest pH was noted at station S-1, S-3, S-6, S-7, S-13, & S-14 while the lowest pH was noted at S-8 & S-11. On an average, the pH ranged between 7.3 to 8.5 throughout the year inclusive of all the three seasons.

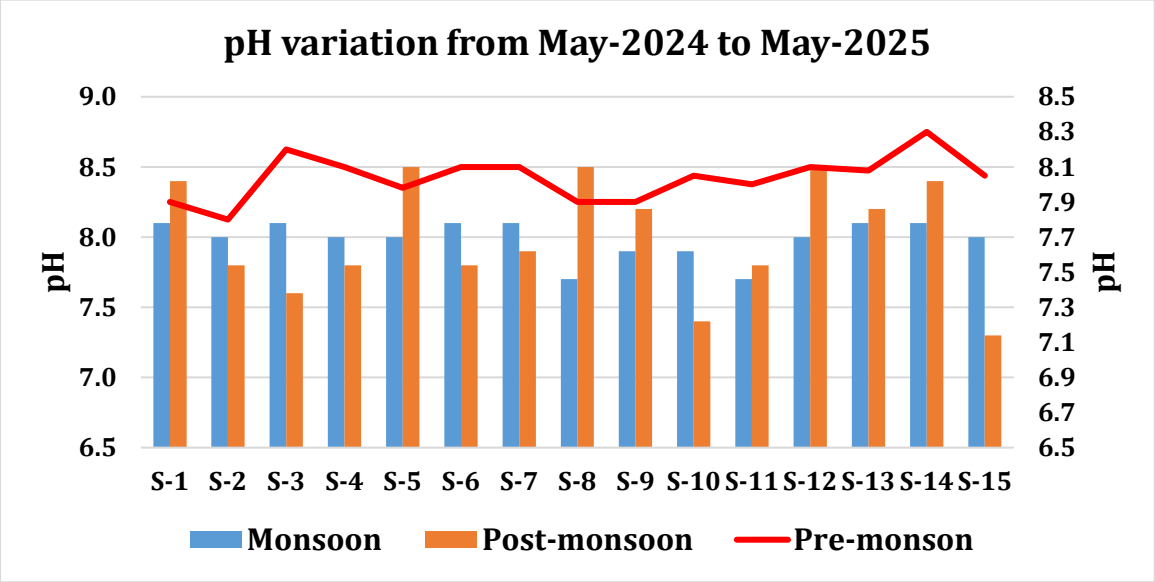


Figure 14. pH variation May 2024 to May 2025 in Deendayal Port Authority

Salinity (ppt)

The salinity obtained from 15 different sampling station for all the three seasons (Monsoon, post monsoon and pre monsoon) have been represented in Figure 15. During monsoon, the salinity ranged from 34 ppt to 42 ppt while in post monsoon observation, the value ranged from 32 ppt to 42 ppt. However, in pre monsoon the values were noted in the range of 32 ppt to 41 ppt. During pre-monsoon, the highest salinity was noted at stations S-10 & S-11 while the lowest salinity was recorded at S-5. It was observed that maximum salinity was recorded in pre-monsoon and post-monsoon seasons while the lowest was recorded during monsoon. The average salinity throughout the year in Deendayal port authority jurisdiction varied from 32 ppt to 42 ppt during 3 seasons.

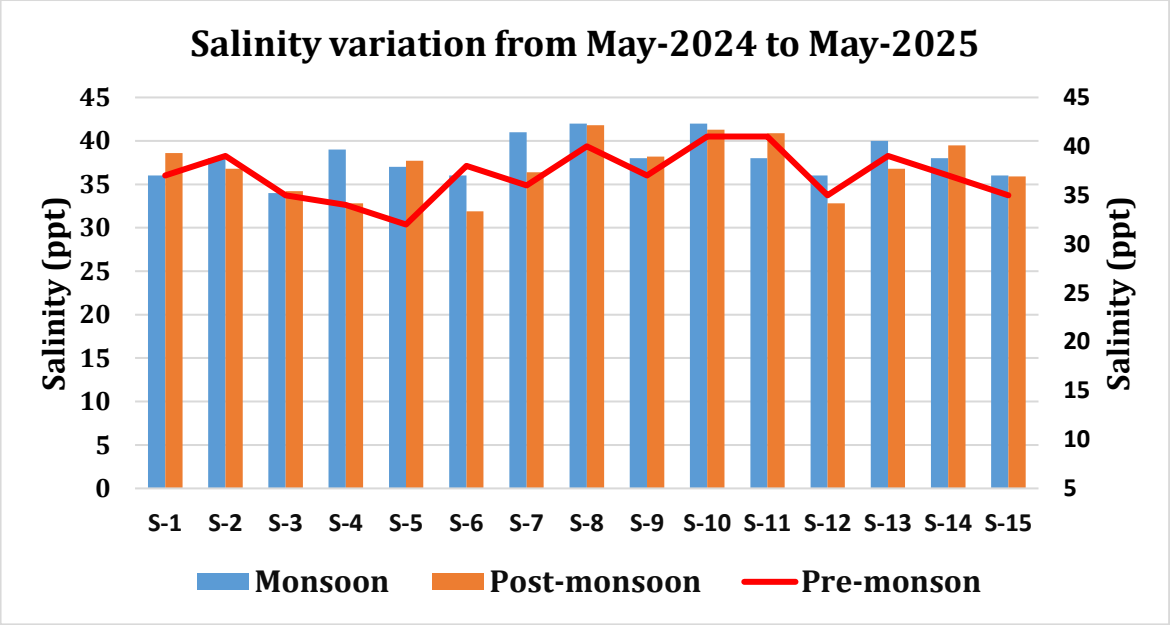


Figure 15. Seasonal variation of salinity during 2024-2025 at DPA

Dissolved oxygen (DO)

The maximum Dissolved Oxygen concentration of the sampling stations for three seasons varied from 5.3 mg/L to 8.2 mg/L with average of 4.1 mg/L to 5.8 mg/L from May 2024 to May 2025. The minimum DO values varied from 2.9 mg/L to 3.9 mg/L. The seasonal variation of water DO among stations is presented in Figure 16.

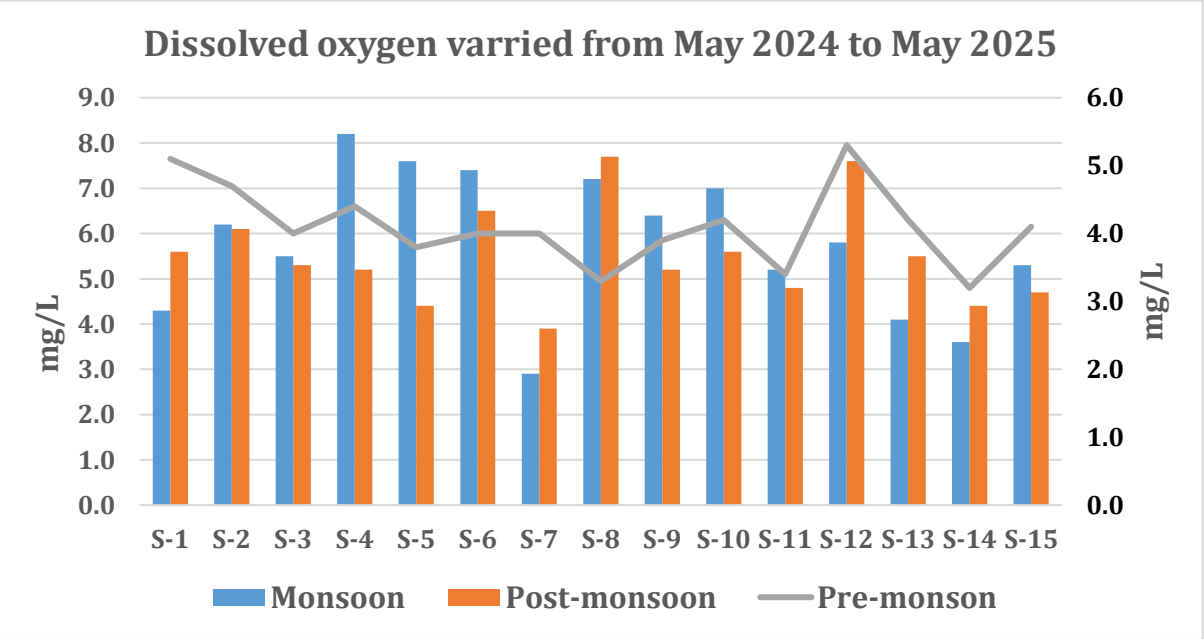


Figure 16. Seasonal variation Dissolved Oxygen from May 2024 to May 2025

During monsoon, the highest DO concentration was observed at station S-4 (8.2 mg/L), and the Lowest dissolved oxygen concentration was observed at S-7 (2.9 mg/L). In post-monsoon, the highest dissolved oxygen was observed at S-8 (7.7 mg/L) and the lowest value at S-7 (3.9 mg/L). During Pre-monsoon, the highest and lowest DO values were observed at stations S-12 (5.3 mg/L) and S-14 (3.2 mg/L) respectively.

Total Suspended Solids (TSS)

The values for the Total Suspended Solids (TSS) obtained from 15 different sampling sites for all the three seasons (Monsoon, post monsoon and pre monsoon) have been represented in Figure 15. During monsoon, the value ranged from 205 mg/L to 729 mg/L, while in post monsoon observation, the value ranged from 222 mg/L to 579 mg/L. However, in pre monsoon the values were noted in the range of 253 mg/L to 722 mg/L. During monsoon, the highest TSS was noted at site S-6 while the lowest TSS value was noted at S-13. The maximum TSS was obtained at S-15 and lowest at S-4 during post monsoon while site S-5 exhibited the highest TSS value and S-12 exhibited the lowest value during the pre-monsoon season (Figure 17).

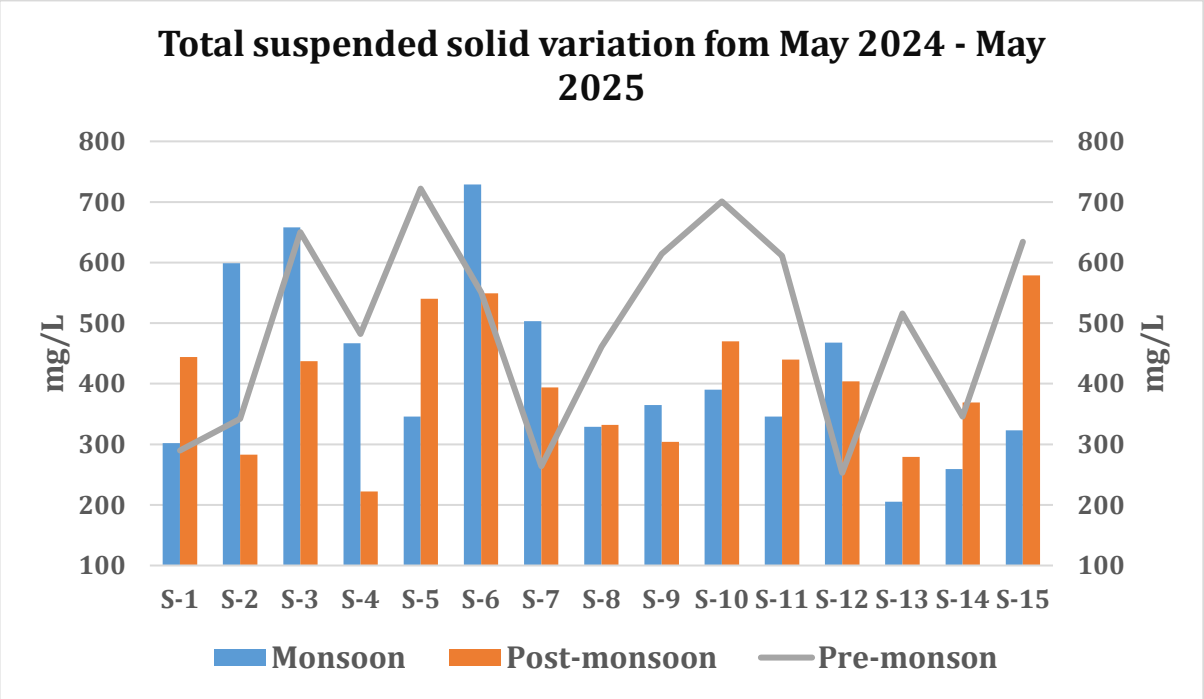


Figure 17 Seasonal variation of TSS during May 2024-May 2025

Total Dissolved solids (TDS)

The values for the Total Dissolved Solids (TDS) obtained from 15 different sampling sites for all the three seasons (Monsoon, post monsoon and pre monsoon) have been represented in Figure 18. During monsoon, the value ranged from 26876 mg/L to 139862 mg/L, while in the post monsoon observation, the value ranged from 9829 mg/L to 95571 mg/L. However, in pre monsoon the values were noted in the range of 3035 mg/L to 41300 mg/L. During monsoon, the highest TDS was noted at site S-10 while the lowest TDS value was noted at S-12. The maximum TDS was obtained at S-14 and the lowest was recorded at S-2 during post monsoon while site S-6 exhibited the maximum TDS value and S-12 showed the lowest value during the pre-monsoon season.

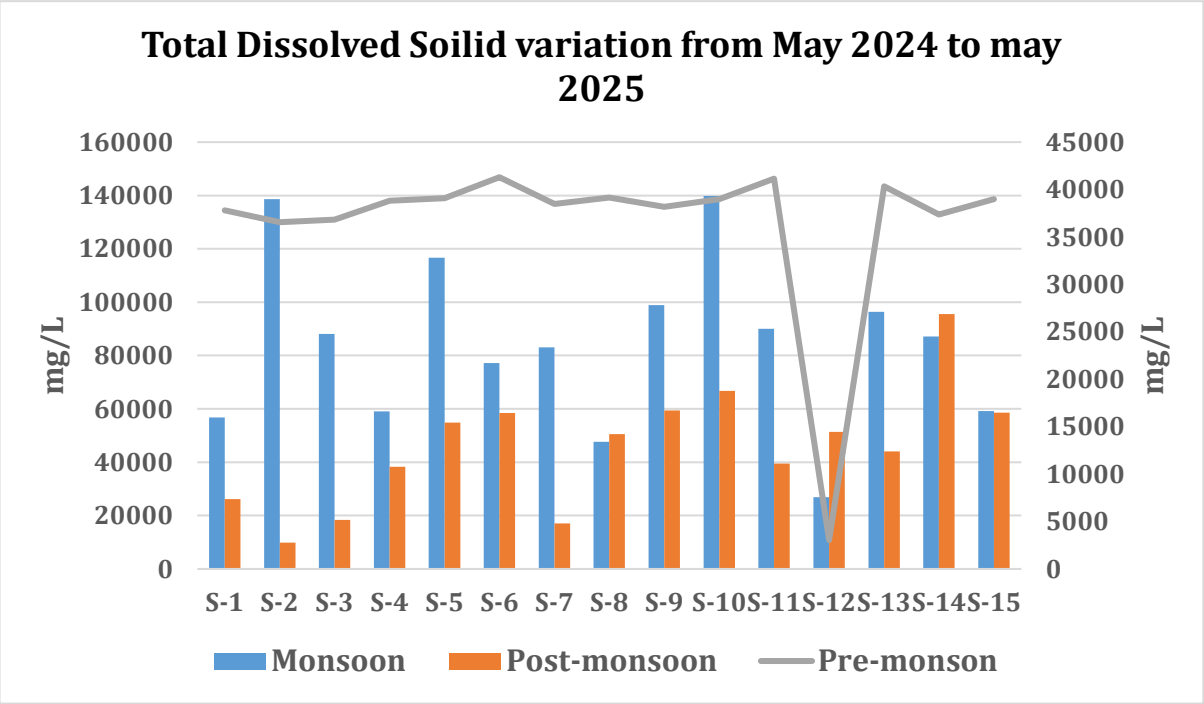


Figure 18 Total Dissolved Solids (TSS) from May 2024 to May 2025

Turbidity

The Turbidity of the sampling stations varied season wise from 20 NTU to 489 NTU for the period May 2024 to May 2025. The seasonal variation of water turbidity among the stations is presented in Figure 19.

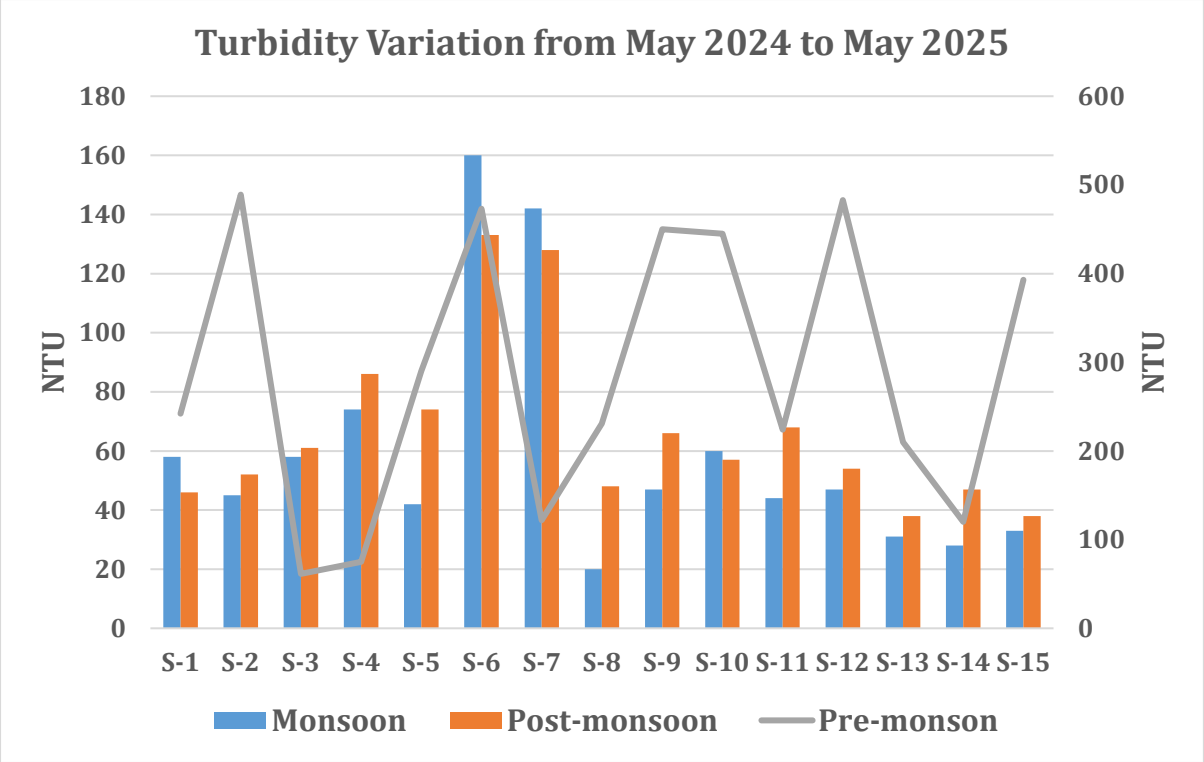


Figure 19 Seasonal variation during Turbidity from May 2024 to May 2025

During monsoon, the highest Turbidity was observed at S-6 (160 NTU) and the lowest was at S-8 (20 NTU). In post-monsoon, the highest Turbidity was observed at station S-6 (133 NTU) and the lowest was at stations S-13 & S-15 (38 NTU). Similarly in Pre-monsoon, the highest and lowest turbidity was observed at S-2 (489 NTU) and S-3 (61.4 NTU) respectively

Nitrate

The amount of Nitrate in the water sample is relatively low throughout the study period. The maximum Nitrate value for the three seasons was 0.140 mg/L from May 2024 to May 2025. This was noted at S-3 during post-monsoon study. The minimum Nitrate values noted during post monsoon were 0.020 mg/L and 0.009 mg/L (during pre-monsoon), both at site S-6. The seasonal variation of Nitrate content in water samples for all the stations is presented in figure 20. During monsoon, the highest Nitrate value observed was 0.003 mg/L at stations S-1, S-6, S-9, S-10 and S-15 whereas the lowest Nitrate value was 0.001 mg/L at station S-7. During post-monsoon study, the values increased and highest Nitrate was observed at S-3 (0.140 mg/L) and lowest at S-6 (0.020 mg/L).

Similarly in Pre-monsoon the highest (0.019 mg/L) and the lowest (0.009 mg/L) were reported S-11 & S-6 respectively.

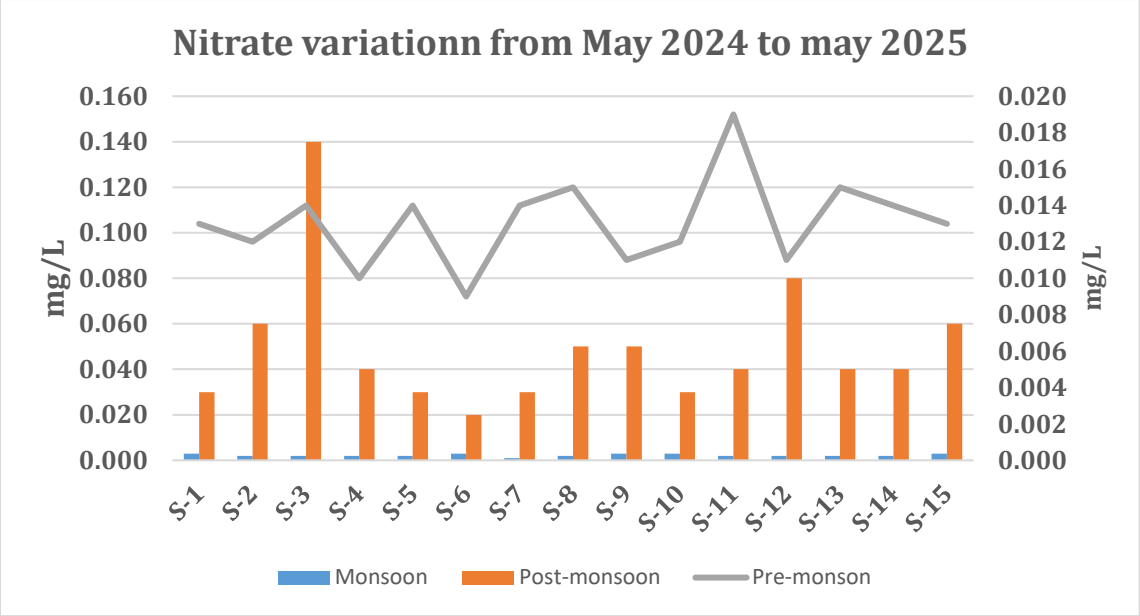


Figure 20. Seasonal variation of Nitrate concentration during May 2024 to May 2025

Nitrite

The amount of Nitrite in the water sample is relatively high compared to the nitrate content throughout the study period. The maximum Nitrite value for the three seasons was 0.173 mg/L from May 2024 to May 2025. This was noted at S-9 during monsoon study. The minimum Nitrite value noted during the study was 0.001 mg/L. The seasonal variation of Nitrite concentration is presented in Figure 21. During monsoon, the highest nitrite concentration was noted at S-9 (0.173 mg/L) and the lowest was recorded at S-14 (0.001 mg/L). In post-monsoon, the maximum value was found at S-1, S-6, S-8, S-12 and S-14 (0.003 mg/L) and lowest nitrite was observed at S-3, S-5, S-10 and S-15 (0.001mg/L). Similarly in Pre-monsoon, the highest nitrite content was (0.128 mg/L) and the lowest content (0.003 mg/L) was observed at S-1 and S-15 respectively.

Total Phosphorous

The total phosphate content at S-4 was highest during the pre-monsoon season during the study period. Seasonal observation revealed that the phosphate values were in the range of 3.16 mg/L to 73.24 mg/L. The seasonal variation for the total phosphorous among stations is presented in Figure 22.

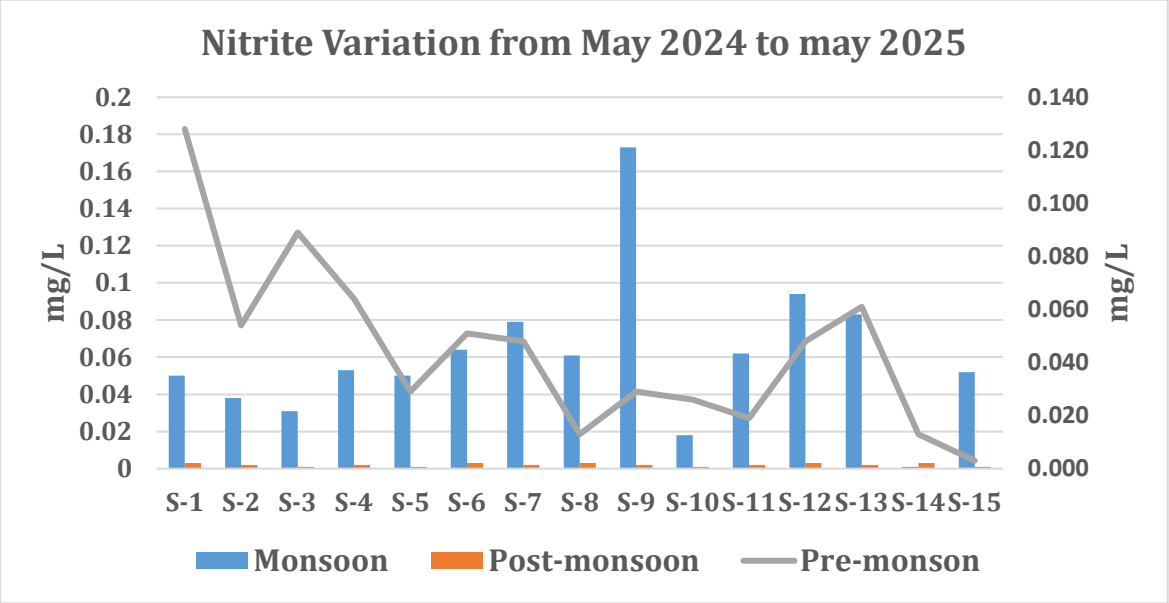


Figure 21. Nitrite concentration during May 2024 to May 2025

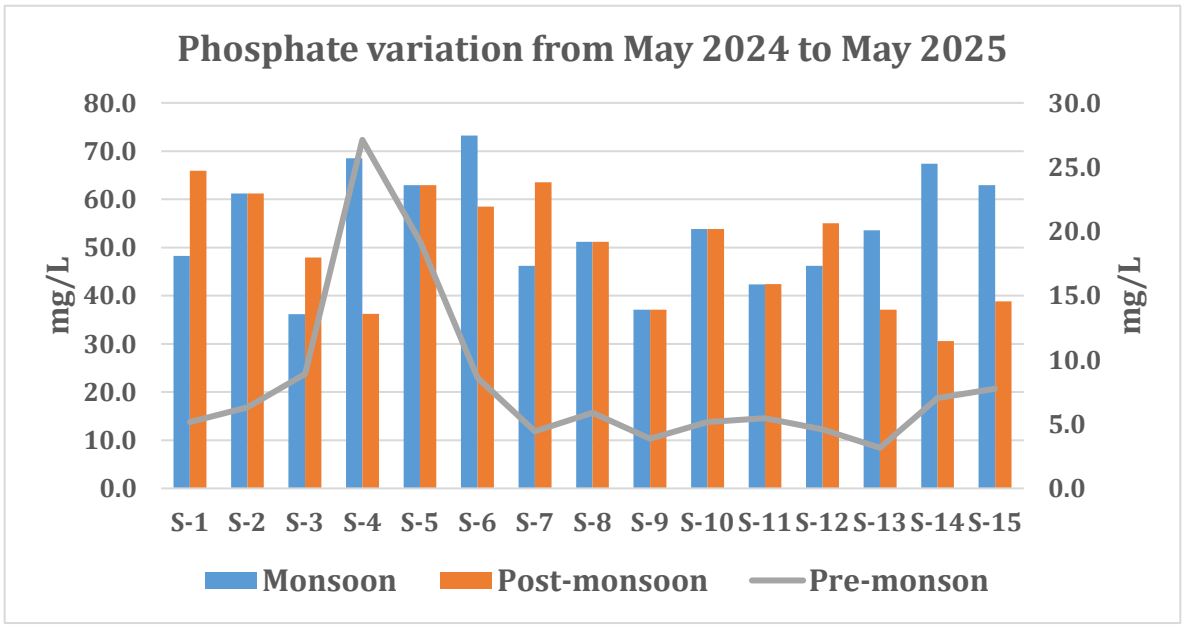


Figure 22 Seasonal variation Total Phosphorou sMay 2024 to May 2025

During Monsoon, the maximum value noted was 73.24 mg/L at (S-6) and the lowest was 36.18 mg/L at (S-3). In post-monsoon, the highest value was 65.90 mg/L at S-1 and 30.60 mg/L at S-14. In Pre-monsoon, the highest and the lowest values observed were 27.12 mg/L and 3.16 mg/L at S-4 and S-13 respectively.

Silicate

The total Silicate content at S-12 was highest during the Pre- monsoon during the study period. Seasonal observation revealed that the silicate values were in the range of 0.012 mg/L to 4.48 mg/L. The seasonal variation for the total silicates among stations is presented in Figure 23. During Monsoon, the maximum value noted was 0.058 mg/L at (S-15) and the lowest was 0.012 mg/L at (S-14). In post-monsoon, the highest and lowest value was 0.07 mg/L at S-15 and 30.01 mg/L at S-10. In Pre-monsoon, the highest and the lowest values observed were 4.48 mg/L and 1.02 mg/L at S-12 and S-13 respectively.

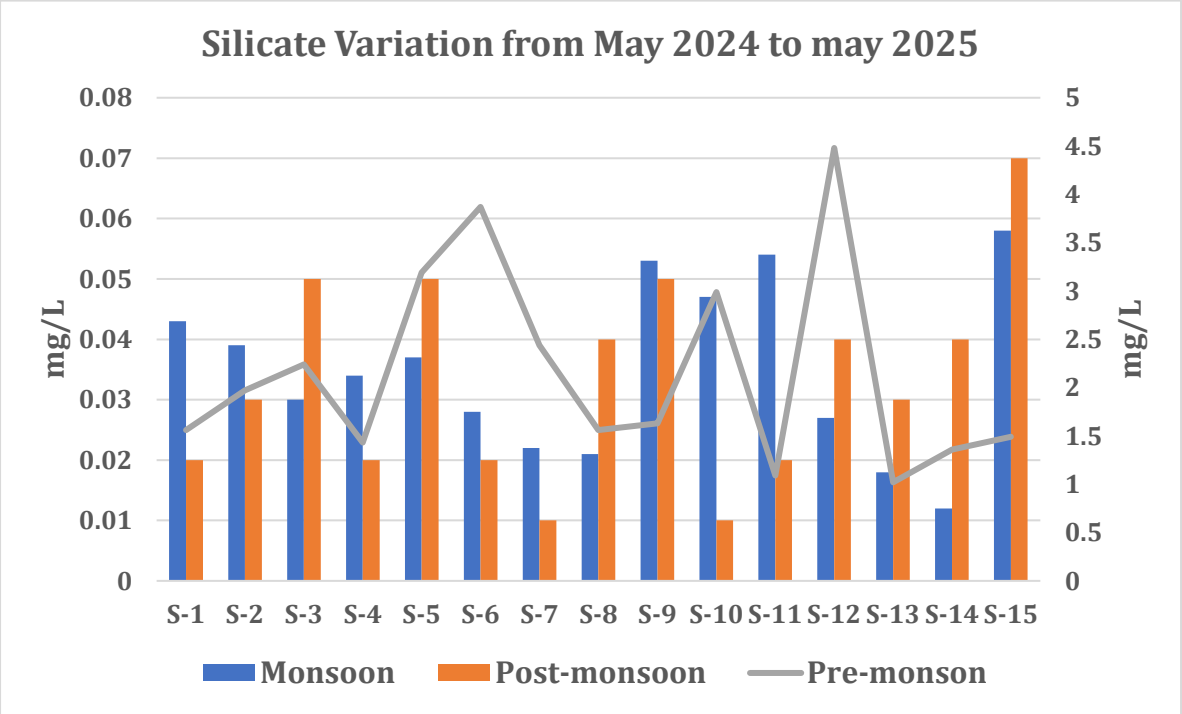


Figure 23. Seasonal variation of Silicate May 2024 to May 2025

4.1.2. Petroleum Hydrocarbon (PHs)

Petroleum Hydrocarbons (PHs) are widely recognized as the most extensively utilized fossil fuels in commercial applications (Kuppusamy et al., 2020). PHs serve as crucial raw materials across various industries and function as primary sources of energy (Varjani, 2017). However, their pervasive use has led to their identification as a major concern in terms of environmental contamination, posing significant threats to ecosystems due to their inherent stability and resilience. The category of PHs encompasses diverse components, including Polycyclic aromatic hydrocarbons (PAHs), alkanes, paraffin, cycloalkanes, organic pollutants, and non-hydrocarbon elements such as phenol, sulfur

compounds, thiol, metalloporphyrin, heterocyclic nitrogen, naphthenic acid and asphaltene. The presence of PHs significantly impacts marine organisms, with bioaccumulation of harmful PHs in the aquatic food chain persisting for extended periods. This, in consequence, affects primary producers, primary consumers, and secondary consumers. Notably, approximately 90% of PH discharges are attributed to anthropogenic activities, particularly oil spills, occurring in both terrestrial and marine environments. Reports indicate an alarming annual discharge of around 8.8 million metric tonnes of oil into aquatic environments (Periathamby and Dadrasnia, 2013).

The PHs values were comparatively high at S-7 and S-8 during post-monsoon than the other seasons. The values for Petroleum Hydrocarbons (PHs) for the three-season varied from 0.19 µg/L to 70.80 µg/L (Figure 24). The PHs concentration in general, is at low level during monsoon and pre-monsoon. During monsoon, the highest PHs were observed at S-4 (10.10 µg/L) and lowest PHs were observed along S-5 (1.20 µg/L). Similarly in Pre-monsoon, the maximum PH content was recorded (8.3 µg/L) at S-4 and the minimum was (0.19 µg/L) at S-13. In post-monsoon, the highest PH value was observed at S-7 (70.80 µg/L) and the lowest PH was observed S-6 (2.50 µg/L).

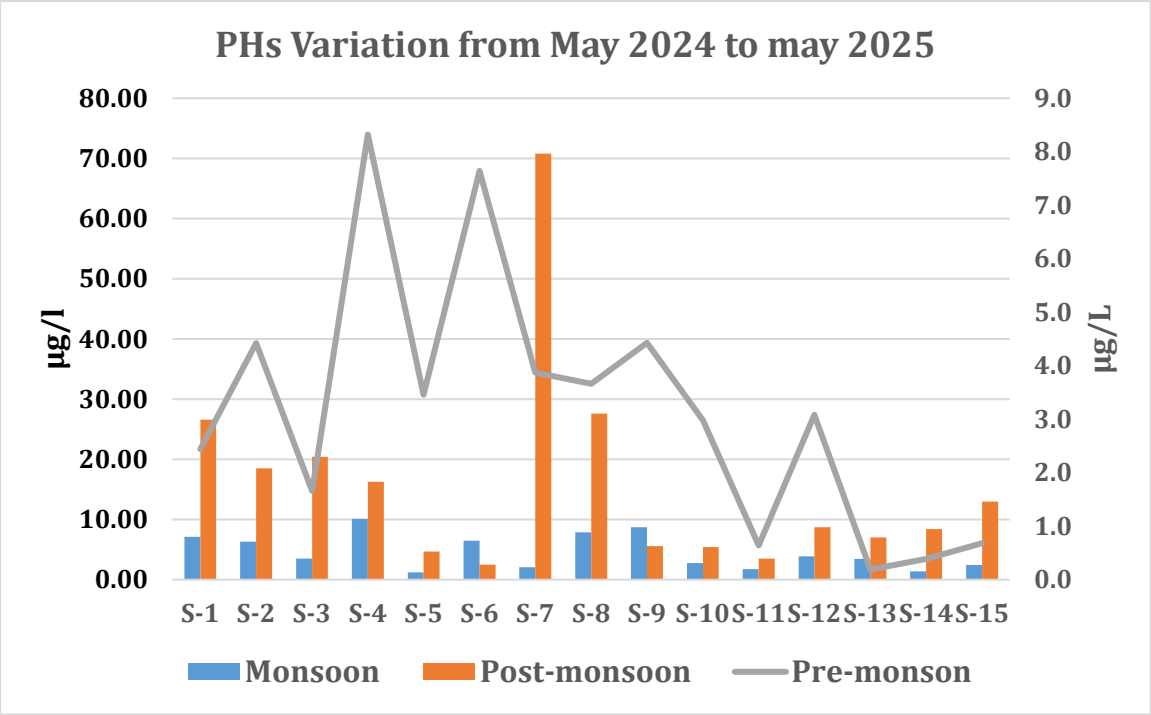


Figure 24 Seasonal Petroleum Hydrocarbon from May 2024 to May 2025

4.1.3 Sediment

Sediment texture

The sediment texture of DPA environment and its premises is presented in figure 25. The textural content mostly include sand , silt and clay. The percentage composition varieds from season to season. Through out the study period from May 2024 to may 2025 ,average sand percentage is during monsoon is more followed by pre-monsoon and Post-monsoon. The clay percentage occupies 2nd percentage composition and the average percentage is more in post and Pre-monsoon followed by monsoon. Average percentage of clay more in post-monsoon followed by pre-monsoon and monsoon.

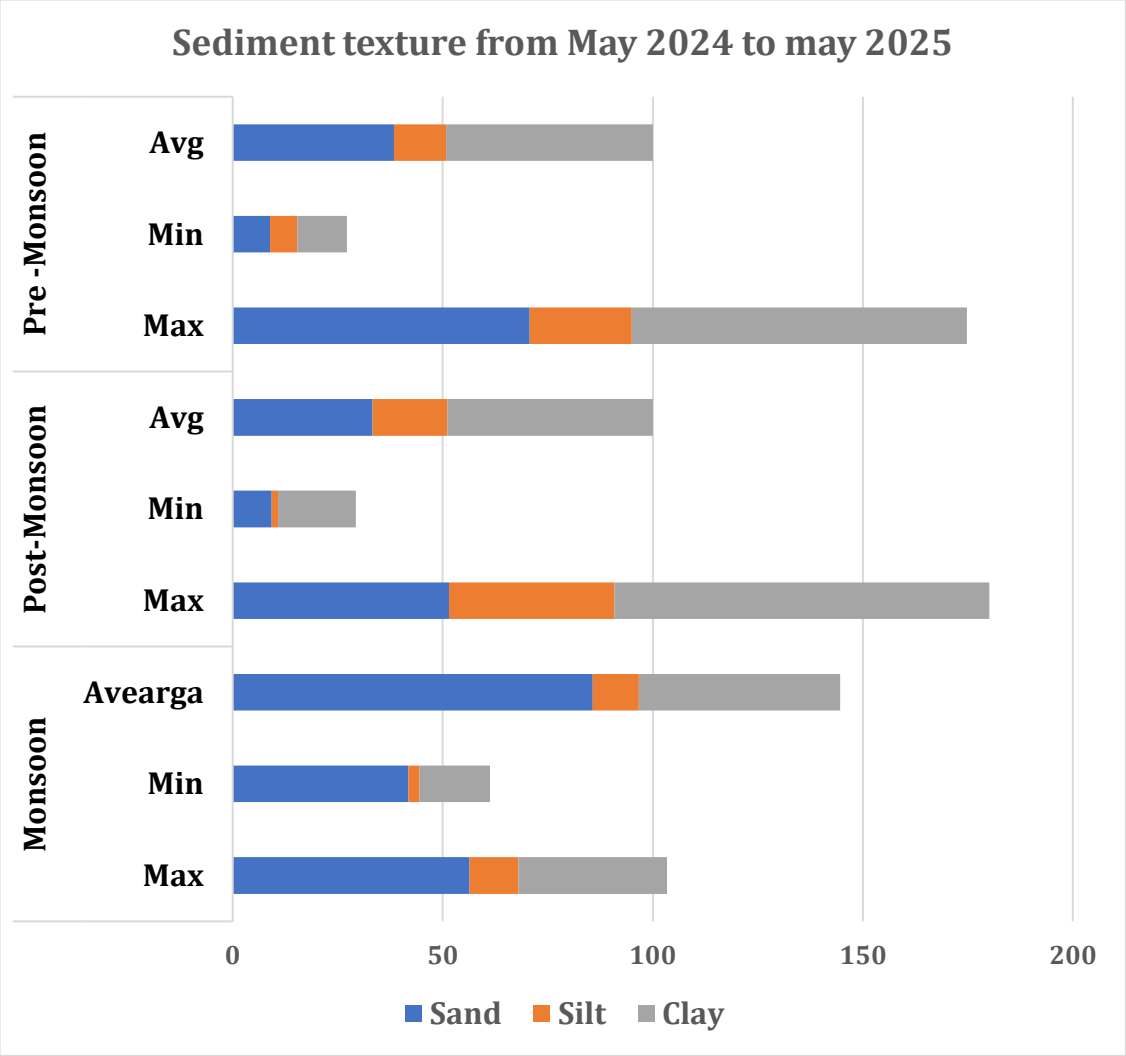


Figure 25. Soil textural chaacteristic from May 2024 to May 2025

4.1.4. Sediment total Organic Carbon (TOC)

The data on the total organic carbon of the sediment samples are presented (Figure 26). Among the station of DPA port area the maximum sediment carbon ranges from 1.2% to 3.2% and the minimum sediment carbon range was 0.5% to 2.4%. Station wise the highest sediment carbon was recorded at station S-12 during post-monsoon (3.2%), whereas lowest sediment carbon was recorded in station S-8 and S-9 during pre-monsoon (0.5%).

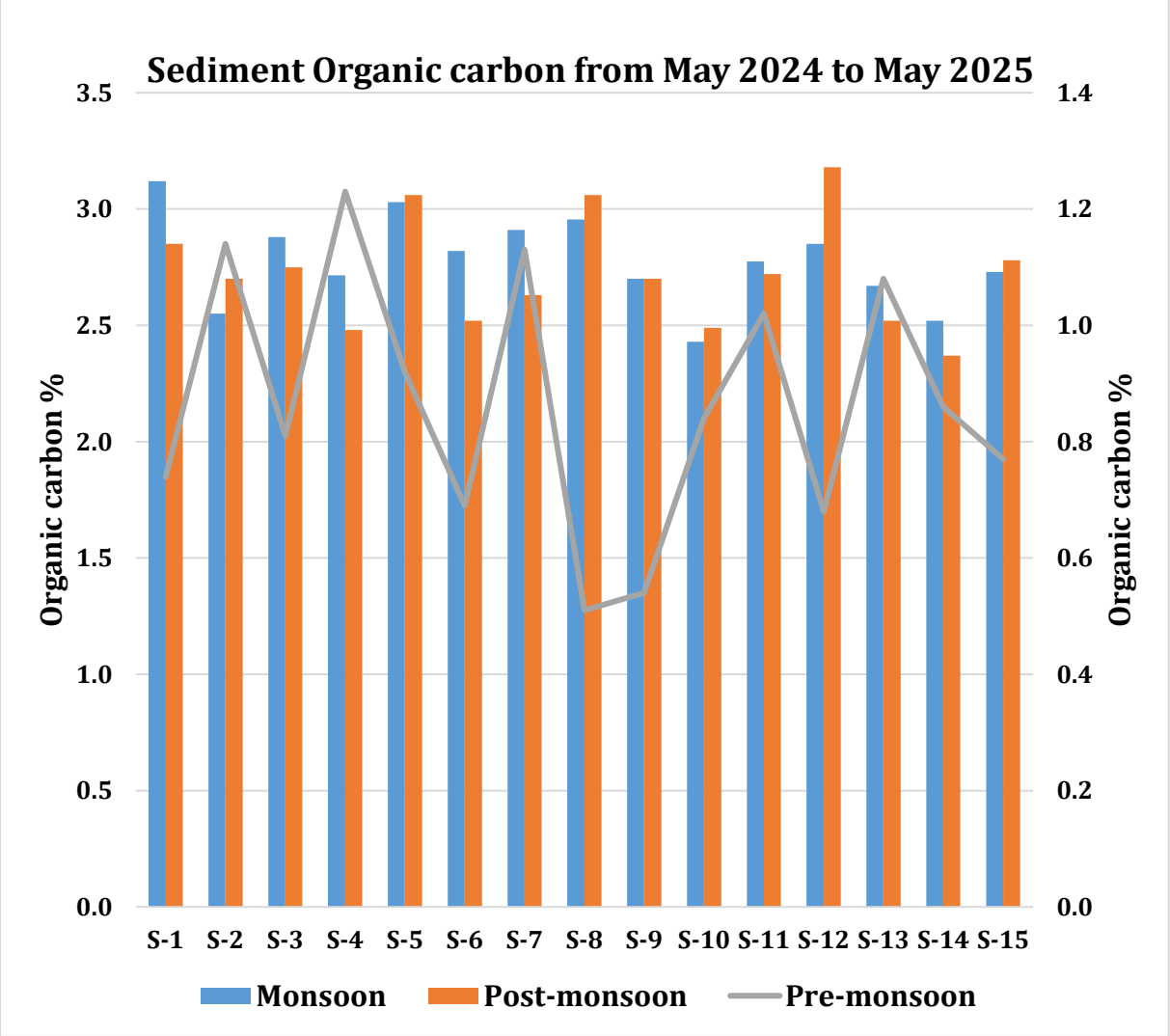


Figure 26. Sediment Organic carbon from May 2024 to May 2025

4.2. Biological characteristics water and Sediment

4.2.1. Primary productivity

Chlorophyll 'a' the photosynthetic pigment which can be used as a proxy for phytoplankton productivity and thus is an essential water quality parameter. Generally, the primary production of the water column is assessed from Chlorophyll 'a' concentration. It is well known that half of the global primary production being arbitrated by the activity of microscopic phytoplankton. . For the period of May 2024 to May 2025, the maximum Chlorophyll 'a' ranged from 0.0 mg/L to 2.98 mg/L inclusive of all the three seasons. The Chlorophyll 'a' value ranged from 0.12 mg/L to 2.98 mg/L during pre-monsoon while during monsoon, the range was recorded between 0.0 mg/L to 0.89 mg/L and during post monsoon, the range was found to be 0.04 mg/L to 0.65 mg/L. The seasonal variation of Chlorophyll 'a' among 15 stations is presented in Figure 27.

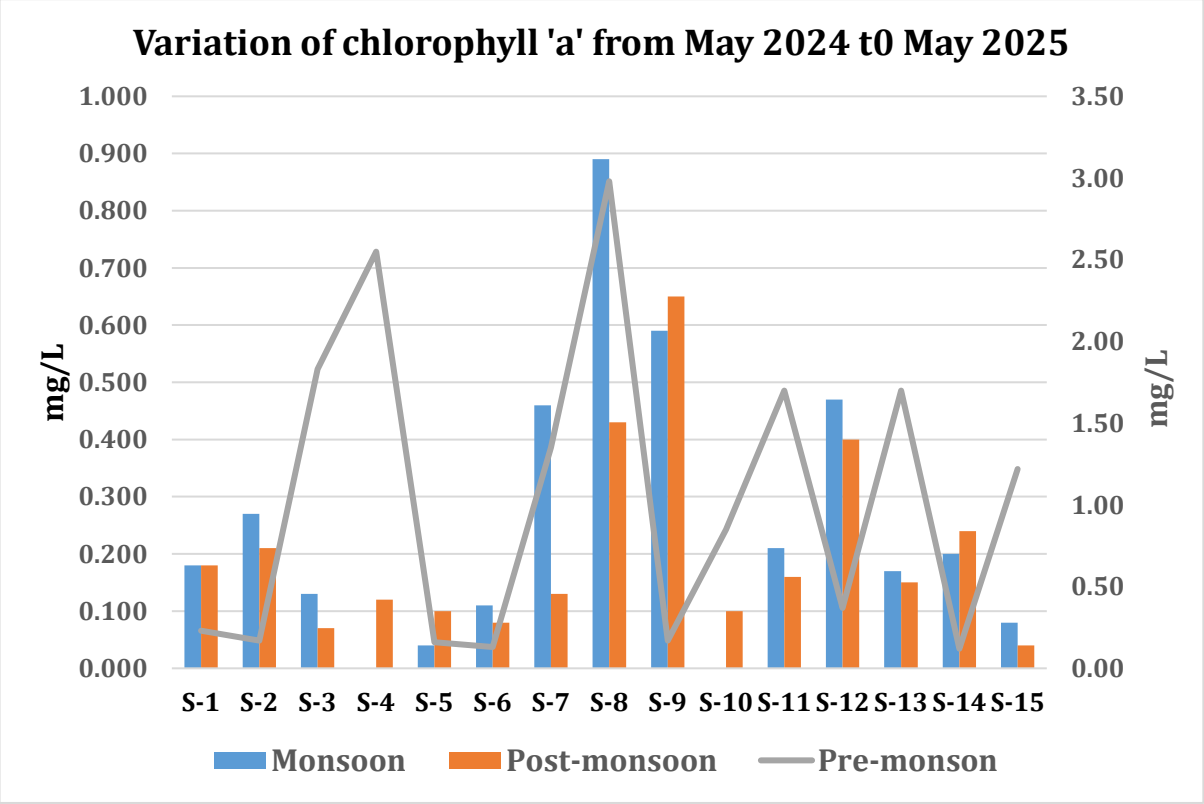


Figure 27. Concentration of Chlorophyl 'a' from May 2024 to May 2025

4.2.2. Phytoplankton

Phytoplankton are a key component of the ocean and freshwater ecosystems and provide many ecosystem services including oxygenation through photosynthesis which is estimated to be about half of the Earth's oxygen. Thus, they are important component of the functioning of ecosystems and climate regulation (Jacqueline et al.,2018). The carbon assimilation during photosynthesis by the phytoplankton enables the transfer of atmospheric carbon dioxide into the biomass which is stored in the cells and later pass on to the food chains and being cycled through the food webs. These microscopic producer community has been influenced by the negative impact from human developments and activities, and hence the service provision afforded by them should be accounted for in marine management processes (Jacqueline et al.,2018). Phytoplankton growth depends on the availability of carbon dioxide, sunlight, and nutrients. Phytoplankton, like land plants, require nutrients such as nitrate, phosphate, silicate, and calcium at various levels depending on the species. Some phytoplankton can fix nitrogen and can grow in areas where nitrate concentrations are low. They also require trace amounts of iron which limits phytoplankton growth in large areas of the ocean because iron concentrations are very low. Other factors influence phytoplankton growth rates, including water temperature and salinity, water depth, wind, and what kinds of predators are grazing on them (Lindsey and Scott,2010).

The numerous species of phytoplankton are the primary producers form the basis of marine food-webs, supporting production of higher trophic levels (a provisioning ES), and act as a sink of carbon dioxide. The spatial distributions of phytoplankton and rates of primary productivity are generally subject to bottom-up control, due to the tight coupling between light, temperature and nutrients. understanding of the spatial and temporal variability in phytoplankton parameters are accounted in marine management as these are correlated with physical and chemical factors of the water. The diatoms form the bulk of phytoplankton and the dinoflagellates are scarce. The phyto-plankton in the Gulf of Kachchh shows a primary peak in September and secondary peaks in January or June are instances of local blooms of more than one genus and species of diatoms.

Generic Status

The phytoplankton genera for the period May 2024 to May 2025 varied from 8 to 29 number with average variation of 16-23 number. Highest genera was reported during post-monsoon followed by monsoon and pre monsoon(Figure 28).

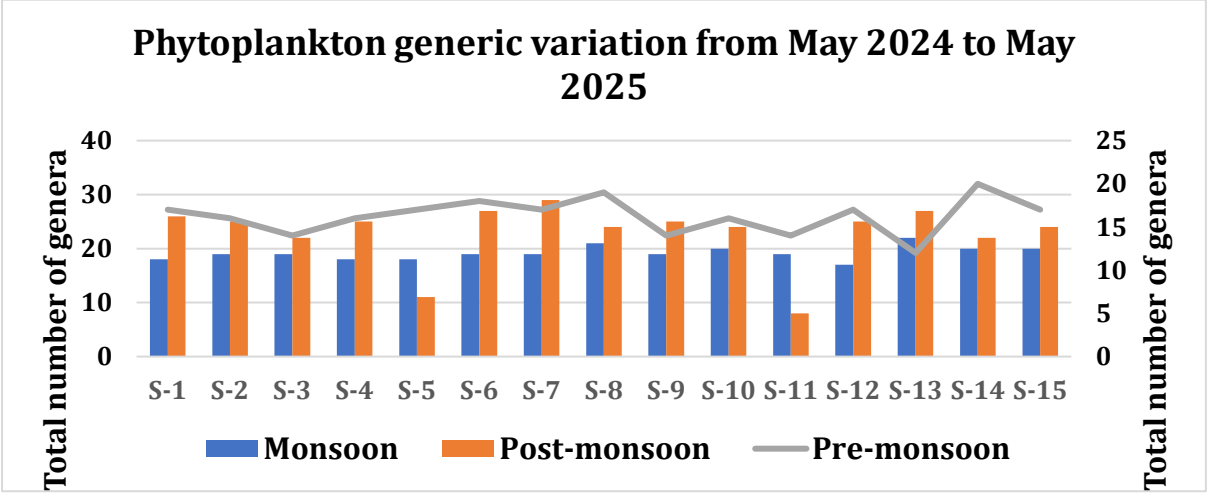


Figure 28. Seasonal variation of Phytoplankton genera from May-2024 to May2025

Percentage composition of phytoplankton

The percentage composition of different phytoplankton varied from 0.9% to 65.1% with average variation of 0.6% to 59.7% for the period May 2024 to May 2025. Four groups such as Pennales, Centrales, Dinophyceae , Cyanophyceae has been encounter during entire study period dominate by Pennales followed by Centrales and group Cyanophyceae represent less percentage of composition (Fig.29).

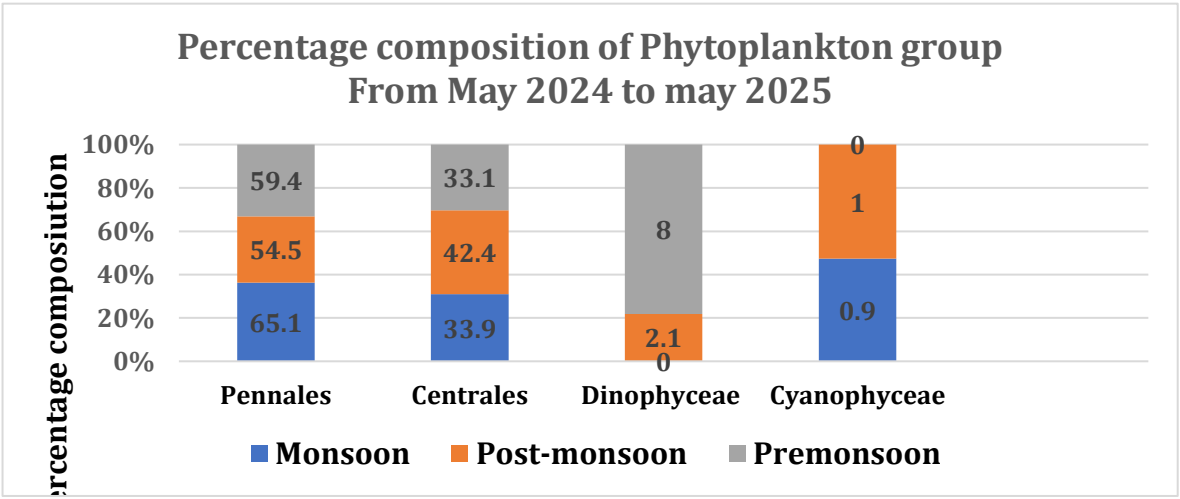


Figure 29 Percentage composition of different phytoplankton groupfrom May 2024 to May 2025

Percentage of occurrence

The percentage occurrence of phytoplankton for the period May 2024 to may 2025 was 13 to 100% . Highest percentage of occurrence was observed monsoon followed by post-monsoon and pre-monsoon. During monsoon 15 genera such as *Cheatoceros, Coscinodiscus, Dictylum, Eucampia, GyrosigmaMelosira, Navicula, Nitzschia, Odontella, Pleurosigma, Pseudonitzschia, Rhizosolenia, Synedra, Thalassionema, Thalassiothrix* represent 100% of occurrence. But in Post-monsoon and pre monsoon represent less number i.e 8 and 5 number of genera represent 100% of occurrence (Fig.30).

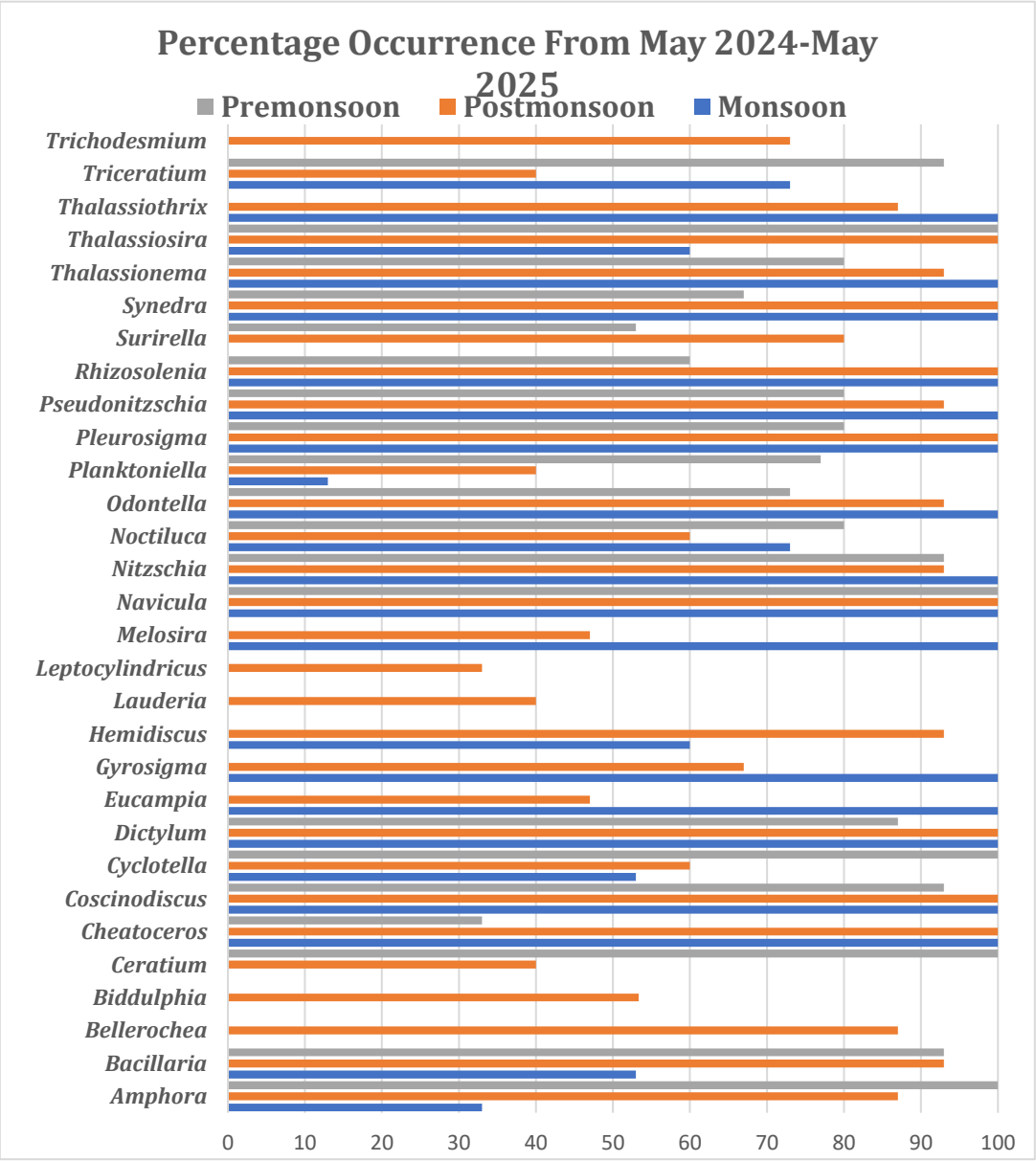


Figure 30. Percentage occurrence of phytoplankton genera from May 2024to May 2025

Phytoplankton density

The density of different phytoplankton group varied from 4000 No/L to 24320 No/L with average variation of 7,627 No/L to 24, 320. Highest phytoplankton density was observed in post-monsoon followed by Pre-monsoon and Monsoon (Fig 31).

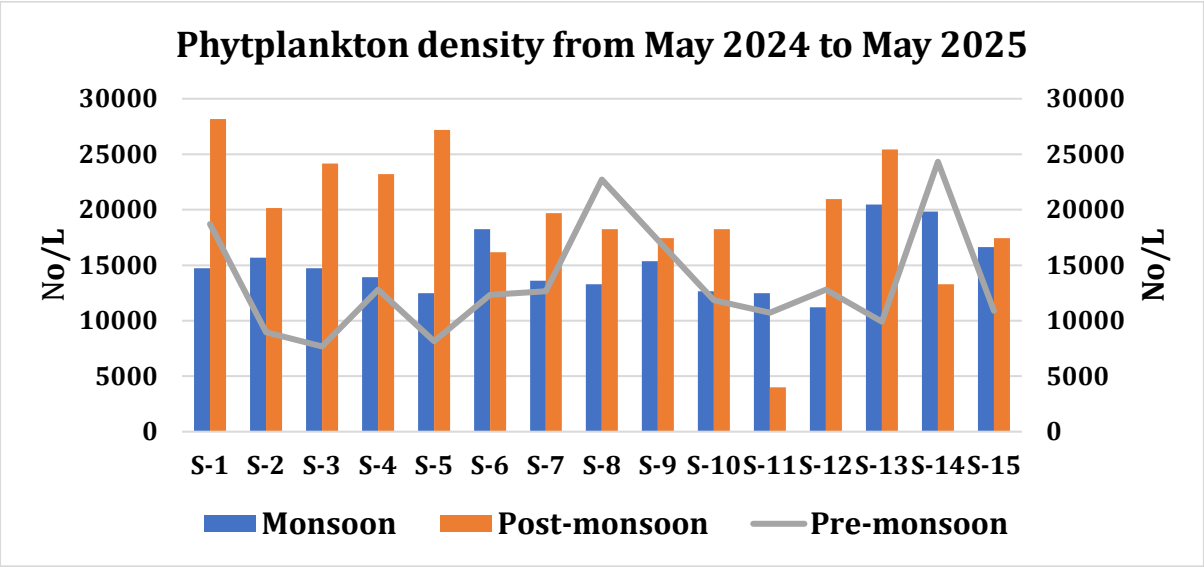
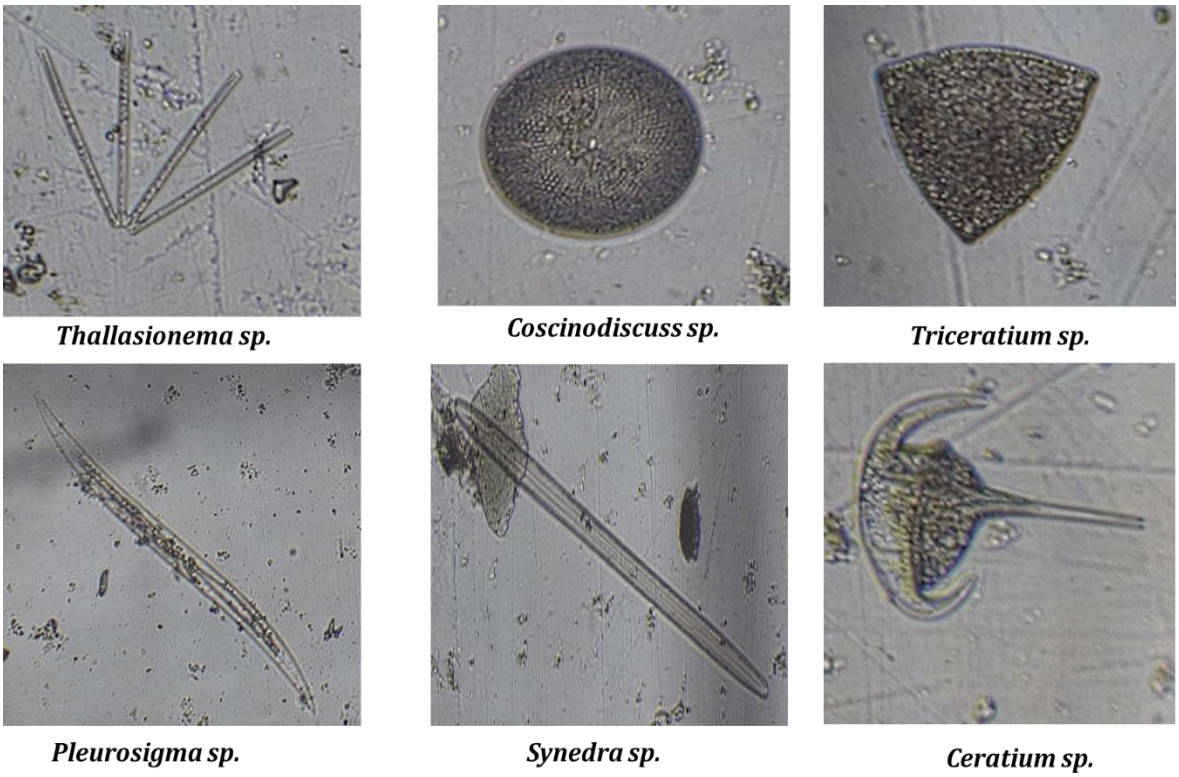


Figure 31. Seasonal variation Phytoplankton density during May 2024 to May 2025



Thallasionema sp. *Coscinodiscuss sp.* *Triceratium sp.*

Pleurosigma sp. *Synedra sp.* *Ceratium sp.*

Plate 8: Phytoplankton of Deendayal Port Authority

4.2.3. Zooplankton

These are the primary consumers that depends on phytoplankton for their feeding and constitute a second trophic level in food chain of marine ecosystem. The size of the zooplankton members varies greatly from microscopic to macroscopic occupying different depths in the pelagic realm. They constitute the primary food for several higher trophic level organisms which includes fishes, crustaceans and mollusks. Zooplankton provides the required amount of protein to the cultured fishes and crustaceans (Koli and Mule, 2012) as well. The zooplankton species quickly respond to the environmental changes and thus are used as bio-indicators for the assessment of aquatic environments (Sharma et al., 2007). Thus, zooplankton are of great ecological significance as they play important role of transferring organic matter from primary producer to secondary consumers like fishes (Kehayias et al., 2013). Zooplankton in the Gulf of Kachchhis dominated by copepods (Saravanakumar et al.,2017) while the microzooplankton is represented by Cilio-phora and Forminifera (Patel et al., 2017). Ramaiah (1997) stated that studies on zooplankton communities, especially copepods are of key importance in assessing the health of coastal ecosystems. The distribution of living organism is controlled by the variation in salinity of water and its variation caused by dilution and evaporation is most likely to influence the fauna in the coastal ecosystem (Sridhar et al. 2006). The density of zooplankton was found to be high during Post-monsoon and premosoon period, bimodal distribution, the primary peak occurring either in October or April and the secondary peak in March or December (Bhaskaran and Gopalakrishnan,2011). Similarly, there occurs gradual increase in number of organisms towards the offshore area with concomitant increase in diversity. The larval forms of echinoderms, cephalopods and brachiopods are usually confined to the offshore (Govindan et al.,1980).

Phylum and group status

The status of phylum and group of Zooplankton for the period 2024 to 2025 showed highest phylum and group during post-monsoon followed by pre-monsoon (Fig,32)

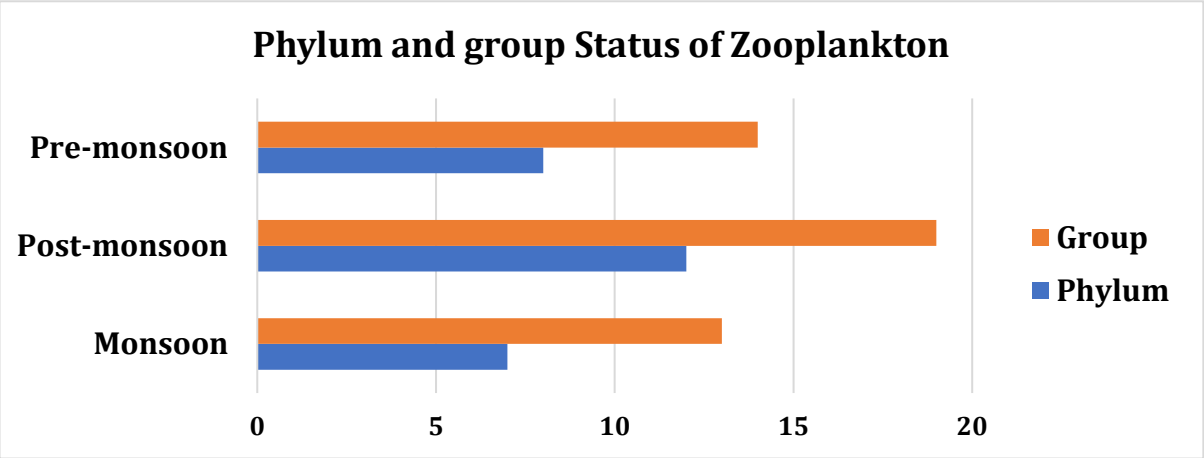


Figure 32. Status of Zooplanktonn and group and phylum from May 204 to May 2025

Generic Status

The generic status of Zooplankton from May 2024 to May 2025 varied from 13 to 37 in number with average variation of 16 to 32 in number. Highest number of genera was observed during Post- Monsoon followed by pre-monsoon and Monsoon (Fig.33)

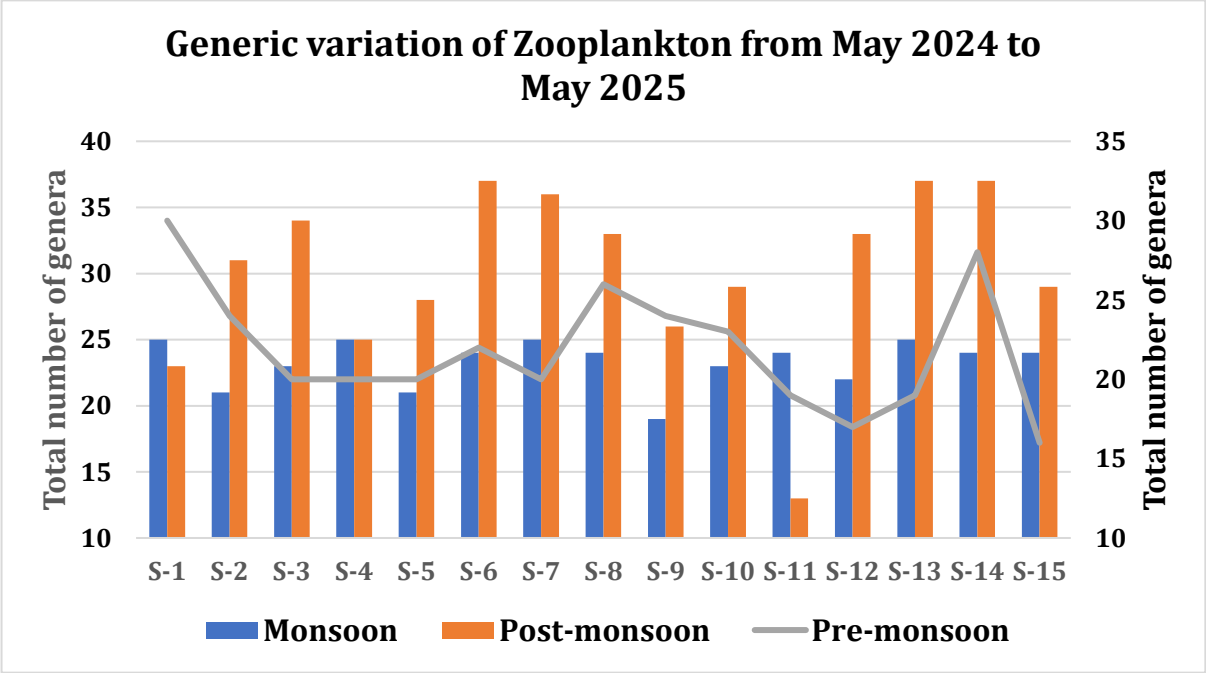


Figure 33. Generic Status of Zooplankton From May 2024 to May 2025

Percentage composition

The average maximum percentage composition of different zooplankton group varried from 26% to 31% with average variation of 29 %. Highest percentage of composition was contributed by *Copepoda-Calanoida* followed by Malacostraca and Tintinnida. Highest percentage of composition was observed in Post-monsoon and least percentage composition was observed in pre-monsoon (Fig.34).

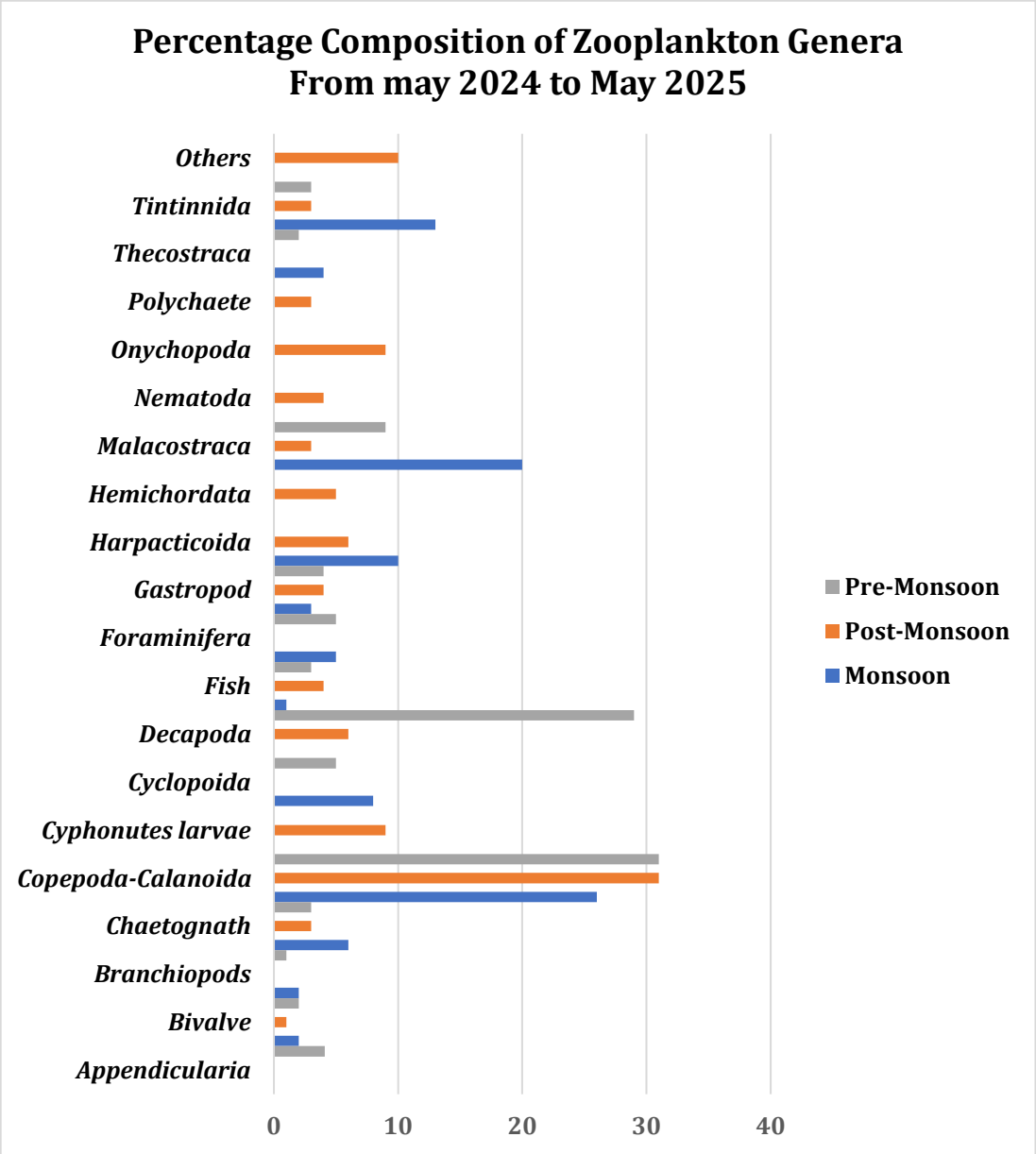


Figure 34. % Composition of Zooplankton Genera at DPA from May 2024 to May 2025

Percentage occurrence of zooplankton

The percentage occurrence of zooplankton from May 2024 to May 2025 was 7 to 100%. Highest percentage of occurrence was observed during monsoon i.e 12 genera such as Acartia, Acrocalanus, Bivalve larvae, Brachyuran larvae, Calanus, Cirripede nauplius, Codonellopsis, Eucalanus, Gastropod larvae,Globigerina, Microsetella, Tintinnopsis occurred 100% of occurrence. Similarly in Post monsoon 7 genera was found 100% of occurrence and during pre-monsoon. In Pre-monsoon least number of genera found 100% of occurrence where the genera Lucifer only found to be 100% of occurrence (Fig 35).

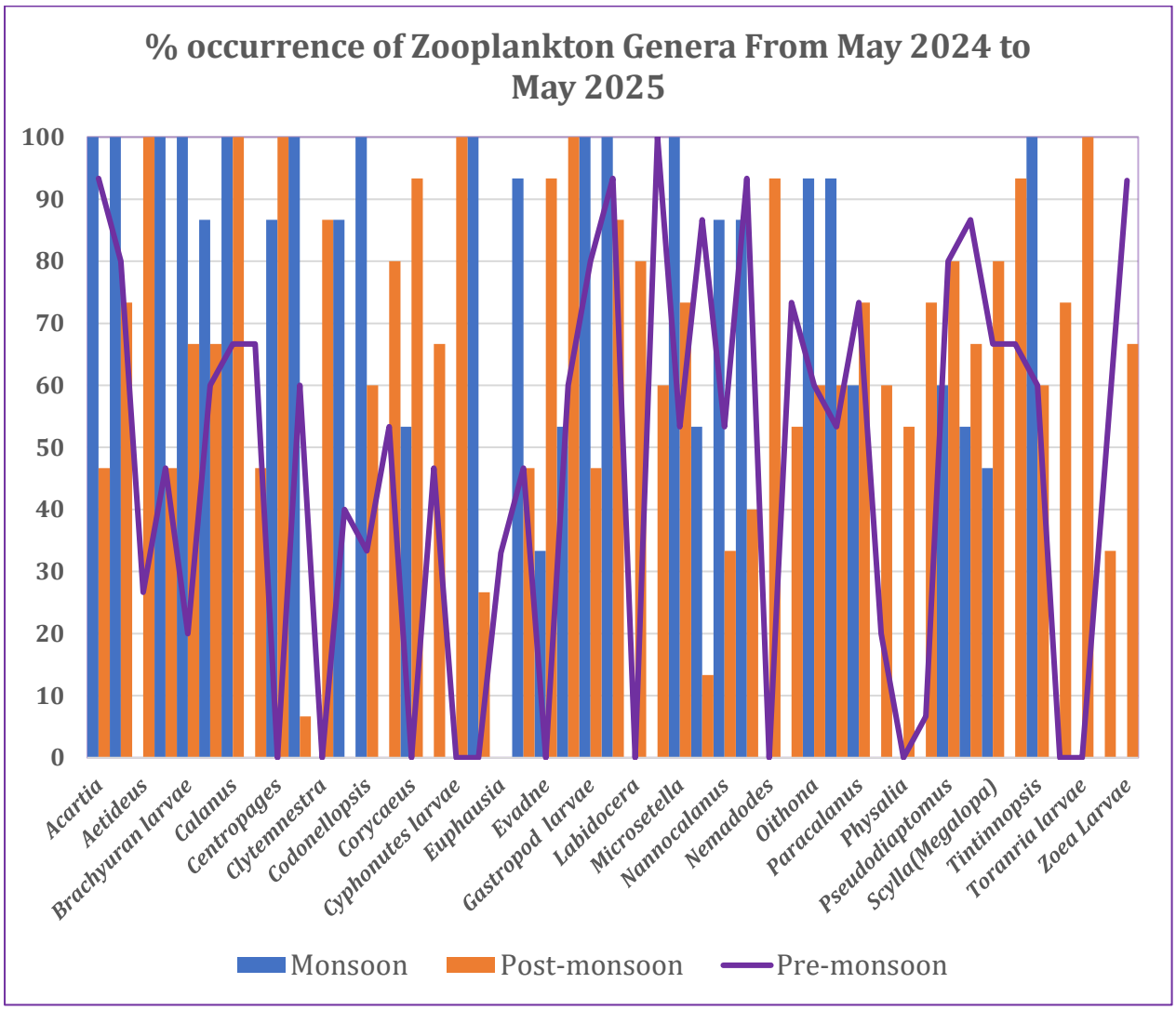


Figure 35. % Occurrence of Zooplankton Genera at DPA from May 2024 to May 2025

Density of zooplankton

The density of zooplankton from May 2024 to May 2025was 8,000 No/L to 20,000 No/L with average variation of 7,653 No/L to 17,660 No/ L. Highest Zooplankton density was observed in Post-mon soon followed by pre-monsoon and Monsoon (Fig.36).

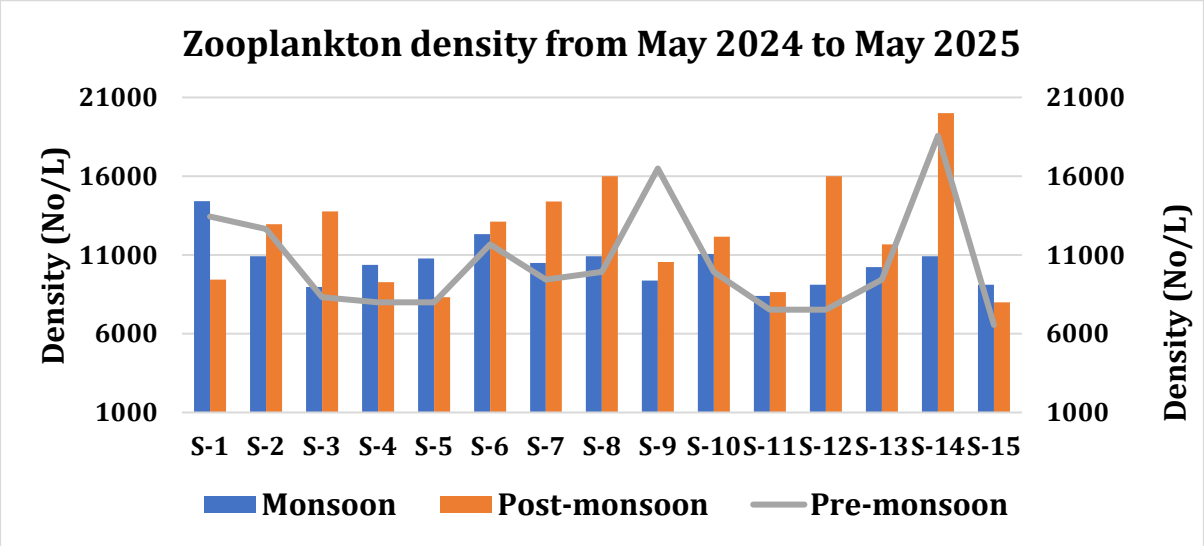


Figure 36. Density of Zooplankton in DPA form May 2024 to May 2025

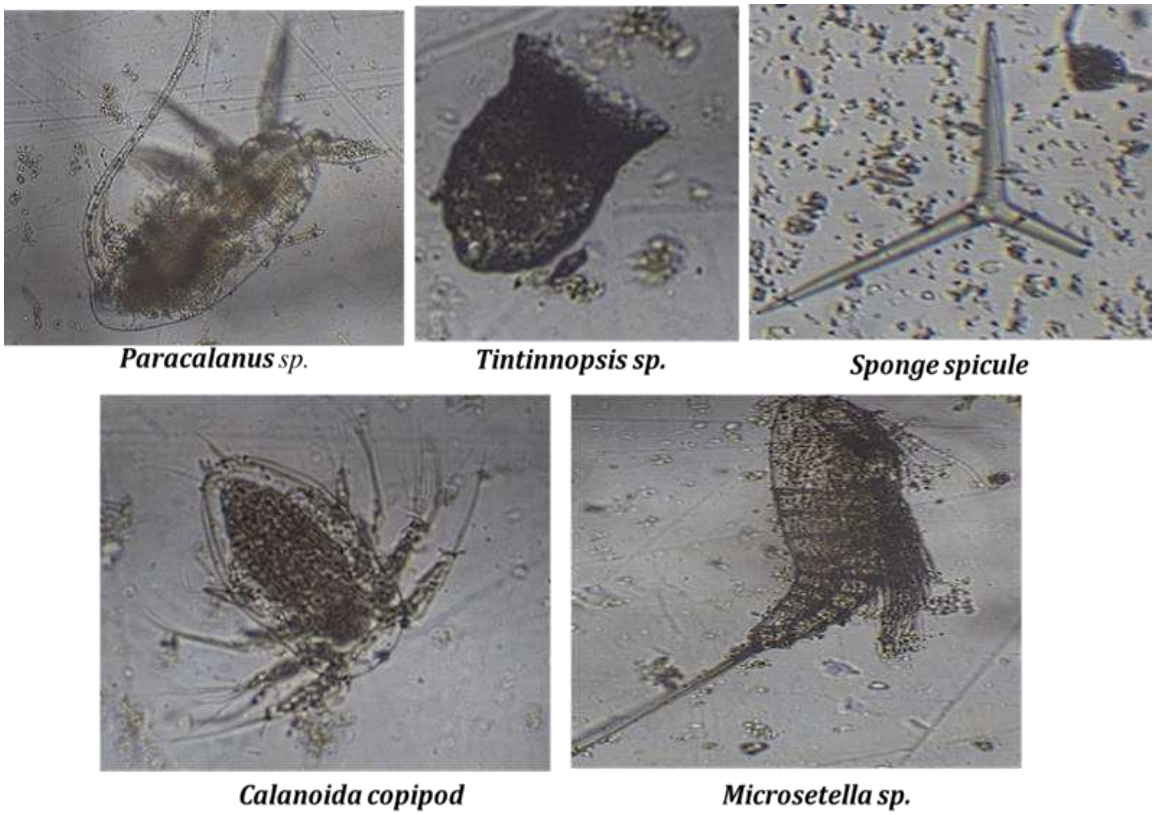


Plate 9: Zooplankton of Deendayal Port Authority

4.2.4 Intertidal Fauna

The intertidal zone, the interface between terrestrial and marine environments, represents one of the most dynamic and ecologically multifaceted ecosystems. Globally, the increasing utilization of the littoral zone for several developmental projects and human activities have contributed increasing level of habitat transformation and consequently degradation of this fragile ecosystem. Such degradation is manifested in the rapid loss of biodiversity, which poses a significant threat to the ecosystem's products and services (Liang et al., 2024).

The intertidal zone is often referred as the littoral zone is the area where the land is submerged temporarily due to the tidal water inundation, and where the benthic region of the ocean begins and below this zone is the sublittoral (shelf) zone, extending from the low tide mark to the shelf break, is permanently submerged. The Intertidal zone can include rocky ledges, sandy beaches, mudflats, salt marshes, and mangrove swamps and the benthic region has a variety of physical conditions, including depth, light penetration, and pressure. The intertidal zone is a marine habitat that experiences extreme and rapidly changing environmental conditions such as water Temperature, salinity, tidal amplitude, turbidity, along with substratum composition and organic matter and carbon content and the vegetation characteristics which are very much correlated with the fauna population density and distribution along the intertidal zone.

Faunal composition of intertidal macrobenthos

The survey of the intertidal Fauna of DPA Kandla area recorded the presence of 4 phyla (Arthropoda, Chordata, Mollusca). The faunal diversity was the highest for phylum Mollusca followed by Arthropoda and Chordata respectively (Fig.37).

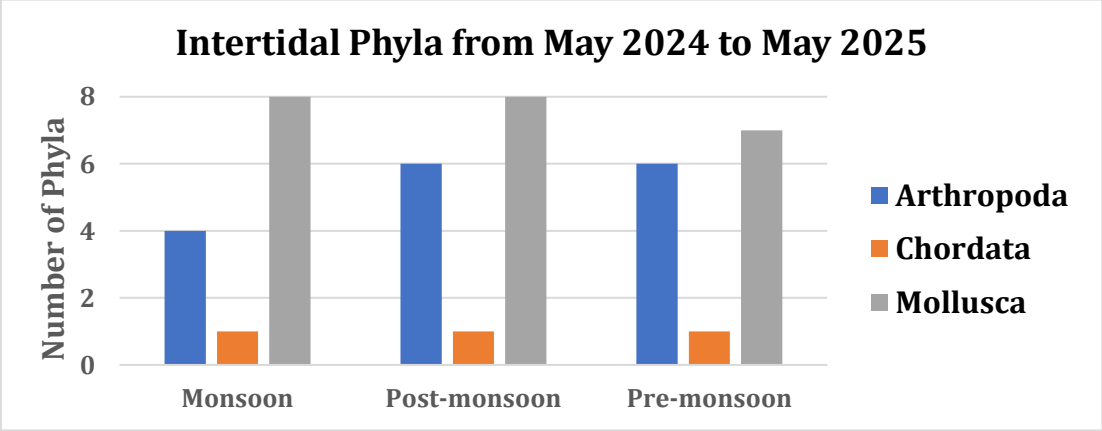


Figure 37. Intertidal faunal diversity in DPA from may 2024 to May 2025

Generic status

The generic status of intertidal fauna from May 2024 to May 2025 varied from 4 to 11 number with average variation of 4 to 10. Highest number of genera was observed during pre-monsoon followed by Post-monsoon and Monsoon (Fig.38)

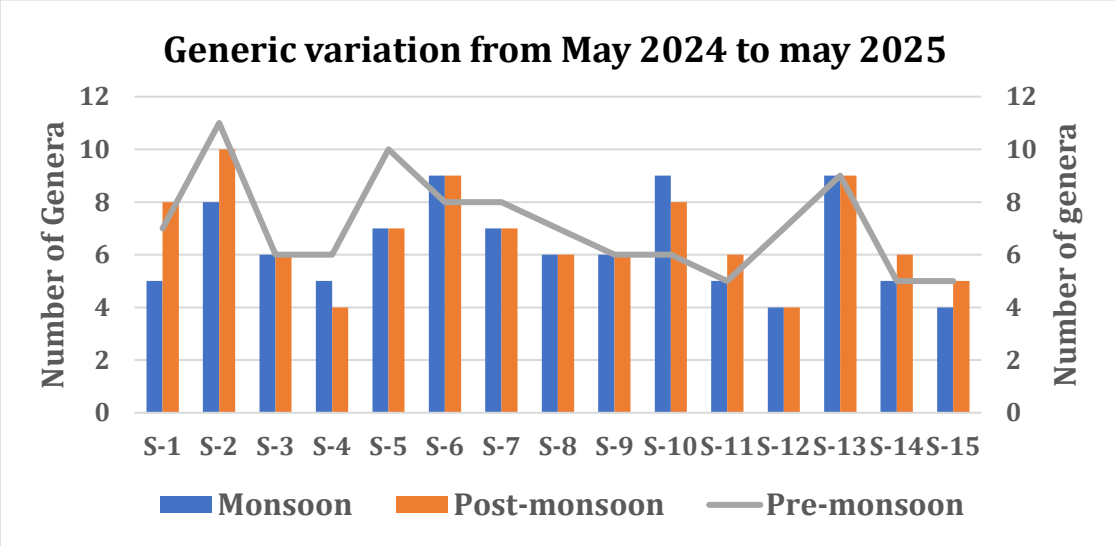


Figure 38. Generic Status of Intertidal Fauna in DPA from May 2024 to May 2025

Percentage composition of Intertidal Fauna

The percentage composition of Intertidal ranged from 0.2% to 245vwith average variation of 0.6% to 22% from May 2024 to May 2025.Highest organism contribute in pre-monsoon followed by followed by Monsoon and Post-Monsoon (Fig.39) .The organism such as *Austruca iranica*, *Austruca sindensis*, and *Austruca variegata* contribute highest percentage of composition.

Density variation of intertidal fauna

The density of Intertidal organism among different station was varied from 17No/m^2 to 133 No/m^2 with overall variation in 3 season was 18 No/m^2 to 97No/m^2 (fig 40). Monsoon contribute highest density of organism followed by Pre- and Post-Monsoon.

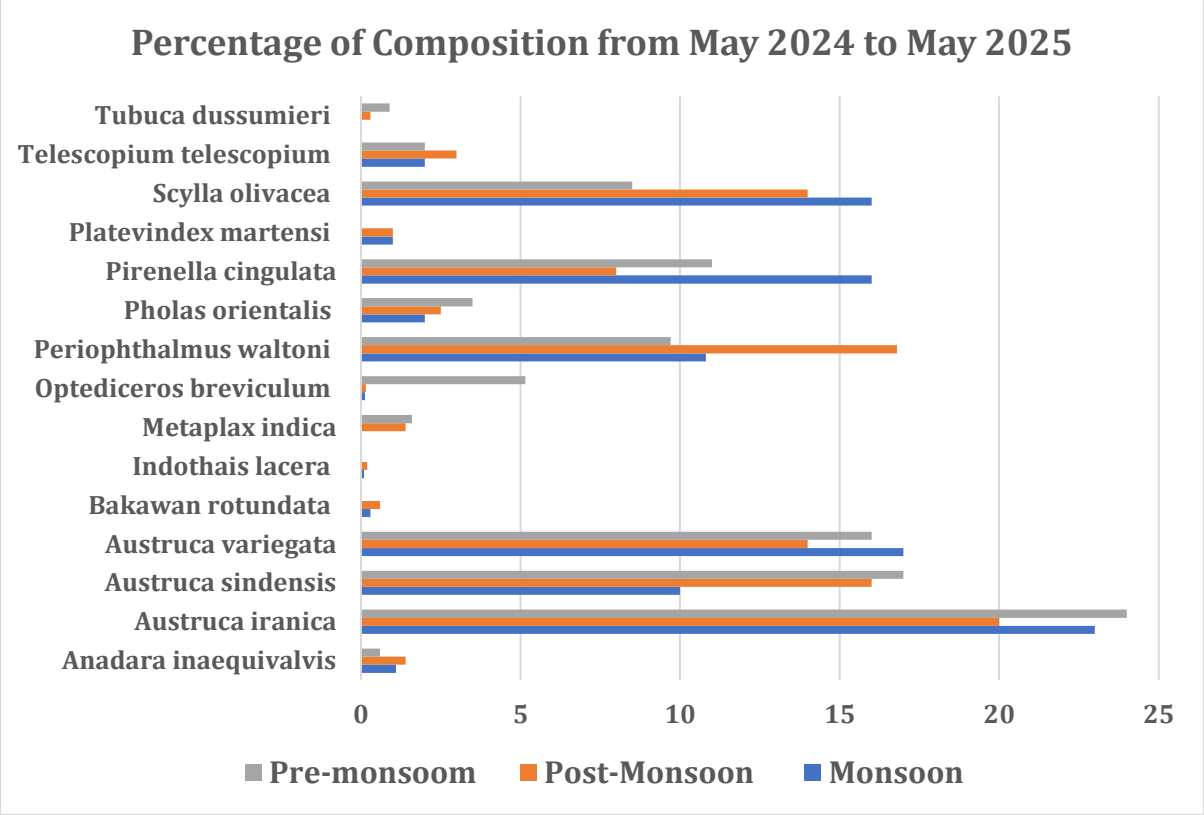


Figure 39.Percentage composition of Intertidal Fauna in DPA

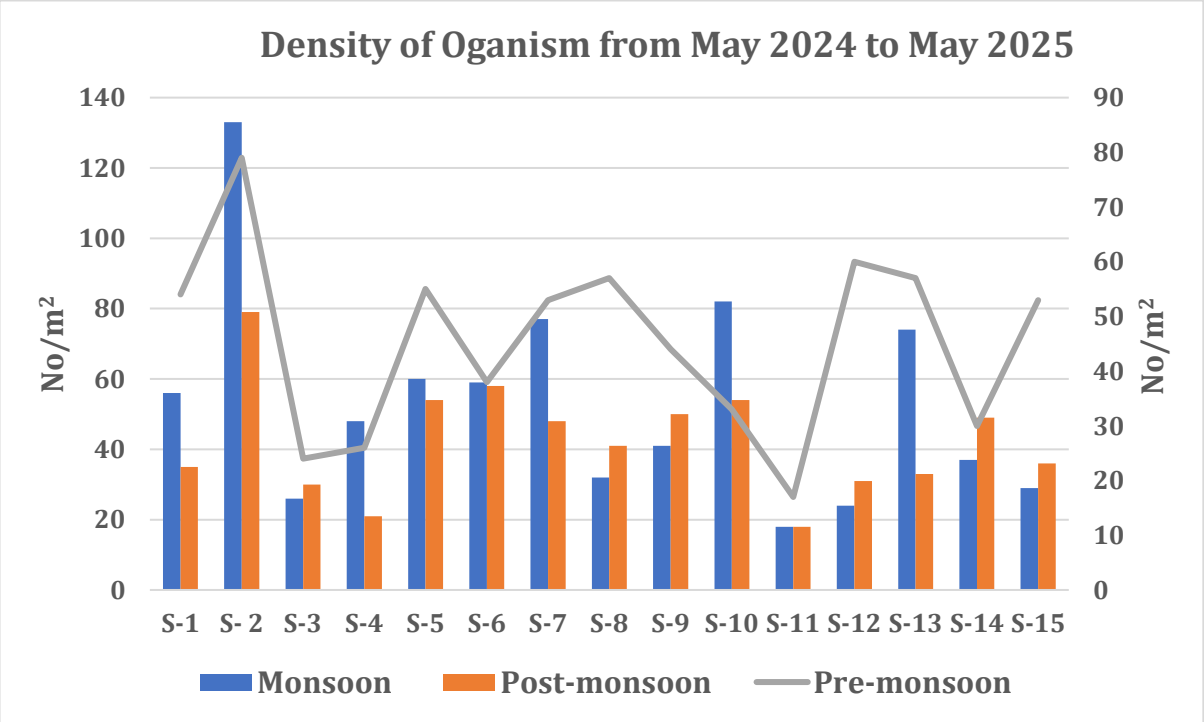


Figure 40. Density of Intertidal Fauna in DPA

4.2.5. Subtidal Fauna (Macrobenthos)

Subtidal ecosystems are permanently submerged due to tidal influence, whereas intertidal ecosystems are found between the high tide and low tide, experiencing fluctuating influences of land and sea. Macrobenthos are an important component of estuarine and marine ecosystems. Benthic fauna is an important component of marine ecosystems, providing key services including secondary production and remineralization. Being sedentary or having only limited mobility, benthic communities are particularly vulnerable to variations in environmental and ecological factors. As a result, they exhibit distinct spatial and temporal distribution patterns on small and large scales. Coastal areas are naturally highly dynamic, with several distinct habitat types coexisting nearby (e.g., estuaries and intertidal habitats) and supporting high biodiversity (Cowie and Woulds,2011). The abiotic factors structuring benthic communities include salinity, temperature, sediment characteristics, and oxygen availability, however, their relative importance varies among the different habitats. On a fine scale, biotic factors such as competition for food and space, predation, reproductive strategies, and life-history traits influence the distribution and abundance of individual species, in turn determining community structure. Moreover, coastal habitats are also the most impacted by anthropogenic pressures, from climate change-related warming and acidification to habitat degradation and pollution. Benthic fauna, through their diverse feeding modes and lifestyles, not only are affected by conditions in the sediment environment, but also actively influence sediment textural and geochemical properties, the flow regime of bottom waters, and, through exchange of particles and solutes between water and sediments, also regulate properties in overlying waters (Meysman et al., 2006)

All marine sediments are anoxic below a certain depth from the sediment surface and, consequently, sulphidic sediments have a worldwide distribution. Organic sediment enrichment occurs through vertical and advective accumulation of organic carbon from the decomposition of the organic matter. On bottoms where accumulation of organic matter happens and leading to the reduction of oxygen at low concentration. The oxygen deficiency may very well be the most widespread anthropogenically induced deleterious effect in me marine environment that causes localized mortality of benthic macrofauna.

Distribution and composition of subtidal macrobenthos

The number of macro benthic fauna of the various groups from the DPA port environment includes Annelida, Arthropoda, Mollusca and Nematoda. The number of various fauna from May 2024 to May 2025 raged from 1 to 11 with maximum contribution was during Post and pre-monsoon (Fig.41).

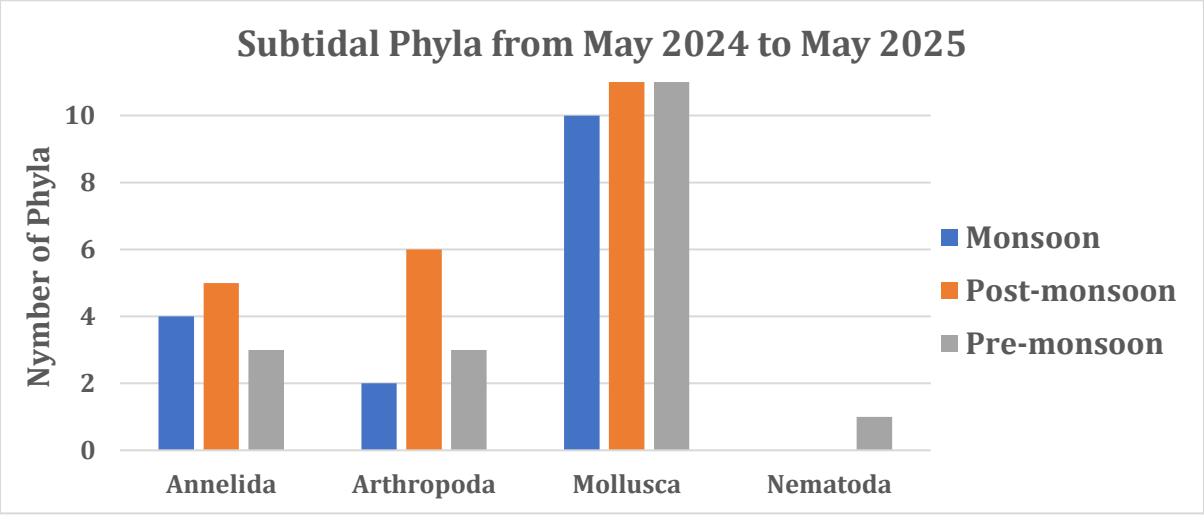


Figure 41. Distribution of Subtidal macrobenthos in DPA

Generic Status

The generic status of subtidal macrobenthos varied from 1 to 12 number with average variation of 2 to 10 number. Highest number of genera contributed during monsoon followed by pre-monsoon and Pre-monsoon (Fig.42).

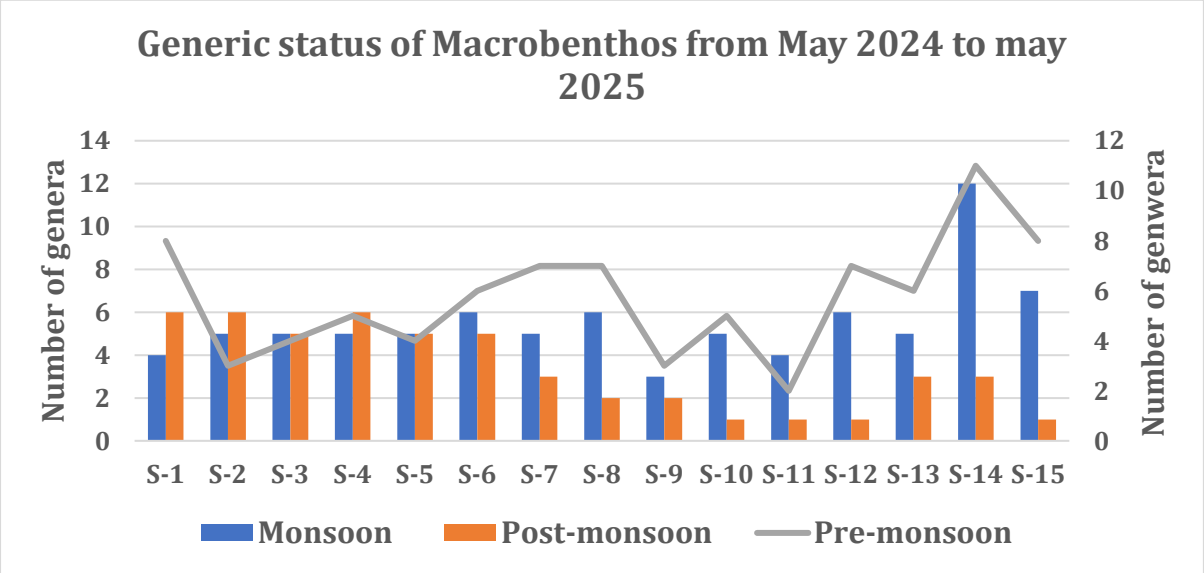


Figure 42. Generic status of Macrobenthos in DPA

Density of subtidal benthos

The average density and population of subtidal macrobenthos from May 2024 to May 2025 varied from 307 N0/m^2 to 507 No./m ^{2} and 12 to 20 in number (Fig.43)

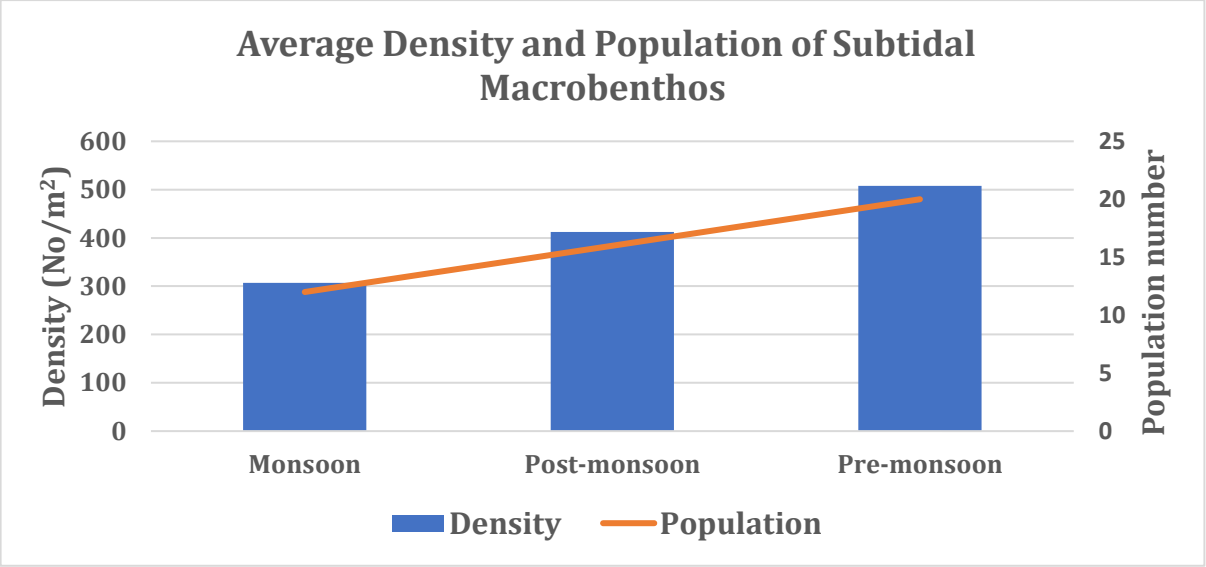


Figure 43 . Average Density of Subtidal macrobenthos in DPA

In station wise density of subtidal macrobenthos varied from 25 no/m^2 to 1150 no /m^2 with average variation of 100 no/m^2 to 754 no/m^2 . Highest dinsith was observed in Pre-monsoon and lowest was observed during post-monsoon (fig 44).

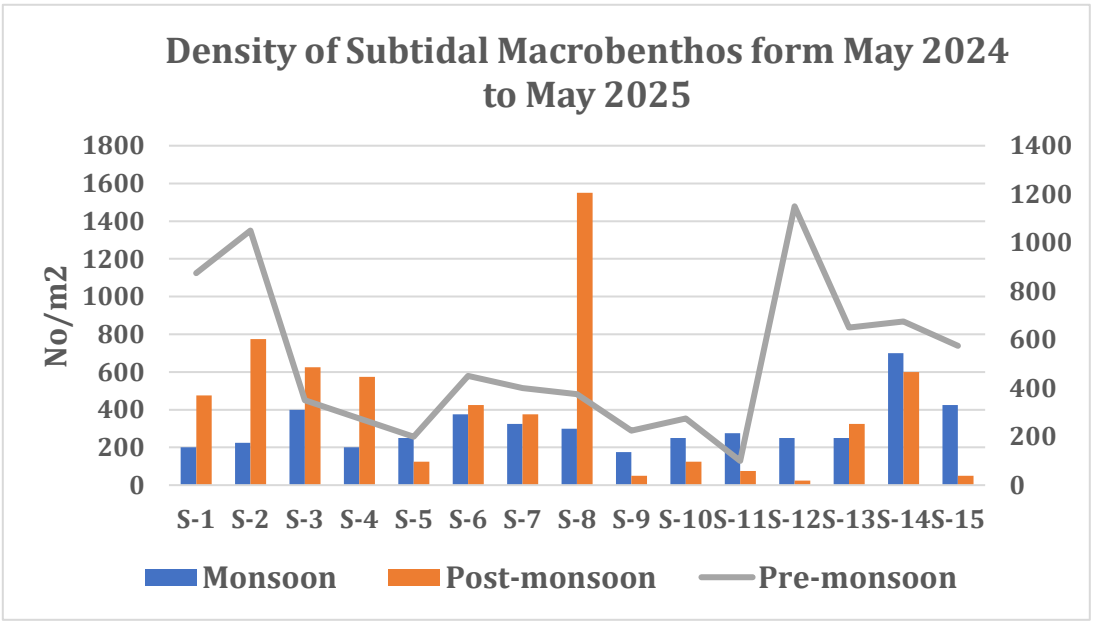


Figure 44 . Density of Subtidal Macrobenthos in DPA along different station

Percentage composition of Subtidal macrobenthos

The percentage composition of subtidal macrofauna varied from 0.4% to 31.8% with average variation of 1% to 26%.Highest percentage was contribution in Pre-monsoon ,followed by Post-monsoon and Monsoon (Fig 45).

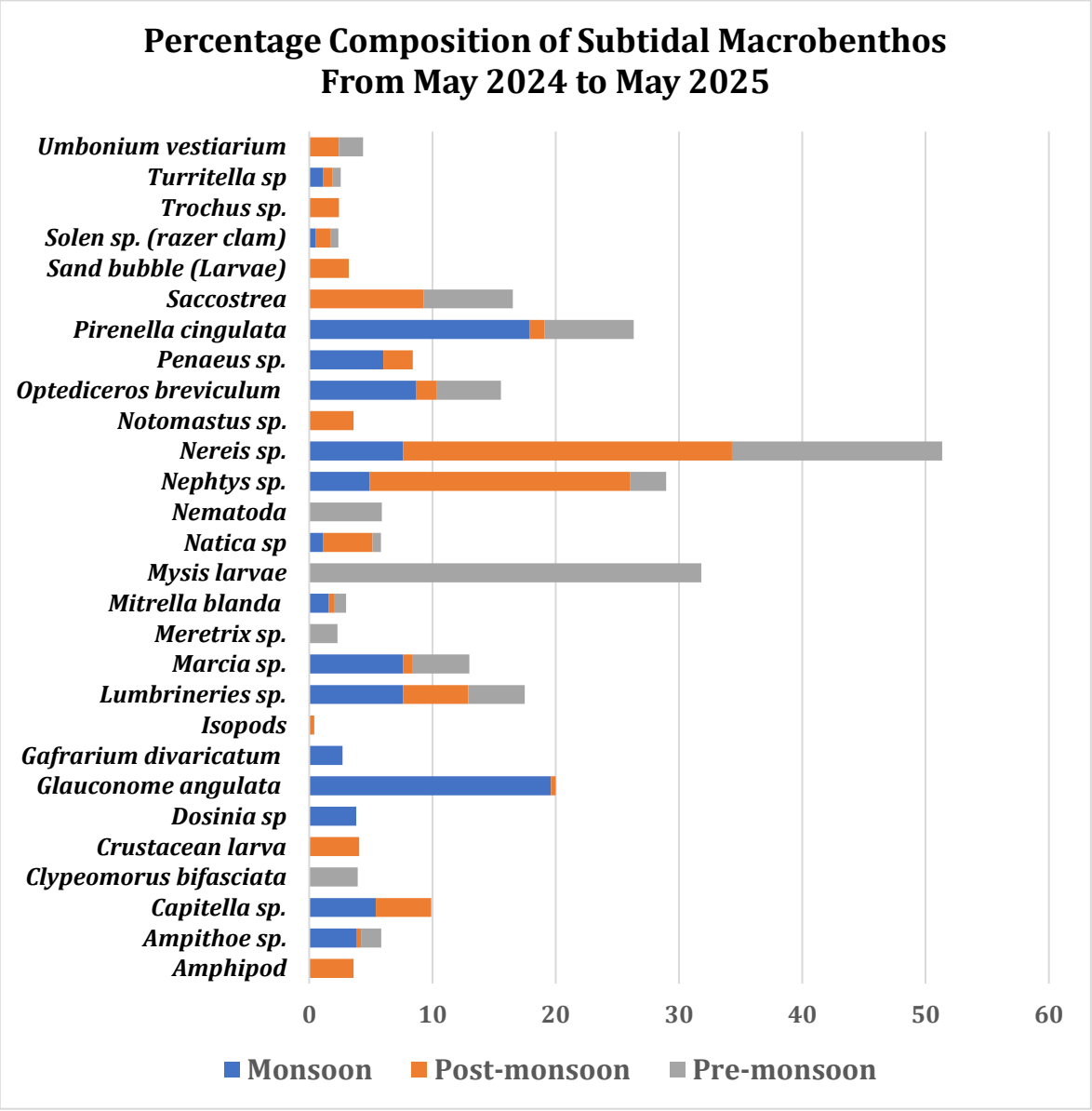


Figure 45. Percentage composition of Subtidal Macrobenthos in DPA

During the study period from May 2024 to May 2025 species such as *Mysis larvae*, *Nereis sp*, *Glauconome angulata* and *Pirenella cingulata* was dominated .

4.3. Mudflats

Mudflats and mangroves establish a major ecosystem of the DPA coastal region and the significance of ecosystem services rendered by mudflat is endorsed in Coastal Regulation Zone (CRZ, 2011) as it accords special status to highly productive zone. Mudflat has an assemblage of plant-animal-geomorphological entities. DPA has been surrounded by two major ecosystems such as mangroves and mudflats which support a number of ecosystem services like nursery grounds for fish and shellfishes and breeding/feeding grounds for the birds (Spencer and Harvey, 2012). The TOC concentration is a direct indicator of mudflat productivity and blue carbon sequestration

4.3.1. Bulk density of the sediment

The sediment bulk density varied from 1.10 gm/cm^3 to 1.89 gm/cm3 with overall average variation of 1.21 gm/cm^3 to 1.68 gm/cm^3 (Fig.46). Highest bulk density was observed in Pre-monsoon followed by post-monsoon and post-monsoon. Among the station highest BD was observed in Pre-monsoon at S-14 (1.89 gm/cm^3) and lowest was observed at S-10 in Pre-monsoon (S-10).

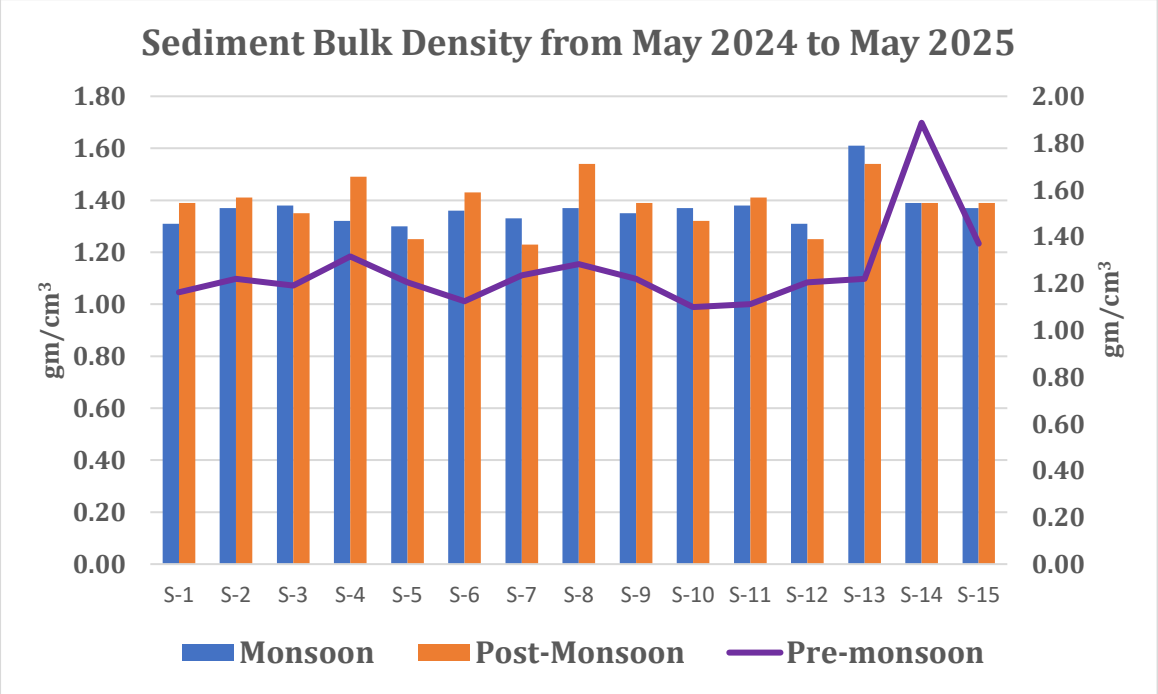


Figure 46. Seasonal variation of Sediment Bulk Density in DPA

4.3.2.Total Organic Carbon (TOC)

The sediment organic carbon of DPA varied from may 2024 to May 2025 was 0.5% to 3.2 % with average variation of 1.8% to 2.5%. Through out season the highest percentage of organic carbon was observed in post-monsoon followed by monsoon and pre-monsoon. Similarly lowest percentage of organic carbon was observed in pre-monsoon followed by equally percentage in monsoon and post-monsoon.

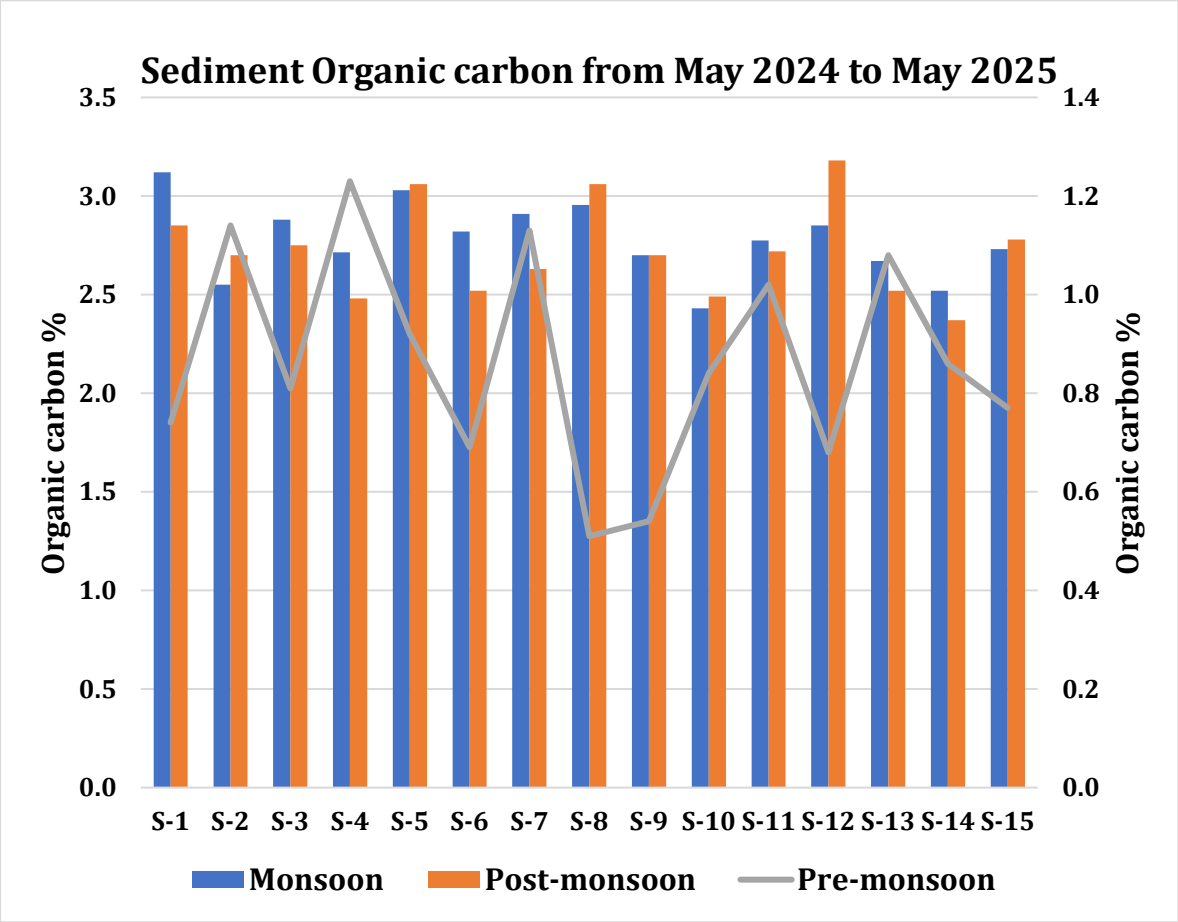


Figure 47. Seasonal variation Sediment Organic carbon in DPA

Among the station highest organic carbon percentage was contributed by S-12 during post monsoon and lowest percentage of organic carbon was observed during pre-monsoon at S-8.

4.4. Mangroves

Gujarat state has the longest coastline of India, with one of the rich coastal areas in terms of biodiversity, and major part of it is covered by mangroves. The mangrove cover in Gujarat ranks as the second largest in India, following the Sundarbans in West Bengal. Mangroves in Gujarat are distributed across four main regions: Kachchh, the Gulf of Kachchh, Saurashtra, and the Gulf of Khambhat including south Gujarat. Among these, Kachchh and the Gulf of Kachchh shows the major contribution of mangrove cover in Gujarat. Around 15 species of mangroves have been recorded across Gujarat's 13 coastal districts, though this number is subject to ongoing debate. However, Avicennia marina is the only species predominates in all the 13 coastal districts of Gujarat.

This unique ecosystem thrives in waterlogged, oxygen-deprived mud, typical of tropical and subtropical zones. The Kachchh coast is characterized by diverse habitats, including vast mudflats and small sandy beaches, shaped by extreme salinity, temperature variations, and tidal influences. These challenging conditions encourage mangrove species to adapt and flourish. Mangroves naturally enrich soil fertility by decomposing leaf litter and root systems, improving surrounding sediments. These ecosystems support a rich variety of flora and fauna, serving as essential breeding, nursery, and feeding sites for numerous marine and terrestrial species.

Despite their ecological significance, mangroves face persistent threats from human activities, such as deforestation, pollution, and climate change. Conservation strategies have been introduced to protect these invaluable ecosystems. The Gujarat Institute of Desert Ecology (GUIDE) has extensively studied and documented these ecosystems, providing insights into their vegetation, species diversity, ecological importance, and conservation status. Mangroves serve as critical habitats for marine and terrestrial wildlife, contribute to coastal protection, preserve biodiversity, and support local communities. The ongoing focus on research and preservation highlights the need for sustainable management practices to ensure their long-term survival. During the study period May 2024 to May 2024 4 species of mangrove such as *Avicenna marina* , *Aegiceras corniculatum* , *Ceriops tagal* and *Rhizophora mucronate* was observed (Plate 10).

4.4.1.Tree Density

Across three seasons of the study, monsoon 2024, post-monsoon 2024, and pre-monsoon 2025, a total of 15 mangrove sites in and around the Deendayal Port Authority (DPA) were assessed. During the monsoon 2024, the overall average tree density recorded was 2,189 trees/ha, with Tuna Creek exhibiting the highest mean density (2,535 trees/ha) and S-6 having the highest individual density (3,673 trees/ha). During post-monsoon 2024, the overall tree density recorded as 1,986 trees/ha, with Kharo Creek leading at 2,788 trees/ha and S-6 remaining the densest (3,156 trees/ha). During pre-monsoon 2025, the overall tree density recorded was 1,907 trees/ha and S-6 continued to show the highest density (3,113 trees/ha), however, major portion of S-11 was observed to go through extensive conversion into salt pans resulting the lowest density for the whole study period (872 trees/ha). The ongoing degradation highlights the pressing need for conservation measures to mitigate the impact of anthropogenic disturbances and preserve the ecological integrity of these mangrove ecosystems.

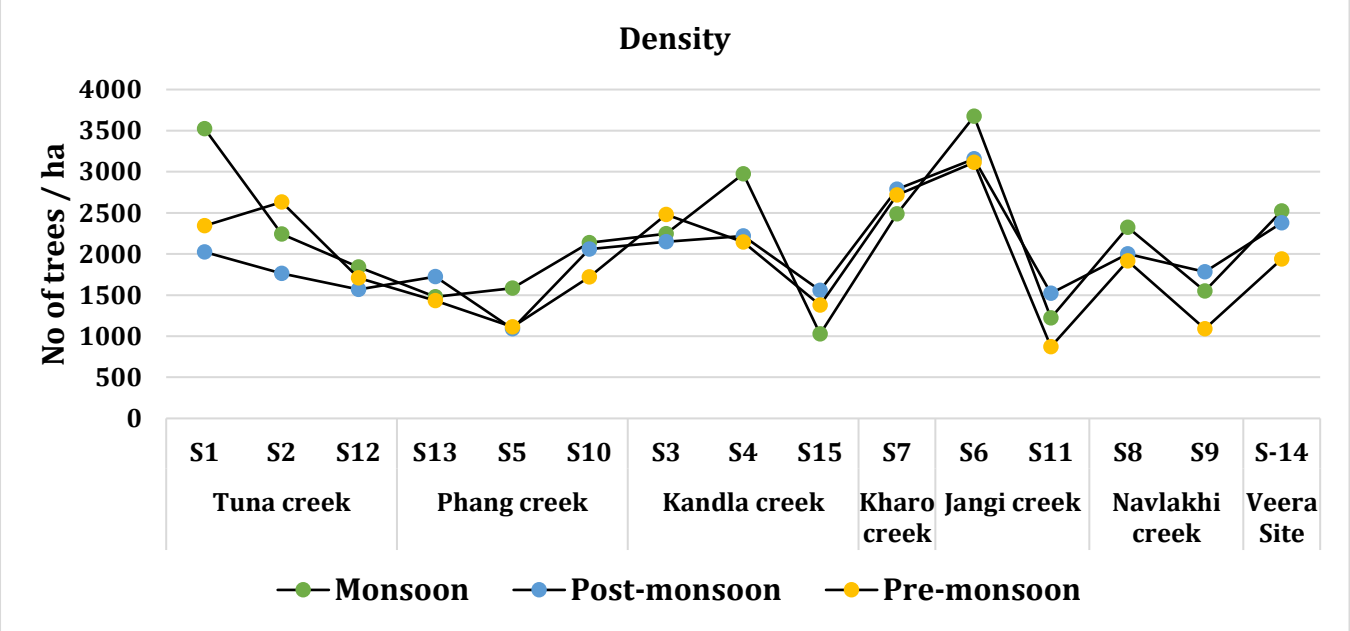


Figure 48. Average tree density during the three seasons study in 2024-2025

4.4.2.Tree Height

The study on mangrove tree height in the DPA Kandla region during 2024-25 revealed seasonal variations in growth. During the monsoon, of 2024, the overall average height of mangrove tree was recorded as 1.8 meters. The highest average was recorded at Veera coast (2 meters), followed by Tuna and Phang creeks (1.8 meters). Site-specific data showed the tallest trees at S-10 in Phang Creek (2.4 meters) and S-12 in Tuna Creek (2.3 meters). The height varied between 1.3 and 2.4 meters across the different locations. However, during the post-monsoon of 2024, the average height was recorded as 1.7 meters. Navlakhi Creek had the tallest mangroves reaching 3 meters while the overall average height was 2.2m. At S-10 in Phang Creek the average height of trees was 2.3 meters. The height of the plants recorded during this season ranged from 1.1 to 3 meters considering all the study stations. During the pre-monsoon of 2025, the average height was 1.6 meters, with Phang Creek recording the highest at 1.7 meters. Site-specific observations showed that S-10 in Phang Creek (2.2 meters) and S-2 in Tuna Creek (2.1 meters) were the maximum height of the plants. The height varied between 1 and 2.8 meters. Mangrove height is a key indicator of the health plants and the ecosystem. The taller trees provide greater protection against storm surges and coastal erosion.

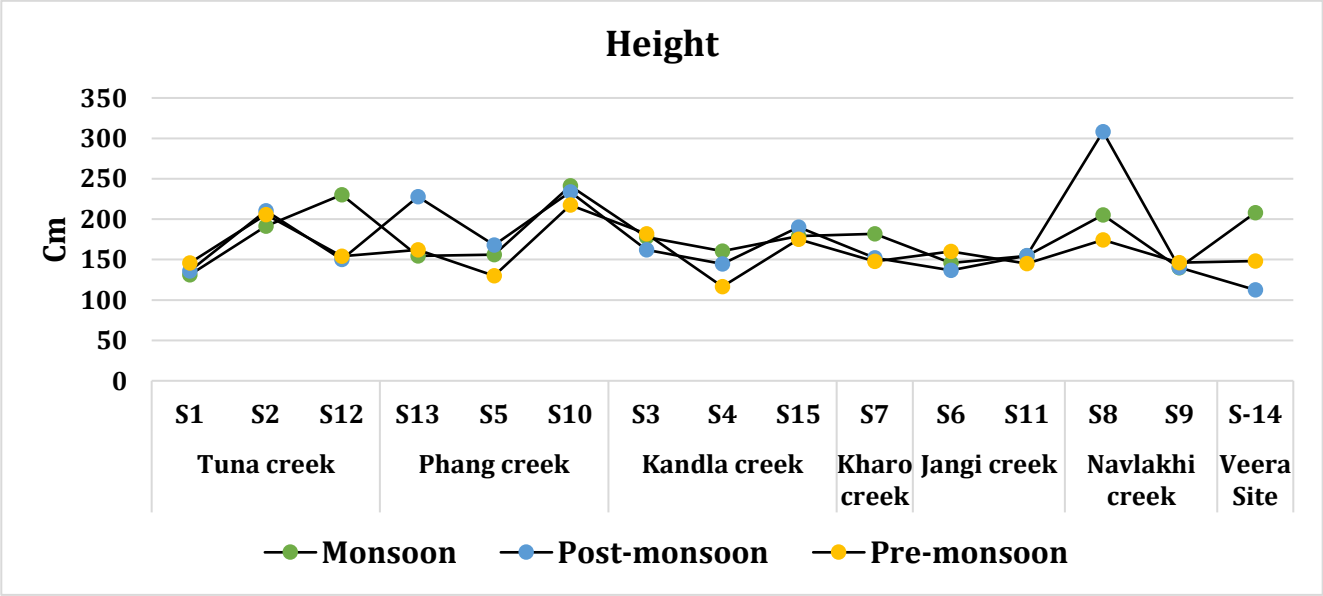


Figure 49. Average tree height during the three seasons study in 2024-2025

4.4.3.Canopy Crown Cover

During the monsoon, the average canopy cover across the mangrove study sites was 3.8 m^2. The highest average canopy cover was recorded at Navlakhi Creek (5.2 m^2), followed by Phang Creek (4.5 m^2). In station wise study, the highest canopy cover was recorded at S-10 (Phang Creek) and S-15 at Kandla Creek, while, S-1 at Tuna Creek, and S-4 at Kandla Creek showed comparatively lower average canopy cover. The post-monsoon survey of 2024 recorded an average canopy cover of 3.45 m^2. In this season the highest canopy cover was recorded at Navlakhi Creek (5.5 m^2), followed by Tuna Creek (3.8 m^2). In station wise observation, stations S-6 at Janghi Creek and S-4 at Kandla Creek recorded relatively lower canopy covers. During the pre-monsoon in 2025, average canopy cover was recorded as 2.25 m^2 across the mangrove study sites. The stations S-10 (4.9 m^2) at Phang Creek and S-15 (3.1 m^2) at Kandla Creek showed higher average canopy covers compared to other stations. However, stations S-4 (0.8 m^2) at Kandla Creek and S-7 (1.7 m^2) at Khari Creek recorded lower canopy covers. Such variations in canopy cover demonstrate how the local environmental factors shape the growth and progression of mangroves.

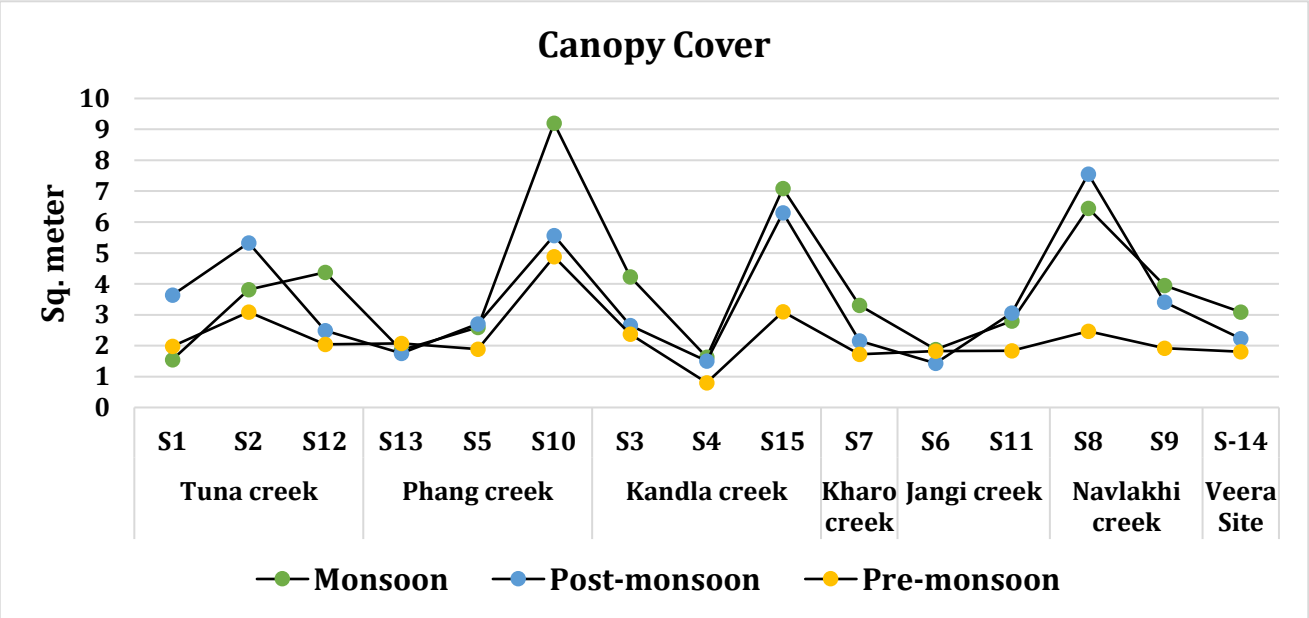


Figure 50. Average tree canopy during the three-season study during 2024-25

4.4.4.Basal Area (Girth)

During the monsoon of 2024, the average basal girth of the mangroves at the DPA sampling sites was reported to be 13 cm. The highest average basal girth was recorded at S-10 (22 cm) and S-8 (18 cm), located in Phang Creek and Navlakhi Creek respectively. The lowest average basal girth was reported at S-6 and S-9 (8 cm) in Janghi Creek and Navlakhi Creek, respectively. During the post-monsoon of 2024, the average basal girth recorded was 12 cm for all the sites while the highest average basal girth was 22cm observed at site S-10 in Phang Creek, followed by S-8 (20 cm) in Navlakhi Creek. In contrast, the lowest average basal girth 8 cm was noted at S-6 and S-14, situated in Janghi Creek and the Veera site respectively. During pre-monsoon of 2025, the average basal girth was recorded as 11 cm and the highest average basal girth were at S-10 (17 cm) in Phang Creek, followed by site S-15 (14 cm) in Kandla Creek. However, the lowest average basal girth was noted at site S-4 and site S-1, both measuring 8 cm, situated in Kandla Creek and Tuna Creek, respectively. Across the DPA Kandla region, Avicennia marina is the dominant species, recognized for its unique multiple-stem growth habit.

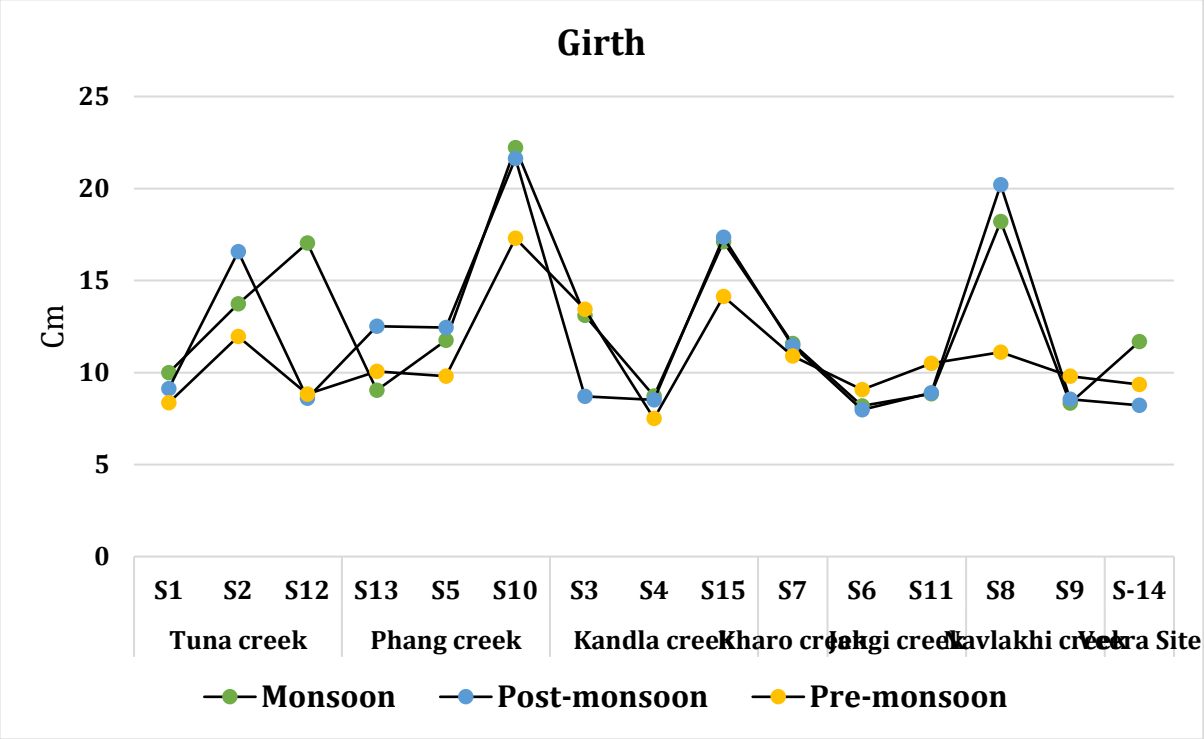


Figure 51. Average tree basal girth during three-season study during 2024-2025

4.4.5.Regeneration and Recruitment Class

During monsoon of 2024, the overall average regeneration class density was recorded as 29,692 plants/ha and the overall average recruitment class density was 5,308 plants/ha. In site-wise observations, the highest average regeneration class density was 73,000 plants/ha at S-8 which is followed by S-9 (52,000 plants/ha) both located along the Navlakhi creek area. For the recruitment class, the maximum plant density (average) was 11,750 plants/ha at S-7 located in the Kharo creek during this survey.

During the post-monsoon survey of 2024, the average density of the regeneration class was recorded as 24,467 plants/ha, while the average density of the recruitment class was noted as 4,785 plants/ha. The site-specific observations revealed that the highest average regeneration class density was at S-12, with 57,100 plants /ha, followed by S-1, which recorded 38,000 plants/ha, both situated in the Tuna Creek area. For the recruitment class, the maximum average density recorded was 10,725 plants per hectare at site S-12 in the Tuna Creek during the survey.

During the pre-monsoon survey of 2025, the average density of the regeneration class was observed at 23,100 plants /ha, while the average density of the recruitment class was3,819 plants/ha. In the station-specific observations the highest average regeneration class density was 46,000 plants/ha at S-11, followed by 36,700 plants/ha at S-3, situated in the Janghi Creek and Kandla Creek area respectively. For the recruitment class, the maximum average density recorded was 7,250 plants/ha at S-8 in the Navlakhi Creek during the survey.

The younger mangroves in these areas promise the future establishment of fully mature trees. These younger class mangroves play a vital role in stabilizing soil and capturing sediments, thereby preventing coastal erosion and maintaining the quality of nearby water systems

a.*Avicenna marina* b. *Aegiceras corniculatum* c. *Ceriops tagal* d.*Rhizophora mucronata*

Plate 10. Mangrove Species of DPA Port Authority

4.5. Halophytes

The halophytes are the plants that are adapted to live in coastal estuaries and salt marshes. It is common in arid and desert milieu which often have substantial salt accumulation. Technically these are the plants which have tolerance to moderate to high salt concentration in its growth substrate. Halophytes, that survive and reproduce in environments where the salt concentration is around 200 mM NaCl or more, constitute about 1% of the world's flora. (Timothy and Colmer, 2008). Halophytes are classified based on their growth conditions as obligate halophytes, facultative halophytes, and habitat-indifferent halophytes.

Percentage of Cover

In entire study period from May 2024 to May 2025 , highest percentage of cover contribute by the halophyte *Salicornia brachiate* (96% -100%) followed by *Sesuvium portulacastrum* (35-50%) , *Salvadora persica* (4% -60%) and *Aeluropus lagopoides* (7%-40%) in monsoon,Post-monsoon and Pre-monsoon. (Plate 11)

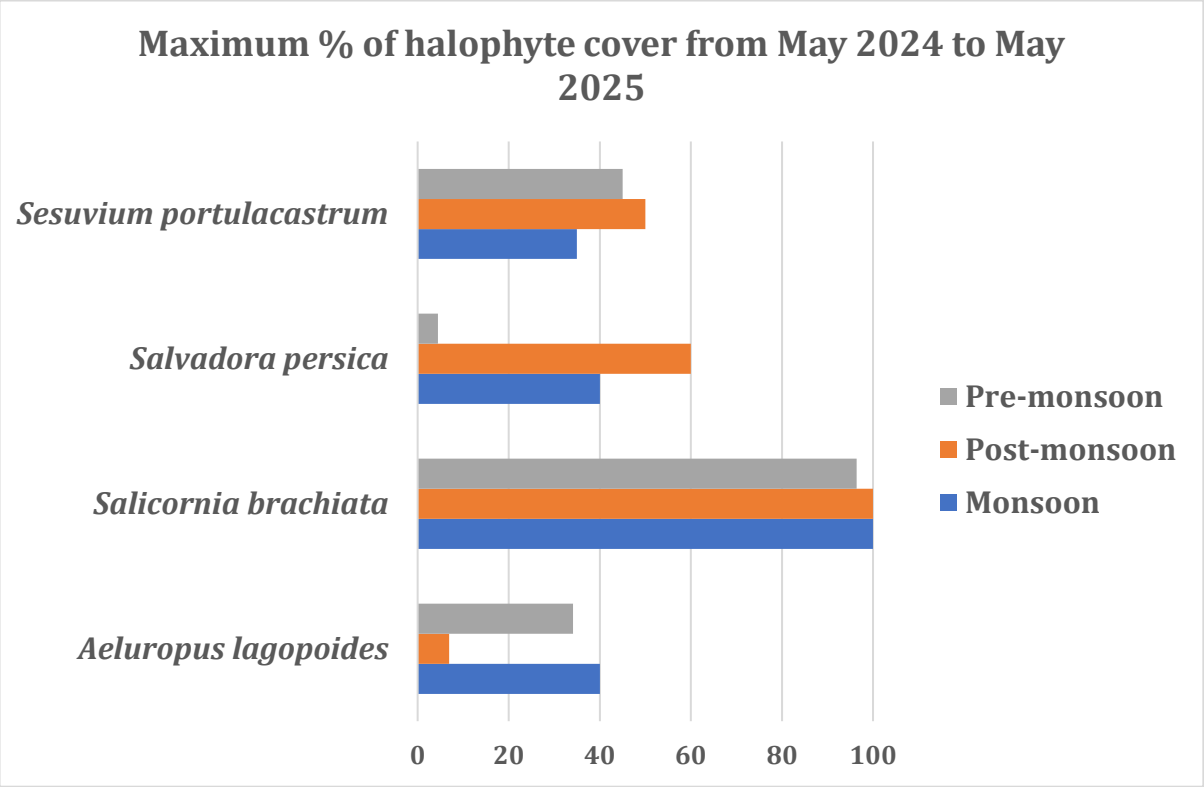
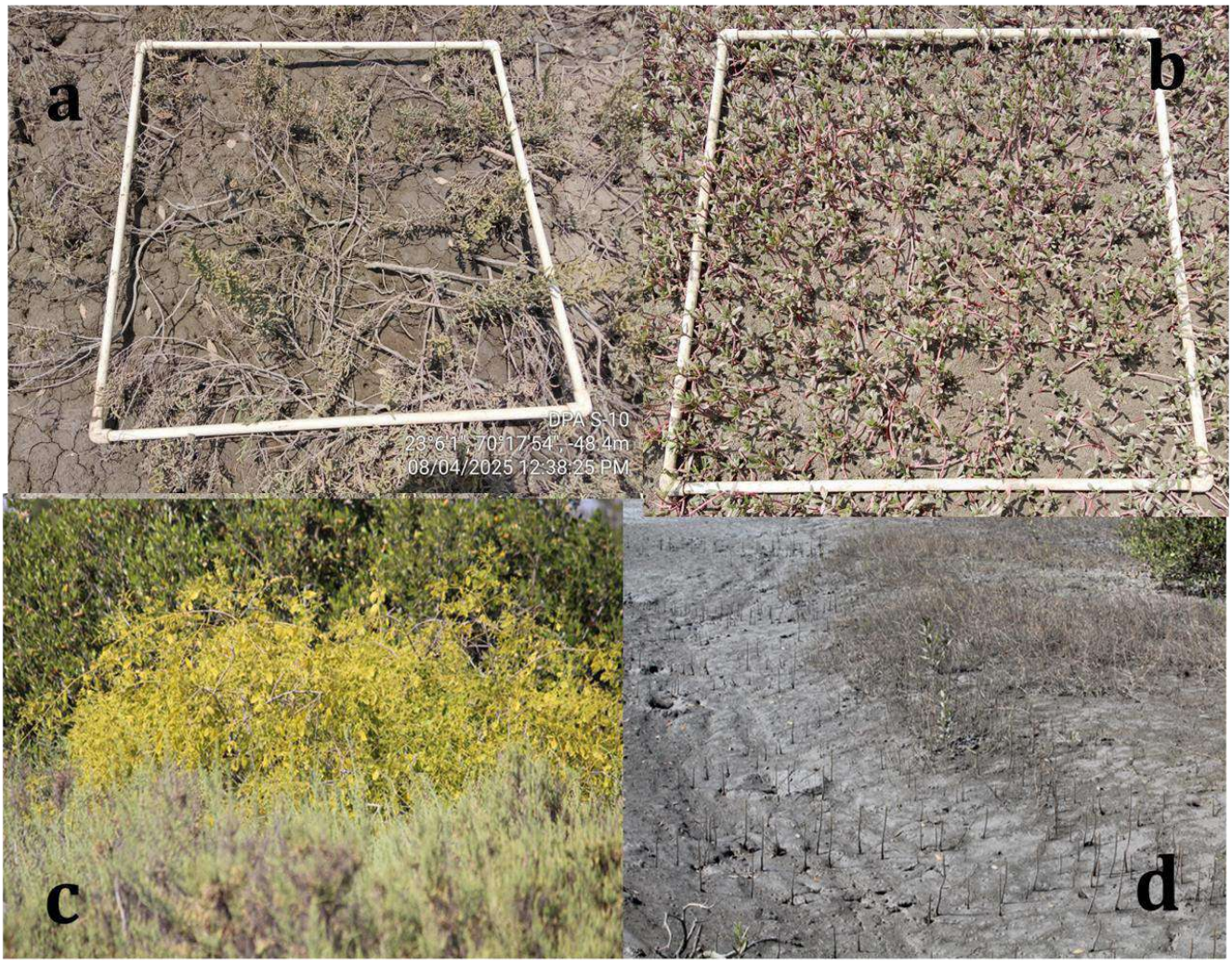


Figure 52. Maximum % cover of Halophytes in DPA and it periphery environment



a. Salicornia brachiata b. Aeluropus lagopoides c. Salvadora persica

d. Sesuvium portulacastrum

Plate 11: Halophyte species recorded along Deendayal Port Authority

4.6. Seaweeds &Seagrass

Both the seagrass and seaweed not observed entire study period from may 2024 to may 2025.

4.7.Marine fisheries

The Ichthyofauna diversity of the Gulf of Kachchh includes a total of 20 orders, 47 families and 96 species (Katira & Kardani 2017). Along the Sikka coast of Jamnagar where 112 ichthyofauna species belonging to 50 families, 12 orders, and 84 genera has been reported. Similarly, the localitynear the Marine National Park, in Jamnagar, Gulf of Kachchh reported 109 ichthyofauna species belonging to 58 families, 19 orders, and 93 genera (Brahmane et al. 2014). Apart from this, a recent study conducted by Sidat et al., (2021) reported 96 species which include 20 order and 47 families. During the field observation from May 2024-2025 , 0.5 kg to 5 kg of fish was catched in 1 km distance with 10 minutes and *Mugil cephalus* is only dominant species which is available in all the season (Plate12).

Plate 12 . Marine fisheries along DPA Jurisdiction

4.8.Reptiles

The saw-scaled viper *Echis carinatus sochureki* normally encountered during mangrove survey Monsoon and Post-monsoon at S-10 location

4.9.Marine mammals

Marine mammals was not observed in entire study period

4.10.Avifauna

Globally, avifauna has the highest level of diversity. Indian subcontinent comprehends around 1340 species of birds which contribute more than 15% of the world's bird species (Ali and Ripley 1987, Manakadan and Pittie 2001, Cox 2010, Grimmett et al. 2011). Thus, understanding the diversity and structure of bird communities to describe the importance of regional or local landscapes for avian conservation and assessment of avian diversity has become an important tool in biodiversity conservation (Safiq et al. 1997). The baseline data on diversity, distribution and species composition plays a significant role for identifying priority areas and formulating the species-specific conservation plan (Peterson et al. 2000, Colin 2000) and evaluate the habitat quality (Chettri et al. 2005, Manjunath and Joshi 2012). Mangrove forest is an important habitat for many bird species and provide high quality habitat for birds because they contain relatively safe nesting and roosting sites, and abundant prey (Nisbet, 1968; van Balen, 1989). Mangrove habitats harbor much of the world's tropical biodiversity and 50% of the world's mangrove forests have been lost as a result of clearing and alteration of coastlines (Duke, 1992). With continuing degradation and destruction of mangroves, there is a critical need to understand the biodiversity of the mangrove ecosystems (Vannucci, 2002). Mangrove vegetation provide a complaint niche for the myriad resident as well as passage migrant aquatic birds, which utilize the system in varying degree from feeding, roosting and breeding (Oswin, 2002).

While, numerous bird species use their foraging ecology to sustain a trophic level, making birds another key animal group in an ecosystem. Scavenging carcasses, eliminating vermin and insect pests, cycling nutrients, dispersing seeds, pollination, and pest control are some of these services. As scavengers and possible pollinators, they have a functional role in the ecosystem and are appropriately referred to as bio-indicators (Bruford 2002, Gregory *et al.* 2003, Parmar *et al.* 2016, Maznikova *et al.* 2024).

Status, Diversity and Distribution of avifauna in different station

The status and diversity of avifauna was studied in coastal areas of Deendayal Port Authority, Kandla, India for the 2024-25. The entire survey was comprehensively carried out by boat survey and walking along the fixed sampling station, for documentation of avifauna. A total of 64 species (34 species terrestrial and 30 aquatic bird) representing 11 order, 26 families and 46 genera were recorded during the study period (Annexture 1, Plate 13). Scolopacidae (nine species) were the most dominant family in terms of species richness followed by Ardeidae and Laridae (eight species), whereas Columbidae and Accipitridae (five species), whereas others represent less species (Fig.53).

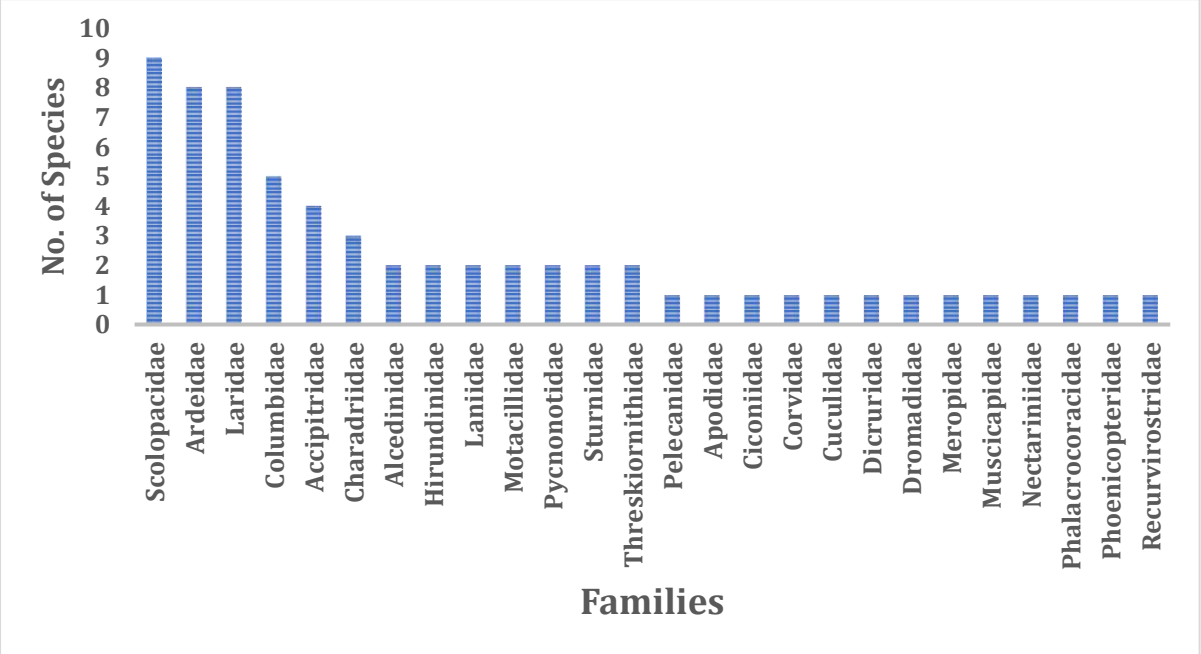


Figure 53. Distribution of families and species at the DPA , Kandla, India

Among the survey station, site 12 (55 species) were the most dominant with 41 genera and 24 families species richness followed by site 13 (53 species), sites 1, 2 and 7 have (47 species) and site 3 have 46 species and other sites have less species composition (Fig.54). The Shannon–Wiener diversity indices shows that site 13 (H=3.756), followed by site 12 (H=3.707), site 7 (H=3.642) and site 5 (H= 3.622), whereas others represent less diversity (Table 13). Based on the movement pattern 42 species (66%) of birds were residence, 18 (28%) are migratory and four (6%) species are regional migratory (Fig. 55).

Table 13. Site wise diversity indices recorded from DPA during 2024-25.

Sites	Taxa	Individuals	Simpson_1-D	Shannon_H	Evenness e^H/S	Margalef	Equitability_J
S-1	47	191	0.966	3.559	0.748	8.758	0.925
S-2	47	212	0.969	3.62	0.794	8.588	0.940
S-3	46	520	0.964	3.575	0.776	7.196	0.934
S-4	42	527	0.969	3.607	0.878	6.542	0.965
S-5	45	499	0.967	3.622	0.832	7.082	0.952
S-6	35	309	0.962	3.405	0.861	5.93	0.958
S-7	47	281	0.968	3.642	0.812	8.158	0.946
S-8	34	288	0.965	3.433	0.911	5.827	0.974
S-9	34	275	0.964	3.405	0.886	5.875	0.966
S-10	36	403	0.963	3.427	0.855	5.834	0.956
S-11	25	241	0.947	3.045	0.841	4.376	0.946
S-12	55	385	0.969	3.707	0.741	9.071	0.925
S-13	53	644	0.972	3.756	0.807	8.04	0.946
S-14	30	199	0.958	3.258	0.867	5.479	0.958
S-15	37	287	0.966	3.488	0.885	6.361	0.966

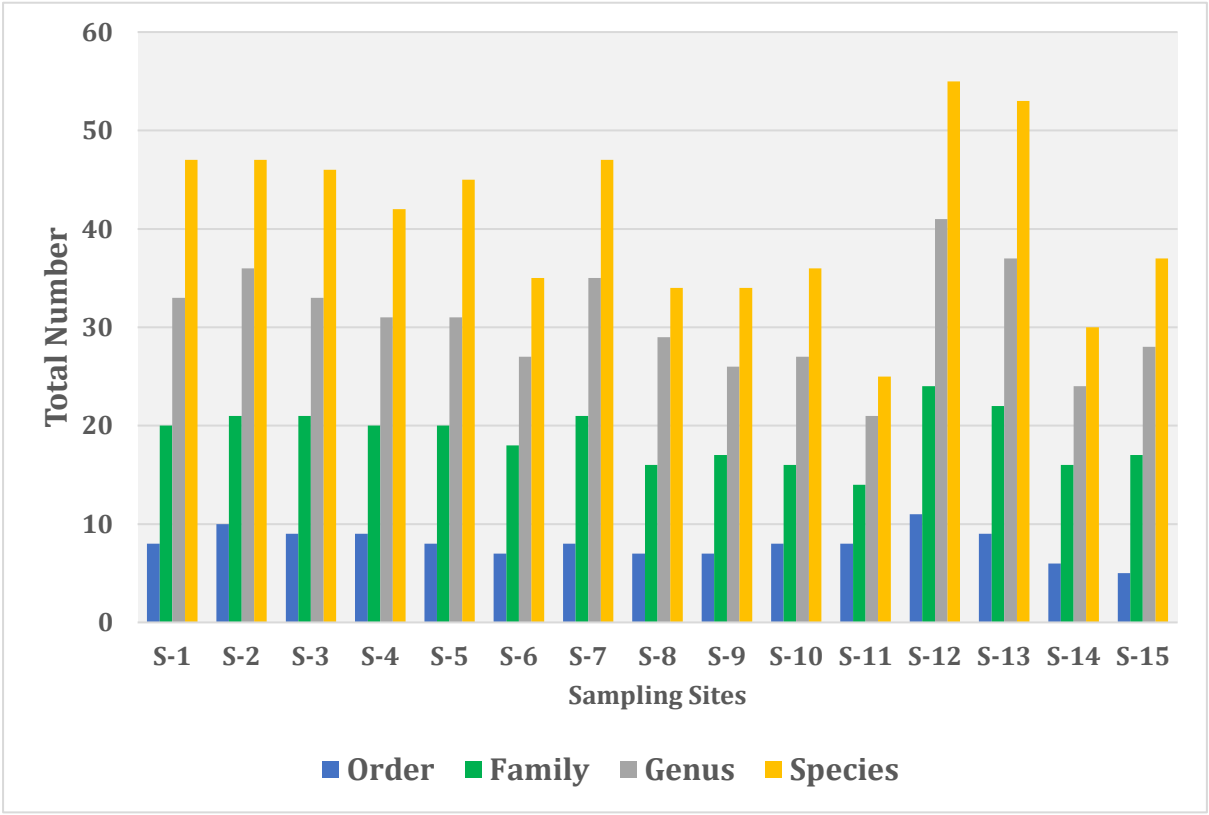


Figure 54. Station wise distribution of Avifauna from May 2024-May 2025 at DPA

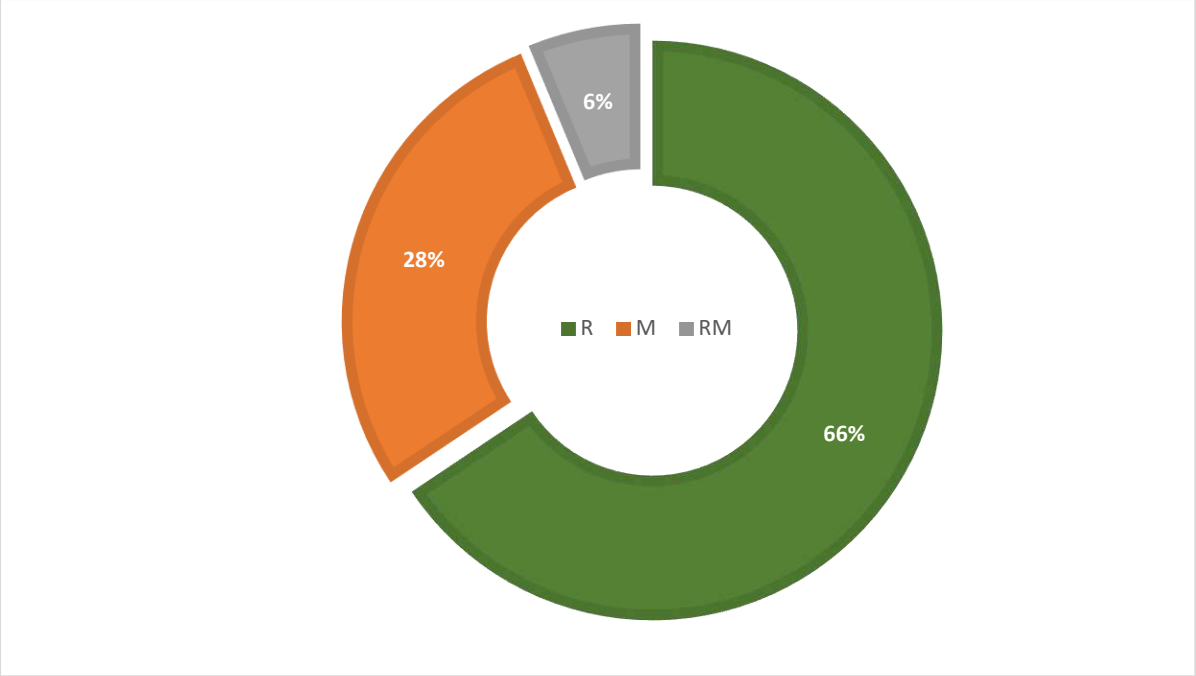


Figure 55. Behavioural status of avifauna from the DPA

Considering the abundance of the species during the study period, 34 taxa (53%) were recorded from terrestrial, 30 species (47%) from aquatic habitat. During the seasonal survey we have noted that, post monsoon season is most productive for avifauna in study area (Table.14)

Table.14. Season wise species recorded from study area

Sites	Monsoon	Post Monsoon	Pre-Monsoon	Overall
S-1	44	14	13	47
S-2	40	21	14	47
S-3	43	44	46	46
S-4	42	42	40	42
S-5	45	45	44	45
S-6	35	35	34	35
S-7	41	22	21	47
S-8	33	34	33	34
S-9	34	34	34	34
S-10	35	36	36	36
S-11	23	23	25	25
S-12	45	37	31	55
S-13	53	53	51	53
S-14	29	29	20	30
S-15	37	37	37	37
Total	**53**	**64**	**60**	**64**

Plate 13. **Common and migratory birds from the Deendayal Port Authority, Kandla.** (A) Western Reef Heron (*Egretta gularis*) (B) Black-headed Gull (*Chroicocephalus ridibundus*) (C) Eurasian curlew (*Numenius arquata*) (D) Grey Heron (*Ardea cinerea*) (E) Greater Flamigo (*Phoenicopterus roseus*) (F) Black-winged Stilt (*Himantopus himantopus*)

Based on the feeding guilds of recorded birds, it was found that carnivore, 20 species (31.35%) were insectivore, 17 species (26.56%) were piscivore were 14 species (21.88%) and 6 species of omnivores and others represents less (Fig 56).

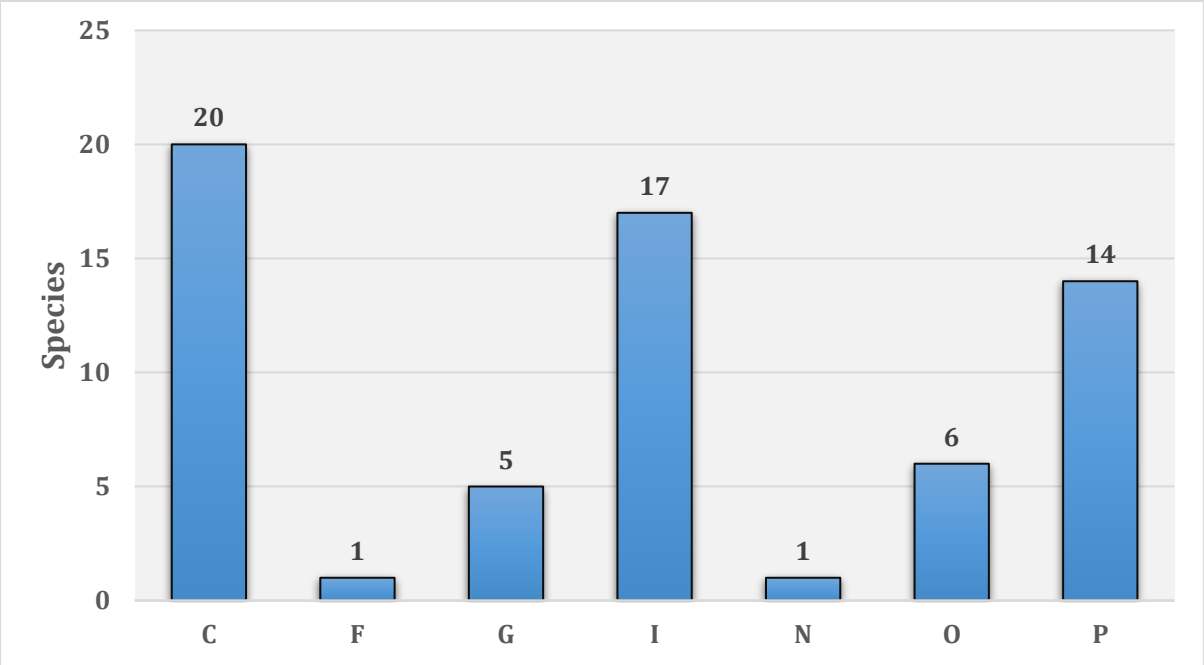


Figure 56. Status of foraging guild of avifauna recorded from Deendayal Port Authority, Kandla, India (C- Carnivore, F- Frugivore, G- Granivore, I- Insectivore, N- Nectarivore, O- Omnivore, P- Piscivore).

Among 64 species, only five species *viz.* Painted Stork *Mycteria leucocephala* (Pennant, 1769), Black-headed Ibis *Threskiornis melanocephalus* (Latham, 1790), Glossy Ibis *Plegadis falcinellus* (Linnaeus, 1766), Black-tailed Godwit *Limosa limosa* (Linnaeus, 1758) and Eurasian curlew *Numenius arquata* (Linnaeus, 1758) are under the Near Threatened (NT), whereas, River Tern *Sterna aurantia* (Gray, JE, 1831) is under vulnerable (VU) categories of IUCN Red List of Threatened Species. Moreover, four species (6.25%) River Tern *Sterna aurantia* (Gray, JE, 1831), Common Greenshank *Tringa nebularia* (Gunnerus, 1767), Black Kite *Milvus migrans* (Boddaert, 1783), Gull-billed Tern *Gelochelidon nilotica* (Gmelin, JF, 1789) and Shikra *Tachyspiza badia* (Gmelin, JF, 1788) were under the Schedule I, and species (90.63%) were under Schedule II categories of Wild Life (Protection) Act, 1972 (Fig 57) and the species rarefaction curve presented in figure 58.

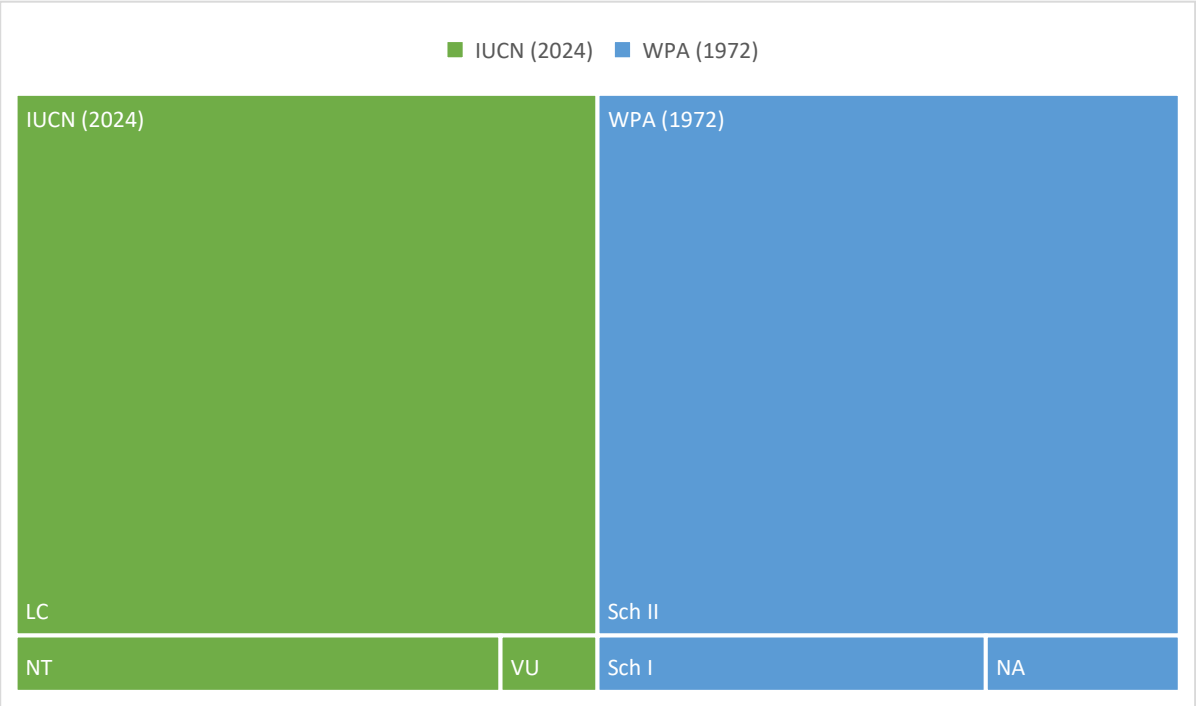


Figure 57. Status of threatened species recorded from Deendayal Port Authority, Kandla, India (Sch=Schedule, LC=Least Concerned, VU= Vulnerable, NT= Near Threatened).

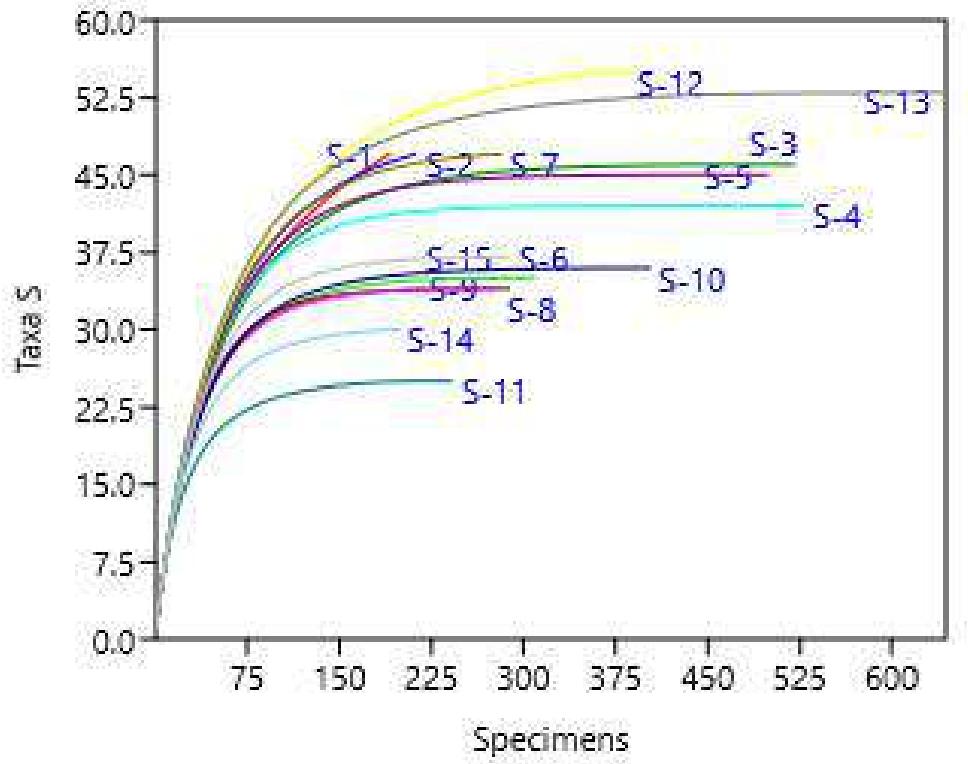


Figure 58. Species rarefaction curves of different sampling sites in study area.

5. Discussion

5.1.Physico-chemical status of Deendayal Port Authority Environment

Water quality of coastal water reveals the state of the overall environment. The quality of water determines the biological and other resources in the marine environment. However, water quality parameters in marine environment vary to a great extent, influenced by the climate,water currents and movements, input of pollutants in the form of effluent and sewage out fall and so on. The geophysical and geo-chemical factors such as shape and size of the coastal areas, prevailing currents, temperature, salinity, tidal impacts, directions of prevailing winds and influx of fresh water also influence the quality of water in the nearshore marine environment. The creeks and the intertidal zones are well known for the biodiversity and their role in the ecological services arewell documented. mangroves are now recognized as one of the most effective nature based solutions for climate change adaption and to reduce disaster risk (Sunkur, 2023). To assess the health of mangrove forest is inevitable in the monitoring programme in which extensive field survey is carried out to select the representative sites for data collection. The plant growth characteristics indicates the status of the mangrove cover for which the height,canopy dimension, Girth, as well as the number of different age groups of plants are considered. The DPA port and the influencing environment are surrounded by the mangroves and tidal flat with marshes are potential carbon stocks which are conserved and restored. Yet,the various human interventions due to the port related activities tendto impair the water and sediment quality which in turn affect the biological productivity. In this regard some of the most influencing physical and chemical water and sediment are considered for the seasonal study from the 15 selected sites. The plankton and benthic fauna diversity, Chlorophyll 'a' are also recognized as indicators of the health status of the environment (Adams,2002). The rate of variations in the different stress indicators in the water are followed in the monitoring process to evaluate the impacts that are likely to occur both in the near future as well as in the long term at the present rate of occurrence.

Temperature and pH

Water temperature in DPA port area generally varies in the range 12°C to 30.°C. However, the present study shows a increased range of water temperature in Kandla DPA port in previous year of 2023-2024. Water temperature Port region varies during monsoon, ranged from 23°C to 30°c to while in post monsoon observation, the value ranged from

12°c to 27°c to . However, in pre monsoon the values were noted in the range of 25°c to 29°C.The monsoon water temperature has been recorded as high (30°C). There is no vertical variation in temperature of marine water in Kandla Port area due to lack of thermal stratification in Creek (NIO,1998). This is because of the strong currents, high tidal impact and low depth of the harbour areas. The currents influence vertical mixing and restrict the stratification of water layer in the harbour area. High temperature during pre- monsoon attributed to high rate of evaporation and less rain fall.

pH

The pH of seawater of DPA Port area varied in the range of 7.3 to 8.5. Generally, the pH of seawater is controlled by Carbonate and biocarbonate system and falls in the narrow range of (0.2-0.3). pH was alkaline during summer and showed downward pattern up to monsoon and remained alkaline during postmonsoon, (Vajravelu et.al 2018). Changes in pH will depend on the factor like the removal of CO2 by photosynthesis through bicarbonate degradation, fresh water influx, reduction in salinity and temperature and decomposition of organic matter (Rajasegar et al., 2002).

Salinity

As temperature influences the salinity of marine water in the tropics, water in DPA region has higher salinity in the range of 36ppt 47ppt during 2023-2024 but at present the salinity ranged 32ppt to 42 ppt which is quite lower in previous year . Highest salinity observed during monsoon and Post-monsoon (42ppt) at station S-8. The higher salinity towards open sea regions around S-8 due fresh ingress of seawater in gulf region and localized effects of seepage of high saline (brine) water from salt marshes and saltpans of salt industries (Zingde& Anand ,1996). Hundreds of salt industries in and around Kandla Port use seawater with salinity in the range of 35 to 50 ppt. They release 'bittern' remains of salt after manufacturing, which has salinity as high as 250 ppt in Kandla Creek, thereby increasing the salinity in isolated regions of port areas (Chhaya, & Chhaya, 1997). Lack of fresh water from catchments coupled with higher evaporation is the cause of higher salinity in Kandla Port area. In the Little Gulf of Kuchchh water salinity has been recorded as high as 50 ppt (NIO,1998).

Dissolved oxygen

DO is consumed in marine ecosystem by the respiration and decaying organic matter in the water column. Loads of high organic matters may deplete the DO to its minimum level, which can be detrimental for the aquatic life. A severe depletion of DO may lead to 'Eutrophication' in an aquatic system. However, no such event has been reported in Kandla port region so far. DO in marine water of DPA region has been found in the range of 2.9 mg/l to 8.2 mg/l for in 3 seasons May 2024 to May 2025. The current range of dissolved oxygen in the marine water of Kandla Port region conforms to the designated best use for Salt pans, Shell fishing, Mariculture and Ecologically Sensitive Zone. For ecologically sensitive zone not less than 3.5mg/l at any time in a year (or 5.0 mg/l at 60 percent saturation level) of DO is essential for the protection of aquatic life. But in presentation observation less content of do in monsoon at S-7 might be due certain nutrient load from mangrove environment.

Total Suspended Solids

Suspended solids in Deendayal port area varied in the range 205 mg/l to 729 mg/l. Generally, the suspended solids in the Deendayal region are high and vary to a great extent from the inner port region to the out harbour region and further towards outer Gulf..The higher value of suspended solids and their variations across the stations in the inner Gulf including Kandla Port regions results from the dispersion of sediment loads due to strong currents and tidal influence Zingde& Anand (1996).

Turbidity

The Kandla Port areas fall under inner Gulf of Kuchch, there is a high turbulence in the· Creek, due to strong an ocean currents and tidal influence. Therefore, the turbidity of tropical seas is higher than other tropical and subtropical seas. The marine water turbidity is expressed in Nephelo Turbidity Unit (NTU). Water turbidity in DPA Port region has been recorded in the range of 16 NTU to 489 NTU. 2023-2024 at present 2024-2025 the turbidity 20 NTU to 489 NTU. Generally, water turbidity is high due to high organic load of mud and silt. (Omprakash, 1997) Higher turbidity of marine water at the DPA Port regions may also be associated with the washed sediment from mangrove environment and partially dredging activities, which is done on a regular basis along the Kandla Creek.

Nutrients

Nutrients in marine water such as Nitrate and Nitrite ,Phosphate and silicate are very crucial for the marine life. Their increase in concentration enhances the primary productivity in marine water. Nonetheless, excessive concentration sometimes can be detrimental to the aquatic life especially in creeks, estuaries and bays where there is a restricted water exchange. These increased nutrients lead to an excessive growth of algae resulting in eutrophication in some extreme cases (NIO,1998). During the period of May 2024 to May 2025 covering 3 season with respect to nutrient concentation it was observed that the concentration were with in permissible limit to marine life expect phosphate concentration which is quite higher from 3.16mg/l to 73.24mg/l which might be due to handling of cargo in port area ,input of sewage and industrial effluent to creek environment

Petroleum Hydrocarbon (PHs)

Petroleum hydrocarbons in the water column of Deendayal port area have been found in the range of 0.3 µg/l to 85.8µg/l for the period 2023 and 2024. For the period may 2024 to May 2025 the PHs ranged from 0.19 µg/l to 70.80 µg/l. High range of petroleum hydrocarbon results from the spills and leakage during the handling of crude petroleum products at the Port especially at oil terminals (NIO,2002).

5.2.Biological status of Deendayal Port Authority Environment

Biological resources of a marine area reflect the overall environment of the region in question. The coastal areas especially bays, creeks and estuaries are rich in biota and are habitat of many marine species. Usually, ports are also built in these areas for their geographical advantages. The port and harbour activities in these locations disturb the habitat of many marine biota. However, in the process many habitats are also created for marine biota. The Gulf of Kachchh is an example of such habitat and has been considered to be rich in biodiversity. Kandla port has been built right in the gulf and has been serving this region nearly seventy years.

Chlorophyll ‘a’ Phytoplankton and Zooplankton

In general the basic parameters of marine biota like Chlorophyll ‘a’ and Phytoplankton are observed to be moderate in their values but similar to those prevailing along the coastal

waters of India (NIO,2002). During the period May 2024 to May 2025 the Chlorophyll 'a' concentration 0.04 mg/l to 2.89mg/l which is quite satisfactory for port environment.

The index value of both phytoplankton and Zooplankton of 3 season shows moderate environmental status (Fig.59).

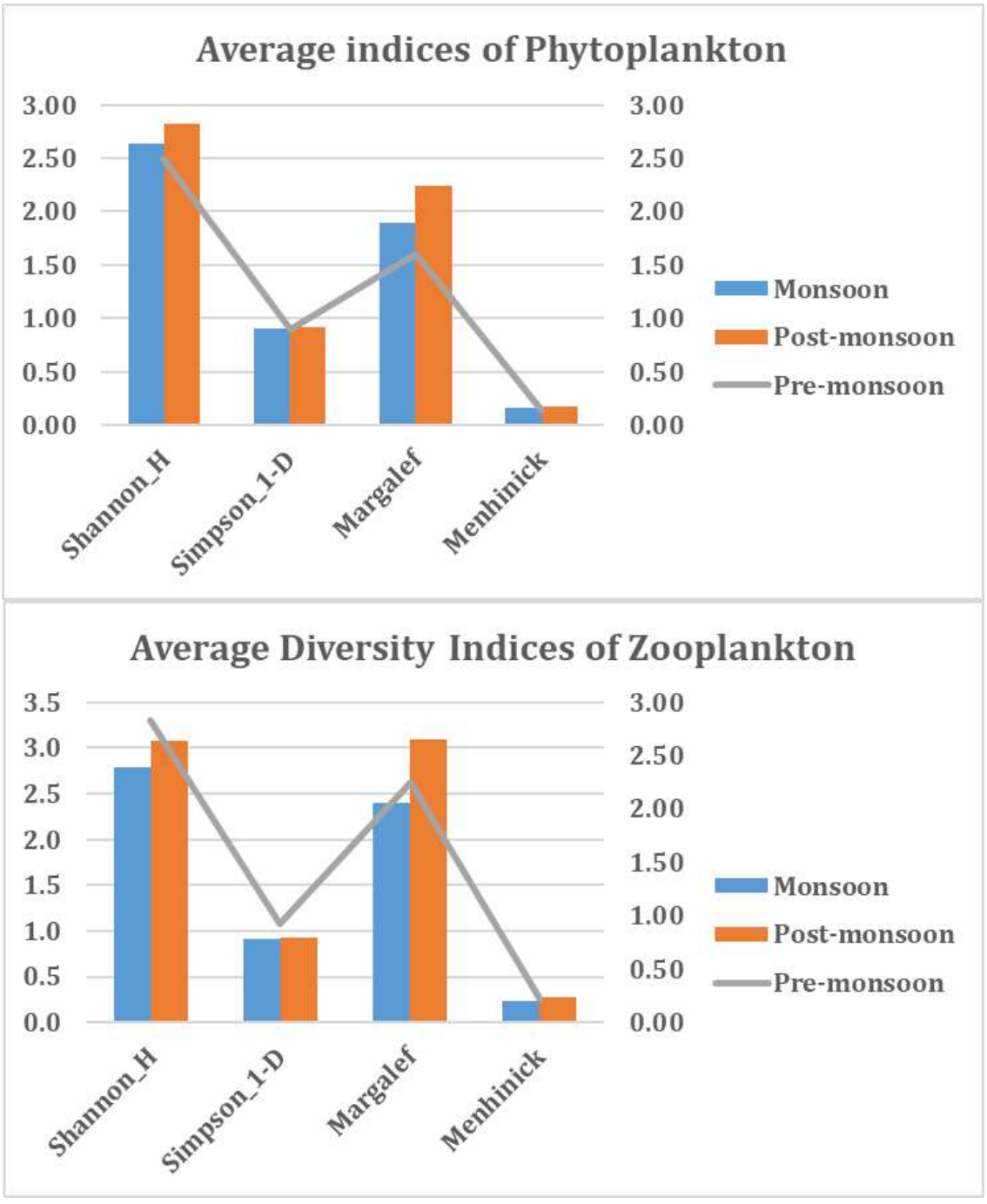


Figure 59 Diversity indices of Phytoplankton and Zooplankton

As per Shannon Wiener's rules the aquatic environment i.e both soil and water classified as very goodwhen H' value is greater than four (>4), whereas the good quality represents the H' value with a range of 4-3, similarly moderate-quality (H' value 3-2), poor quality (H' value 2-1) and very poor-quality H' value significantly less than one (<1). Presently DPA port and its periphery environment has been influenced by contaminants deposited from industries and the cargo movements. Accordingly, species diversity decreases at sites with poor water quality. As deduced from the Shannon diversity index values between 3-4 overall 3 season representing the moderate quality of environmental status dominated by the few genera such as Coscinodiscus sp. and Synedra sp,and copepod sp. A community dominated by relatively few species indicates environmental stress (Plafkin et al., 1989). According to Staub et. al (1970) species diversity index value between 3.0 to 4.5 represents slightly polluted and the lightly polluted environment, the index value characterizes 2.0-3.0, similarly, moderately polluted environment shows index value of 1.0-2.0 and finally, the heavily polluted environment index value is 0.0-1.0. While considering the overall index values it is inferred that the study sites can be included under the category of lightly polluted environment.Natural geographical processes such as strong currents and higher tidal influence have been responsible for the high turbidity and suspended solids which in turn reduce the light penetration thereby reducing the growth of Plankton and primary productivity.

Intertidal Fauna

Macrofaunal communities did not show much spatial and temporal variation in their components at 15 sampling locations. The distribution of intertidal Fauna seems to be entirely governed by the environmental parameters like Physico-chemical and biological characteristics of the ambient milieu. Generally, intertidal Fauna on the Kachchh coast scope a harsher environment with relatively high salinity, wide temperature fluctuations, seasonal fluctuation of different hydrological parameters and a high sedimentation rate. The water suspended solids (SS) were generally found due to the dispersion of fine sediment from the bed and the intertidal mudflats due to tidal movements at the mouth of the Kachchh coast (Kandla).

An earlier study by Saravanakumar et al. (2007) revealed the presence of five intertidal Fauna in the mangrove environments along the Kachchh coast, with a diversity index such as Shannon_H, Simpson_1-D, Margalef and Menhinick ranging from 1.84 to 2.45 in 2023 to 2024 at present from may 2024 to may 2025 it is 0.77 to 1.66. The species composition and diversity indices reported during 2018-2019, 2019-2020, 2020-21, and 2021-2022 2022-2023 and 2023 to 2024 did not vary significantly in the DPA port environment. It was understood that the intertidal fauna community in the Kachchh mangrove had not varied much in terms of its species diversity. An earlier study by Saravanakumar et al. (2007) revealed the presence of five intertidal Fauna in the mangrove environments along the Kachchh, with a diversity index ranging from 1.84 to2.45. During the 2023 to 2024 average Shannon diversity indices varied from 1.51 to 1.6 similarly the Margalef and Simpson indices ranged from 1.43 to 1.5 and 0.7 to 0.73 and similar patter the index value also run parallelly (Fig. 57). According to Magurran (1991), the Shannon diversity index of >3.0 indicates a healthy coastal environment. However, diversity indices around the DPA coastal environment were <2.0, indicating that the lower moderate faunal diversity.In the present observation, the species composition of the benthic macrofauna showed dominance in the Phyla Molluscs, Arthropoda, Annelida, Nematoda, Nemertea and Chordata. Previously, Ansari et al. (1986), Mohammed (1995) and Kumar (2001) recorded the presence of the Molluscs, Arthropoda, Annelida, and Chordata in various parts of Indian coastal waters.

Subtidal Fauna

The Shannon diversity indices ranged from 0.65 to 1.77, similarly Margalef and Simpson indices ranged from 0.75 to 2.18, 0.35 to 0.80 during 2023 -2024 . The results obtained from this study represent and the indices such Shannon_H,Simpson_1-D, Margalef, and Menhinick reflect similar moderate to lower environmental status for the period 2024-2025 (Fig.61). There is a need for an in-depth study of Fauna and their interactions in mangrove ecosystems. Also, practices directed at managing mangrove resources should go hand in hand with conservation strategies.Mahapatro et al. (2011) documented the macrofaunal diversity in Bhitarkanika (Odisha coast) mangroves, and the diversity ranged from 1870 No/m2. Ramakrishna et al. (2011) recorded the population structure and density of macrofaunal from the Andaman and Nicobar Islands and documented diversity from 1015 No/m2 in the. In the Gulf of Katchh, Saravanakumar et al. (2007) documented that from 1999 to 2000.

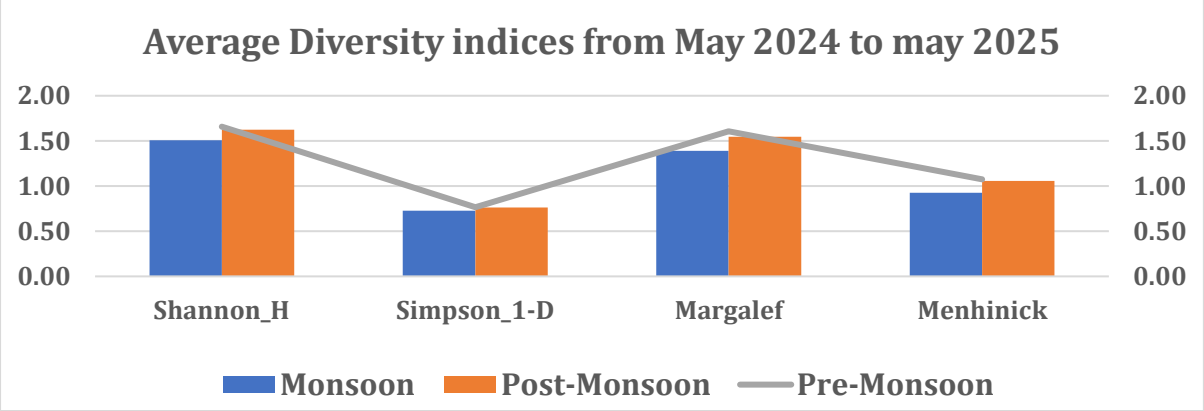


Figure 60. Average diversity indices of intertidal fauna of DPA

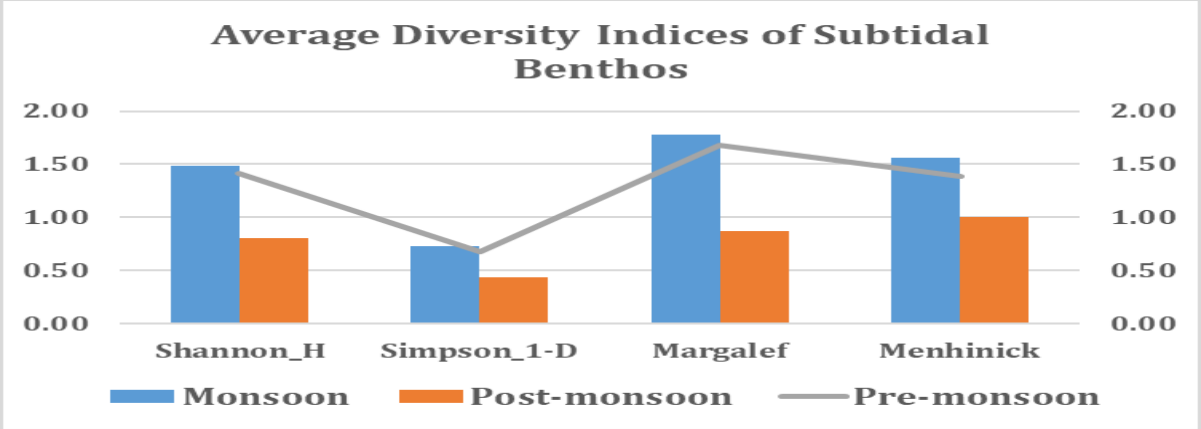


Figure 61 Average diversity indices of Subtidal fauna of DPA

6. Impact identification and Evaluation

The Deendayal Port, Kandla, in Kachchh district is surrounded by a large number of port associated industries and salt pans and salt processing industries. There are a number of minor and creeks that are connected to the Gulf of Kachchh. The DPA has been the prominent industrial and transport facility primarily associated with the inter connected creek environment which influences the open oceanic zone. The adjacent marine zone is well known for the multitude of the biological resources however, the very sensitive ecosystems like coral reefs, sea grass meadows and salt marshes are not found within the 10 km radius of the DPA port Jurisdiction, and the direct impacts are not experienced.

The general consequences of the port associated activities, particularly on the free-floating microscopic animals and plants, the macrofauna inhabiting the sub-tidal and Intertidal habitats and the birds have been well known, in this respect it is imperative to analyze the major impacts and to put forth effective mitigation measures.

Routine dredging Impact

- Dredging and dredge spoil disposal activities for port development and maintenance can induce short and long-term impacts on aquatic systems, namely degradation of marine resources such as fisheries and other aquatic biota.
- Dredging activities often disturb sediments reducing visibility and transparency of water.
- Dredging activities potentially affect not only the site itself, but also the surrounding areas, through a large number of impact factors such as turbidity, sedimentation, resuspension and release of contaminants which can be within the site or to the nearby area on a temporary or over a long period.
- **Impact on Air quality of the Port premises**
- Emissions from burning waste materials and the escaping dust particles due to handling of fine-particulate materials such as fertilizers and minerals causing air pollution in port areas.

Impact on Avifauna

Impact-I Location of the Deendayal port site in the close vicinity of the ecologically sensitive terrestrial ecosystem (migratory route, breeding and nesting sites of avifauna)

may impact the overall biodiversity values due to the project associated activities such as A. Habitat degradation due to pollution

B. Loss of habitat and population of faunal groups

C. Overall impact on biodiversity of the protected area

Evaluation: The Deendayal SEZ project site located in the mid of the Deendayal Port area surrounded by port associated industrial sectors, predominately salt industries. There is no any ecologically sensitive ecosystem (Protected Areas) located within 10 km radius of the project site. Due to the prevailing land use no impact on protected areas was foreseen. Further the study area also not reported any migratory route of major animal groups, nesting and breeding sites of avifauna.

Impact on threatened flora and Fauna – Inter-tidal coastal habitat.

Impact 2: Direct loss of inter-tidal habitat like mangrove and saltpan will impact the threatened floral and faunal species existing within it due to; Loss of inter-tidal habitat (mangrove) and degradation due to project associated activities will overall population status of threatened aquatic avifauna.

Evaluation: As per land use land cover study, the project area dominated by intertidal habitats like, Mangrove, creeks and salt pans. The study area reported total 5261 birds belong to 64 species (Annexure 1). However, this list includes only five species *viz.* Painted Stork *Mycteria leucocephala* (Pennant, 1769), Black-headed Ibis *Threskiornis melanocephalus* (Latham, 1790), Glossy Ibis *Plegadis falcinellus* (Linnaeus, 1766), Black-tailed Godwit *Limosa limosa* (Linnaeus, 1758) and Eurasian curlew *Numenius arquata* (Linnaeus, 1758) are under the Near Threatened (NT), whereas, River Tern *Sterna aurantia* (Gray, JE, 1831) is under vulnerable (VU) categories of IUCN Red List of Threatened Species. Moreover, four species (6.25%) River Tern *Sterna aurantia* (Gray, JE, 1831), Common Greenshank *Tringa nebularia* (Gunnerus, 1767), Black Kite *Milvus migrans* (Boddaert, 1783), Gull-billed Tern *Gelochelidon nilotica* (Gmelin, JF, 1789) and Shikra *Tachyspiza badia* (Gmelin, JF, 1788) were under the Schedule I of Wildlife Protection Act, 1972 (amendment 2022).Since the study area beyond 5 km supports large extent of similar (Inland wetlands and Salt pans) habitat types and supports large number of aquatic birds, the overall impact on few aquatic threatened avifauna reported in the study area would be minimal (Annexure 1). In spite of that, implementing, proper mangrove plantation activity can take care of this minimal impact. Further, no endangered aquatic birds reported in the study area.

7. Mitigation

Adopting mitigation techniques for reducing the carbon concentration in the atmosphere through green belt/plantation, conservation of water and energy in the agriculture and several production sectors have been very much familiar. Various other considerations to control air and water quality in the port and influencing environment have been suggested and implemented in many states. Depending on the physical and chemical characteristics of the dredged material, disposal may be confined, unconfined or treated prior to release in open water, along the shoreline, or on land. Ultimately, EMMP acts as a comprehensive manual for environmental protection, reduction in carbon (GHG) emission and finally it helps in converting major ports into "Green Ports". The ultimate goal of a Green Port Plan program is to achieve long-term environmental, societal and economic benefits through resource conservation, waste reduction and pollution prevention. The Green Port Program unifies the Port's environmental sustainability goals (in many key areas) by way of setting measurable goals and evaluating progress in each area on an annual basis.

Pollution control

The major health impacts of pollution from ports are related to the gaseous and particulate emissions arising from the combustion of petroleum products and coal leading to various respiratory tract diseases, cardiovascular disease, lung cancer and also climate change related issues. Petroleum contamination is a very common problem these days arising from leaking tanks, oil spill, and gas into the surrounding water and soil and takes long time for reclamation by bioagents or physical and chemical treatments. A process called thermal soil remediation helps in the remediation of contaminated soil which can be reclaimed and reused by this method.

The possible soil contamination due to spillage of oil residues, petroleum products, cement, paint, plastics, non -degradable solids etc. are to be handled effectively by scrupulous preventive management guidelines. The laborer and officials should be aware of the extent of damage they can bring on the ecosystem and in turn to human as well through the process of biomagnification through the marine food chain. In this regard any potentially contaminated soils from construction activities must be handled,

transported and disposed off in accordance with the Environmental Management Act (EMA) and its Regulations of Government of India.

Afforestation

The port authority should take up plantation of various kinds according to the space, soil types and water availability. Also, it is utmost necessary to carry out promotion compensatory mangrove and associated vegetation plantation along the shoreline at the suitable tidal level with the common species. The development such green belts surrounding the whole project area will enhance the integrity of the ecosystem and provide ecological and economic services at large on a long and regular basis. The plantation needs to be carried out with higher density of seedlings to realize high survival rates and growth performance considering the past experiences in the coast and the type of natural stands existing along the shores of the creek system as well.

Mangrove plantation

The Green Port Program is an umbrella program designed to achieve the Port's environmental sustainability goals by adopting appropriate afforestation programs to develop large green belt areas at all prospective locations. The afforestation would not only contribute to the aesthetics but also would serve as a 'sink' for the pollutants released from the station and would thereby protect the quality of ecology and environment in and around the projects. Green belt will help in supporting the biological diversity, controls soil moisture, erosion control and coastal protection, increase the rate of ground water recharge and act as carbon sink to reduce climate change. Green cover interventions capture the fugitive, attenuate the noise, subside the particulate matter in the air and reduce the temperature in the surroundings. The mangrove plantation is expected to support the avifauna diversity of the local environment. It is recommended that construction activities to be restricted during the non-migratory season of the birds (November – February) to avoid disturbance to the migratory species as the Kachchh wetlands serve as major wintering grounds, located in the major central Asia fly way. Since the intertidal zone of the creeks comprising the mangroves and salt pan habitats support many benthic fauna including finfishes and shell fishes, aquatic and terrestrial migratory birds, the protection of these productive environments is very much essential for the restoration of the biodiversity and the livelihood of the fishermen. The above

suggested mangrove plantation needs to be monitored for the next five years till it attains maturity and later on evaluation of the ecosystem and economic services rejoiced by the community in view of the evolving climate change related issues. The monitoring of the mangrove and coastal zone should include the study of species composition, population characteristics, growth rate of plants, abundance of the flora and fauna in order to estimate the diversity and health status at every season of the entire environment.

Soil erosion control

Shore line substratum erosion is a major threat to the intertidal habitats in DPA port jurisdiction. Often the rate of erosion is severe in the port environment due to the continuous vessel movement and the churning effect induced hydrological regime and other natural causes. During the present study it was noticed that few creeks stretch in Kandla are susceptible to erosion due to high water currents and tides. The dual purpose of controlling erosion and promoting intertidal biodiversity could be best achieved by installation of artificial reef structures, limestone rocks, laterite, cement and granite as well as bio reefs. Artificial coastal structures are cheap and installation is easy and adaptable and for better results it can be supplemented with the addition of a substrate that will support marine organisms as that of the natural intertidal and sub tidal environment. The structural diversity of the artificial reef will determine the diversity of marine organisms utilizing the created habitat. Artificial reefs once built will last for decades and would enrich marine biodiversity in a short period of time by providing ideal habitat for sessile and free-living benthic organisms and their larvae. Natural materials such as dead shells can be used for building artificial reefs and are environment-friendly. Reef balls are another form of artificial reef increasingly used in western countries to create sustainable marine reef habitat which may be easily attempted at Deendayal port Areas. Both reef balls and artificial reefs being inexpensive and locally available, can be built in different creek systems of the port jurisdiction. Application of coir mats are also suitable to control the shoreline erosion in the mangrove patches and open shore in conjunction with the rocky and cement structures.

Phosphate mitigation

- Optimizing fertilizer and detergent application in the households and industries
- Creating awareness among the stakeholders
- Planting perennial crops or crop rotation to avoid bare fields, which experience higher erosion and phosphate runoff.
- Planting trees and shrubs around fields to absorb excess nutrients.
- Restricting runoff from livestock rearing areas and maintaining treatment systems for sewage
- Bioremediation methods to be adopted for the removal phosphorous in agriculture and waste water.
- The most reliable and most frequently applied removal process is chemical phosphorus precipitation by addition of metal salts. Dissolved phosphorus is converted to solids which are removed from the waste water together with the sludge.
- The decay of the organic material produced by photosynthesis under aerobic conditions again results mainly in mineral phosphorus compounds in the sediments with low availability. Under anaerobic conditions decomposition process results in the release of phosphorus in dissolved and therefore easily accessible form.
- By precipitation with calcium cations manifold reactions are known, which are hard to predict. High phosphorus removal efficiency can be achieved at pH-controlled crystallisation of calcium hydroxyapatite which has a very low solubility product.

8. Conservation and Management Plan

Conservation of biodiversity is considered as the key component for administration of natural assets. Biodiversity is an all-encompassing concept that describes the magnitude of ecological diversity addressing the wide range of life associated with different types ecosystems. Biodiversity conservation is the protection and management of the biotic ad abiotic resources for sustainable development and existence and preservation of the diverse species, Sustainable utilization of species in the ecosystem along with the maintenance of the life-supporting systems are essential for the functioning of the various ecological processes. It is an integral part of any commercial activity and infrastructure development in the marine environment. Emphasis is given towards the reinstatement of the physical, chemical and biological characteristics of the coastal ecosystem which are much complex and vulnerable on which the human is highly dependent. Management of the marine biodiversity is the prime concern in the development of Ports and harbors which occupy the fragile continental shelf which is highly productive and harbors numerous living resources. Hence Environmental Management Plan (EMP) is considered as an important component in any developmental activity with sustainable management goals which are to be fulfilled within a time frame. Thus, EMP aims to suggest concrete measures that would mitigate the impacts paving way for maintaining the integrity of the project environment.

Development of ports involves effective management plan towards environmental wellbeing that guarantees both sustainable port growth and a healthy ecosystem functioning in its vicinity. There is a need for innovative solutions for port development which are in harmony with the ecosystem and which are robust or adaptable under change. The recent trends like growth of global trade, increasing vessel movements and size, modernize port facilities, driving urgent investments in ports have been found negatively impact water quality and marine flora and fauna. This simultaneously calls for sustainable and inclusive development which ensures productive nature of its marine environment.

The port authorities mandate to their activities environmentally sustainable and benign need to understand the marine ecological setting of their ports including water quality, biotic components and the factors that impact them. In spite of all the pressures, the ecosystem continues to deliver many services which are often intangible. In order to maintain these services intact, it is imperative that different biotic and abiotic components of the port environment are to be sustainably managed in the long run.

Accordingly, Deendayal Port has initiated several environmental management measures as mandated by the MoEF &CC from time to time with the purpose of maintaining and preserving its terrestrial and coastal environmental integrity.

The following measures have been taken by the port authorities:

Ongoing Environment Management Measures by DPA

A holistic and comprehensive study on the marine ecology of the port including different marine faunal and floral components and preparation of a management plan based on the results obtained has been initiated as per the specific condition No. xviii of the EC & CRZ Clearance accorded by the MoEF & CC, GoI dated 19/12/2016. The results of the seasonal observations on the environmental characteristics and biodiversity of the intertidal zones have been compiled along with the conservation plan recommendation for three consecutive years (2017 to 2021). Mangrove plantation has been carried out to the tune of 900 ha in Sat Saida Island, 150 ha in Nakti creek, 450 ha in Kantiyajal by Deendayal Port. The black mangrove Avicennia marina was used in these plantation activities as this species is more suitable to the existing environmental condition of this coast.

Based on the information gathered through the seasonal studies on the different biotopes and the biodiversity along with the mangrove, macrofauna, plankton density and diversity, productivity of mudflat and avifauna for the period 2018-2022 within the limits of the Deendayal port, it is evident that the impact is insignificant since management action plans are showing positive responses to a large extent in spite of the climate change induced impacts on the marine

ecosystem. This project aims to draw a holistic management framework for conserving the Marine Biodiversity and Ecology of the DPA port marine environment which include many biotopes such as mangroves, intertidal and subtidal realms, mudflats and salt marshes, each serving as an abode for a variety of fauna and flora. Given the economic importance of DPA port and the increasing national and global demand for sustainability, it is planned to study the marine ecology of this port seasonally, with the long term objective of rendering the port existence and operations environmentally sustainable. The proceeding section outlines management initiatives to be undertaken by the port authorities for holistic management of marine biodiversity within the port limits envisaging several facilities will be built within port premises in the future.

Intertidal and Subtidal Biodiversity Management

The intertidal zone constitutes the coastal environment where land and sea meet, i.e., the area between extreme high-water springs (EHWSs) and extreme low water springs (ELWSs). The subtidal zone lies below the lowest water level beyond the intertidal zone. Both these zones provide habitats for various marine fauna and flora and needs to be managed effectively for the overall wellbeing of the ecosystem. In addition, intertidal zone biodiversity index did not vary very much in the recent years but the population density has not increased and remained stable. The intertidal zone may be susceptible to natural and anthropogenic pressures such as soil erosion, industrial pollution, continuous dredging and sedimentation. Hence, interventions are required to mitigate or support the natural recovery of the fauna in the bottom sediment. The sedentary benthic species produce a large number of their larva as an adaptation for their survival which get attached to the mangrove surfaces and metamorphose into adults and also serve as food for several fishes and shellfishes. Hence, soil erosion control interventions could help to improve the restoration of many benthos and plankton productivity. In the DPA vicinity, intertidal and subtidal zones are mostly dominated by clayey substratum admixed with silt and there are no rocky or sandy

shores. The intertidal belts of the study area support many biological elements indicating the overall health of the ecosystem.

Mangrove Management

The mangrove cover in the vicinity of DPA is 23.967km^2 encompassing the major and minor creek systems within its limit of which the port infrastructure occupies only ~1% of the total area. Establishment of facilities is a continuous process and the expansion of infrastructure over the coming years will bring remarkable changes in the landscape and seascape in and around the port area. Mangrove environment will continue to be stable and balanced if there are no external stressors such as change in hydrology, elevation and slope, soil and water salinity and pH, soil texture and wave energy are maintained in a natural condition without wide fluctuations. In addition, human centered stress factors such as resource collection, camel grazing, tree felling and other habitat modification activities are to be minimized. Generally, micro-topography controls the distribution and well-being of mangroves, and physical processes play a dominant role in the formation and their functioning through reproduction, seed germination and establishment of young plants. The mangrove forests undergo self-repair over a period of time, provided that the normal tidal hydrology is not disrupted and the availability of water borne seeds are not blocked. Regular monitoring of mangrove hydrology through simple scientific methods will go a long way in maintaining ecosystem balance. The natural regeneration capacity of the stand is to be assessed by quantifying the degree and extent of the entrance of younger classes such as saplings into the mature tree category. The ratio between these different size classes will indicate the dynamic state of the mangrove forest. Only if the natural seedling recruitment is not occurring does the system requires an assisted recovery by plantation and physical amendments. The present study displays that natural regeneration in the studied mangrove formations is expected, as indicated by the entry of younger classes into adult categories. In addition to *A. marina,* three species namely, *Rhizophora mucronata, Ceriops tagal* and *Aegiceras corniculatum*, have been recorded sporadically within DPA limits. It is strongly recommended that in all the future plantation efforts, these additional species also could be selected at appropriate locations and tidal levels.

Conservation of Island

Islands support a rich marine fauna, flora and avifauna diversity and deserve special conservation efforts. Land cover classification of Sat Saida Island using GIS tool revealed sparse and dense mangroves, mudflats and halophytic vegetation other than mangroves are other prominent land cover categories. Though equipped with all the features to support a dense mangrove formation, the Sat Saida Island has sparse and scrubby plants confined mostly to creek banks. Different elevation features of the Island render the reduced flooding rate at the interior regions results in sparse and open mangrove formations. This Island could be an ideal site for mangrove plantations while implementing plantation activities, other mangrove restoration and rehabilitation activities with biophysical amendments such as desilting the existing the minor creeks could help to increase the mangrove cover in this Island. These physical activities in the mangrove lined minor creeks will increase tidal flooding and hydro-period and convert sparse to dense mangroves in due course of time. The Deendayal port authority has already carried out 1400 ha of mangrove plantation since 2006 with good success rate in various locations and additional 100 ha is in progress.

Management plan to improve the water quality in the port area

- The drains and outfall should be cleaned regularly to avoid anaerobic decomposition and also for proper flow of water/wastewater. This will also enable the characterization of wastewater and calculation of waste load.
- Domestic and canteen wastewater should be discharged only after proper treatment.
- The solid waste generated from the canteen and other diffused sources should be collected and disposed properly for which modern purification system should be established.
- The discharge of oil waste into the sea from the following main sources should be controlled
    1. Discharge of oil waste from liquid chemical corridor area. This liquid waste is generated during tanker cleaning, and oil spills during filling operations,
    2. Oil spills at berth during unloading operations.
    3. Tanker ballast discharge from ships.
- Bulk material should not be disposed into the sea. All drains and roads should be cleaned before the rainy season to avoid runoff from land to sea carrying a myriad

of pollutants, including chemicals that may be impose oily discharges in and around the port.

Management plan for marine fisheries

Regular dredging activities in the Port area can impact marine fauna and the flora particularly the phytoplankton and seaweeds. The fishes and other fishery resources such as shrimps and crabs are distracted through noise and vibration levels, water quality and habitat loss along with food sources. Generally, fishes in the water column are free swimming in nature, they tend to avoid the turbid areas and move to safer zones. Once the turbidity increase becomes reversed due to sedimentation and dispersion by current and wave influences, the fishes are expected to occupy the area. Hence, there will be virtually no impact on fish due to dredging in the long term. The dredging is usually carried out on the main channel of the creeks, the impact on the fishes are minimum during the dredging phase. The most important potential impact would be the rise in suspended solid load, which hinders the photosynthesis of the producer communities, especially the phytoplankton and affects the pelagic food chain. The high turbidity due to heavy suspended solids load during dredging and reclamation can result in the clogging of the gills of the filter feeding organisms, thereby causing asphyxiation.

Co-Management with the Community

Management program for mangroves is feasible in the case of Deendayal Port Authority since all the mangrove formations are under its legal control and hence any management program could be implemented without any sectoral conflicts with forest or any other government departments. It was proven in many instances that involving the stakeholder communities in the surrounding villages will yield better results in mangrove management. Though the population in the port surroundings has different livelihood activities, fishermen community could be targeted to involve in community-based mangrove management.

The fishermen in the villages such as Vera, Khari Rohar, and Tuna close to the port could be involved by forming “Samithies” for the conservation of mangroves with possible funding resources. The communities are expected to involve in the plantation and management activities for which awareness campaign and interactive sessions are to be conducted time to time and the feedback and experiences are to be recorded and duly acknowledged. The community’s resource dependency, perception about the conservation of mangroves and associated flora and fauna and their level of involvement

in such resource management activities are to be assessed before forming such a community-based organization. They could be assigned the specific task of conserving the mangroves by involving them in plantation/restoration activities, physical protection and other conservation measures. This could be taken up as part of the port's CSR activity.

Mannagement plan for Avifauna

1. Direct and indirect impact on ecologically sensitive ecosystems

The Deendayal SEZ project site is located in the mid of the Deendayal Port area surrounded by port associated industrial sectors and salt industries. Since there are no Protected Areas located within 10 km radius of the SEZ site, impacts on sensitive ecosystem was not visualized.

2. Loss of Inter-tidal habitats - Coastal

- The project proponent (Deendayal Port Authority) should take up compensatory mangrove plantation in and around the project area
- The plantation needs to be carried out with fourfold density of seedlings compared to the natural mangrove density of the Kandla creek area and to maintain the density at the required level
- This mangrove plantation expected to support mangrove associated bird species and thereby enhance the avifauna diversity of the local environment
- Since the intertidal (mangrove and creeks) and salt pan habitats supports few thousands of aquatic and migratory species, the project proponent should plan the establishment /construction activities (if any) should be planned non migratory season (November – February) to avoid the disturbance to the migratory species.
- The above suggested mangrove plantation needs to be monitored at least for the next five years till it attains maturity with the expert team to understand the growth rate and enhancement and assemblage of associated faunal species.
- Since the area located in the Intertidal habitat and adjacent areas supports thousands of aquatic avifauna, the project proponent (Deendayal Port authority) should take up long-term (five years) Ecological Monitoring Program of the creek, mangrove and salt pan habitats to assess the change in avifaunal diversity due the any developmental activities take place in the future project.

Phosphorus management

Anthropogenic inputs of nitrogen (N) and phosphorus (P) from agriculture, aquaculture, wastewater treatment, urban runoff, and burning of fossil fuels, are now reported to exceed the natural inputs worldwide (CENR, 2000, NRC, 2000). The nutrient enrichment has led to deadly blooms of phytoplankton and seaweeds, coral reef deterioration and altered ecosystem functioning. As marine ecosystems continue to experience land use change, rising sea levels, altered weather patterns, and global warming, the threat of nutrient enrichment is predicted to intensify.

It is understood that mangrove wetlands can alleviate nutrient pollution through rapid nutrient uptake, long-term burial, or denitrification, thus protecting surrounding marine waters and organisms (Valiela and Cole, 2002). However, coastal wetlands themselves are still vulnerable to the impacts of nutrient enrichment. In this circumstance studies have reported that due to high rates of nutrient uptake and denitrification, nutrient enrichment can have direct and indirect impacts on mangrove trees (Kaplan et al., 1979; Seitzinger, 1988).

The blue-green algae (Cyanobacteria) blooms are predominantly), tend to grow in high density under situations of low ratios of nitrogen to phosphorus. numerous long-term studies have pointed out that reducing inputs of a single nutrient: phosphorus could control the incidence of algal bloom and also by introduction of iron, alum, or other compounds to sequester phosphorus in sediments. This management is possible in inland water bodies.

In creeks and coastal environments, the water is dynamic in nature mitigation measures are in general impractical. It is recommended that it is necessary to identify the possible primary sources of input and to control awarenessdrive are to be implemented to the concerned community, industries and the government bodies.The influx of sewage ,land run off from the cropland and the industries are major sources of phosphorus/phophates into aquatic systems. Traditional wastewater treatment methods do not fully remove phosphates, leading to their accumulation even though modern filtration technologies can effectively eliminate phosphates which are expensive. Many countries have imposed strict regulations on the use of phosphate-containing detergents and implemented laws to reduce phosphate pollution.

Phosphates are salts of phosphoric acid formed with the reactions of metals and there is dihydrogen phosphate that dissolves in water while the hydrogen phosphate is less

dissolution in water. In water, phosphorus exists in the form of inorganic, organic, and organo-mineral compounds and is also part of the cells of aquatic organisms. Notably, inorganic compounds have the highest bioavailability. Today, phosphates in marine and freshwater systems present a significant environmental challenge. Human waste is a natural source of phosphorus. In this context it is understood that improper sewage treatment could lead to higher level of phosphate-phosphorus in the coastal water bodies. These effluents contain biological phosphorus as well as phosphate components from detergents, food products, etc. When phosphorus and nitrogen levels in water become excessive, microorganisms receive more nutrients, leading to rapid reproduction. This process, known as eutrophication, reduces oxygen levels, kills fish, and makes water treatment more complex due to the increased biomass.

Petroleum hydrocarbon Management

Increasing petroleum consumption and a rise in incidental oil spillages have become global concerns due to their persistent nature and toxicity to aquatic and terrestrial living organisms. Various physicochemical and biological treatment strategies have been studied to tackle them and their impact on environment. Combinations of biological, chemical, and eco-toxicological techniques are used for this process while monitoring the efficacy of bacterial products and nutrient amendments to stimulate the biotransformation of contaminated soil. One of such approaches in this regard in the marine environment is the use of microbial processes due to their being “green” and also apparent low cost and high effectiveness. Different hydrocarbon removal levels were observed with bacterial augmentation (*Beta proteobacterium* and *Rhodococcus ruber*), exhibiting a total petroleum hydrocarbon (TPH) reduction of 61%, which was further improved to a 73% reduction using bacterial augmentation combined with nutrient amendment (nitrogen, potassium, and phosphorus). Mixed bacterial consortia isolated from the hydrocarbon-contaminated soil samples were used

Chemical treatments suggest agents like dispersants, solidifiers, and chemical oxidants are the remediations are grouped. The surfactants present in dispersants help to break down oil slicks into smaller droplets,then undergo rapid dilution by transferring it into the water and are degradable. This method makes oil spills less harmful for living organisms and the marine life. Nokomis 3-F4, Slickgone NS,Finasol OSR 52, SPC 1000™, Neon AB3000, ZI-400, Corexit 9500, Corexit 8667, and Saf-Ron Gold are some of the examples of chemical dispersants.

Bioremediation is a cost-efficient method used for the treatment of petroleum consisting of biodegradable hydrocarbons and indigenous microbes. Biological techniques are more economical and proficient than physicochemical techniques.. Three distinctive approaches are adopted in the context of bioremediation, namely, bioaugmentation, biostimulation and bioventilation. Bioaugmentation is used to enhance the performance of the microbial population through the addition of bacterial with specific catabolic activities, strains or enrichment consortia to increase the rate of contaminant degradation.Many microorganisms are responsible for increasing the surface area of the substrate by excreting emulsifiers including *Bacillus licheniformis, Pseudomonas putida, Bacillus cereus, Pseudomonas aeruginosa, Bacillus subtilis,* and *Bacillus laterosporus* are well known for degradation of oil pollutants. The water should maintained be suitable for the normal growth of the oil degrading microbes so that by natural processes by itself the PHCs will be degraded under with time.The biodegradation rates are improved by the biosurfactant's addition which increases the elimination and solubility of these pollutants.

It is recommended that proper measures should be taken to avoid the introduction of petroleum related products from the ports, during the loading and unloading of consignments , navigation channel maintenance and such activities.

9. Summary and Conclusion

The physico-chemical characteristics during the entire year was dynamic with respect to sptio-temporal situation in the gulf environment. The phytoplankton genera for the period May 2024 to May 2025 varied from 8 to 29 number with an average of 16-23. The highest number of genera was reported during post-monsoon which is followed by monsoon and pre monsoon. The Zooplankton for the period 2024 to 2025 showed high number of representatives of phylum and group during post-monsoon followed by pre-monsoon than the monsoon period.

It is imperative to create strong baseline data on the marine environment in the port vicinity in tune with the spatial extent of developmental activities. Continuous marine ecological monitoring study since May 2017 focused on the biological diversity and productivity of the mudflats. Based on the detailed investigations of marine ecological components and the possible impacts of the DPA port environment, it could be concluded that the effects on the various biotic components are minimal and confined to high activity areas only with limited impacts on the surroundings. From the results of the studies conducted by GUIDE, 2017 to 2024, it was inferred that there was no significant variation with respect 2024 to 2025 on the taxa/genera/species composition as well as fauna and plankton community, eventhough the values of and in term of phosphate and petroleum hydrocarbon compounds were slightly increased. The mangrove tree category density has shown higher values in all the sampling locations in the Deendayal port Authority and its creek environments.

In this respect it is recommended that In addition to the monitoring of the biological parameters, of the water and sediment in the creeks, petroleum hydrocarbons and phosphate level in the port environment to be assessed intensively in future in order to sort out the more effective management plans in the mangroves and the encompassing creek environment nearer to the Deendayal Port Authority .

Knowledge of marine species diversity is incomplete, however, studies have highlighted an increase in the rate of decline in the population density of many vulnerable species with space and time due to several reasons including habitat destruction and alterations and the related stresses. The biodiversity of the coastal zone has been explored more extensively than the deep offshore areas due to the accessibility for sampling. These areas

are considered to be highly productive due their shallow and dynamic nature suitable for the growth of the flora , phytoplankton, seaweeds and sea grasses. The, bio-geochemically more active zone provides all the major,minor and trace elements for the floating micro flora as well as the macroscopic algae and sea grasses that flourishes in the nearshore environments. The abiotic physical and chemical parameters of the water in all the study sites are found to be within the optimum level during the seasonal assessment. The prevailing higher turbidity of the water due to the high tidal currents inhibits the primary productivity of the phytoplankton and the benthic algae and seagrass. However, there exists several diatoms which have higher adaptive features to survive under such circumstances as evidenced from the present study. There are indicator species to assess the biodiversity status of ecosystems, the keystone species, such as the coral reefs, sea grasses and macro algae which are specific for the benthic habitat. These groups of plants and the fauna require clear water, optimum temperature aided through the high rate of light penetration through the water column. The absence of the seaweeds and seagrass beds could be well correlated with the relatively high level of suspended particles in the water in the selected study sites. The sediment entire creek environment bottom substratum is dominated by fine clay which holds organic and inorganic elements and acts as a sink for essential nutrient elements for the multitude of micro algae which are the primary source for the pelagic and benthic food chain, including the fin fishes and shell fishes in the creek as well as the nearby oceanic zone. The concentration of petroleum hydrocarbon at some locations is higher than the admissible level in the coastal waters. This chemical compound is highly hydrophobic in nature and tends to attach to the surface film of the water. Though the degradation is a slow process it has been distributed to longer distances and tends to settle down as tarballs. Also, the residues if such particles persist for longer duration, affects the pelagic communities and ultimately the fishes and higher vertebrates. In the Kandla adjacent creek complex such incidents have not been reported and fishing is a regular activity in the mangrove environment by the fishermen who have a valid registration from the port Authority.

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Annexture 1. Checklist of Avifauna recorded during the pre-monsoon season from the Deendayal Port Authority, Kandla, India.

Sl. No.	Order, Family, Common & Scientific Name	MS	FS	IUCN 2024	WPA, 1972	Habitat
A	**CHARADRIIFORMES**					
1	**Charadriidae**					
1	Little ringed plover *Charadrius dubius* Scopoli, 1786	R	C	LC	Schedule II	A
2	Red-wattled Lapwing *Vanellus indicus* (Boddaert, 1783)	R	I	LC	Schedule II	T
3	Yellow-wattled Lapwing *Vanellus malabaricus* (Boddaert, 1783)	R	I	LC	Schedule II	T
2	**Dromadidae**					
4	Crab-plover *Dromas ardeola* Paykull, 1805	M	C	LC	Schedule II	A
3	**Laridae**					
5	Common tern *Sterna hirundo* Linnaeus, 1758	RM	P	LC	Schedule II	A
6	Little tern *Sternula albifrons* (Pallas, 1764)	R	P	LC	Schedule II	A
7	River Tern *Sterna aurantia* (Gray, JE, 1831)	R	P	V	Schedule I	A
8	Caspian gull *Larus cachinnans* Pallas, 1811	M	P	LC	Schedule II	A
9	Lesser black-backed gull *Larus fuscus* Linnaeus, 1758	M	C	LC	Schedule II	A
10	Black-headed Gull *Chroicocephalus ridibundus* (Linnaeus, 1766)	M	O	LC	Schedule II	A
11	Brown-headed Gull *Chroicocephalus brunnicephalus* (Jerdon, 1840)	M	P	LC	Schedule II	A
12	Gull-billed Tern *Gelochelidon nilotica* (Gmelin, JF, 1789)	M	P	LC	Schedule I	A
4	**Recurvirostridae**					
13	Black Winged Stilt *Himantopus himantopus* (Linnaeus, 1758)	R	C	LC	Schedule II	A
5	**Scolopacidae**					
14	Black-tailed Godwit *Limosa limosa* (Linnaeus, 1758)	M	O	NT	Schedule II	T
15	Common Greenshank *Tringa nebularia* (Gunnerus, 1767)	M	I	LC	Schedule I	T
16	Common Redshank *Tringa tetanus* (Linnaeus, 1758)	M	I	LC	Schedule II	A
17	Common Sandpiper *Actitis hypoleucos* (Linnaeus, 1758)	M	I	LC	Schedule II	A
18	Eurasian curlew *Numenius arquata* (Linnaeus, 1758)	M	C	NT	Schedule II	A

19	Green Sandpiper *Tringa ochropus* Linnaeus, 1758	M	I	LC	Schedule II	T
20	Marsh Sandpiper *Tringa stagnatilis* (Bechstein, 1803)	M	C	LC	Schedule II	T
21	Temminck's stint *Calidris temminckii* (Leisler, 1812)	M	C	LC	Schedule II	T
22	Whimbrel *Numenius phaeopus* (Linnaeus, 1758)	M	P	LC	Schedule II	A
B	**COLUMBIFORMES**					
6	**Columbidae**					
23	Blue Rock Pigeon *Columba livia* (Gmelin, JF, 1789)	R	G	LC	NA	T
24	Spotted Dove *Spilopelia chinensis* (Scopoli, 1786)	R	G	LC	Schedule II	T
25	Eurasian Collared Dove *Streptopelia decaocto* (Frivaldszky, 1838)	R	G	LC	Schedule II	T
26	Laughing Dove *Spilopelia senegalensis* (Linnaeus, 1766)	R	G	LC	Schedule II	T
27	Red Collared Dove *Streptopelia tranquebarica* (Hermann, 1804)	R	G	LC	Schedule II	T
C	**CORACIIFORMES**					
7	**Alcedinidae**					
28	Common Kingfisher *Alcedo atthis* (Linnaeus, 1758)	R	P	LC	Schedule II	A
29	White-throated Kingfisher *Halcyon smyrnensis* (Linnaeus, 1758)	R	C	LC	Schedule II	T
8	**Meropidae**					
30	Green Bee-eater *Merops orientalis* Latham, 1801	R	I	LC	Schedule II	T
D	**PELECANIFORMES**					
9	**Pelecanidae**					
31	Great White Pelican *Pelecanus onocrotalus* Linnaeus, 1758	M	P	LC	Schedule II	A
10	**Ardeidae**					
32	Cattle Egret *Bubulcus ibis* (Linnaeus, 1758)	R	C	LC	Schedule II	T
33	Great Egret *Ardea alba* (Linnaeus, 1758)	R	P	LC	Schedule II	A
34	Indian Pond Heron *Ardeola grayii* (Sykes, 1832)	R	C	LC	Schedule II	A
35	Intermediate Egret *Ardea intermedia* (Wagler, 1829)	R	P	LC	Schedule II	A
36	Little Egret *Egretta garzetta* (Linnaeus, 1766)	R	C	LC	Schedule II	A
37	Grey Heron *Ardea cinerea* Linnaeus, 1758	R	P	LC	Schedule II	T
38	Western Reef Heron *Egretta gularis* (Bosc, 1792)	RM	P	LC	Schedule II	A

39	Purple Heron *Ardea purpurea* Linnaeus, 1766	R	C	LC	Schedule II	A
11	**Threskiornithidae**					
40	Black Headed Ibis *Threskiornis melanocephalus* (Latham, 1790)	R	C	NT	Schedule II	A
41	Glossy Ibis *Plegadis falcinellus* (Linnaeus, 1766)	R	C	NT	Schedule II	T
E	**CICONIIFORMES**					
12	**Ciconiidae**					
42	Painted Stork *Mycteria leucocephala* (Pennant, 1769)	R	C	NT	Schedule II	A
F	**PHOENICOPTERIFORMES**					
13	**Phoenicopteridae**					
43	Greater Flamingo *Phoenicopterus roseus* Pallas, 1811	RM	C	LC	Schedule II	A
G	**PASSERIFORMES**					
14	**Corvidae**					
44	House Crow *Corvus splendens* (Vieillot, 1817)	R	O	LC	NA	T
15	**Dicruridae**					
45	Black Drongo *Dicrurus macrocercus* Vieillot, 1817	R	I	LC	Schedule II	T
16	**Hirundinidae**					
46	Barn Swallow *Hirundo rustica* (Linnaeus, 1758)	RM	I	LC	Schedule II	T
47	Wire-tailed Swallow *Hirundo smithii* Leach, 1818	R	I	LC	Schedule II	T
17	**Laniidae**					
48	Bay-backed Shrike *Lanius vittatus* Valenciennes, 1826	R	I	LC	Schedule II	T
49	Brown shrike *Lanius cristatus* Linnaeus, 1758	R	I	LC	Schedule II	T
18	**Motacillidae**					
50	White Wagtail *Motacilla alba* Linnaeus, 1758	M	I	LC	Schedule II	T
51	Yellow Wagtail *Motacilla flava* Linnaeus, 1758	M	I	LC	Schedule II	T
19	**Muscicapidae**					
52	Oriental Magpie Robin *Copsychus saularis* (Linnaeus, 1758)	R	I	LC	Schedule II	T
20	**Nectariniidae**					

53	Purple Sunbird *Cinnyris asiaticus* (Latham, 1790)	R	N	LC	Schedule II	T
21	**Pycnonotidae**					
54	White Eared Bulbul *Pycnonotus leucotis* (Gould, 1836)	R	O	LC	Schedule II	T
55	Red-vented Bulbul *Pycnonotus cafer* (Linnaeus, 1766)	R	O	LC	Schedule II	T
22	**Sturnidae**					
56	Common Myna *Acridotheres tristis* (Linnaeus, 1766)	R	O	LC	Schedule II	T
57	Brahminy Starling *Sturnia pagodarum* (Gmelin, JF, 1789)	R	I	LC	Schedule II	T
H	**SULIFORMES**					
23	**Phalacrocoracidae**					
58	Little Cormorant *Microcarbo niger* (Vieillot, 1817)	R	P	LC	Schedule II	A
I	**Apodiformes**					
24	**Apodidae**					
59	House Swift *Apus nipalensis* (Hodgson, 1837)	R	I	LC	Schedule II	
J	**ACCIPITRIFORMES**					
25	**Accipitridae**					
60	Black-winged Kite *Elanus caeruleus* (Desfontaines, 1789)	R	C	LC	Schedule I	T
61	Black Kite *Milvus migrans* (Boddaert, 1783)	R	C	LC	Schedule II	T
62	Oriental Honey Buzzard *Pernis ptilorhynchus* (Temminck, 1821)	R	C	LC	Schedule II	T
63	Shikra *Tachyspiza badia* (Gmelin, JF, 1788)	R	C	LC	Schedule I	T
K	**CUCULIFORMES**					
26	**Cuculidae**					
64	Asian Koel *Eudynamys scolopaceus* (Linnaeus, 1758)	R	F	LC	Schedule II	T

Note: FG- Feeding Guild, C- Carnivore, F- Frugivore, G- Granivore, I- Insectivore, N- Nectarivore, O- Omnivore, P- Piscivore; MS-Migratory Status, R- Resident, M- Migratory, RM- Resident Migrant; IUCN- International Union for Conservation of Nature, LC- Least Concern, NT- Near Threatened, VU- Vulnerable

Annexure -C

FINAL REPORT

For the Project entitled

Monitoring of Mangrove Plantation (1600 Ha) carried out by Deendayal Port Authority, Kandla

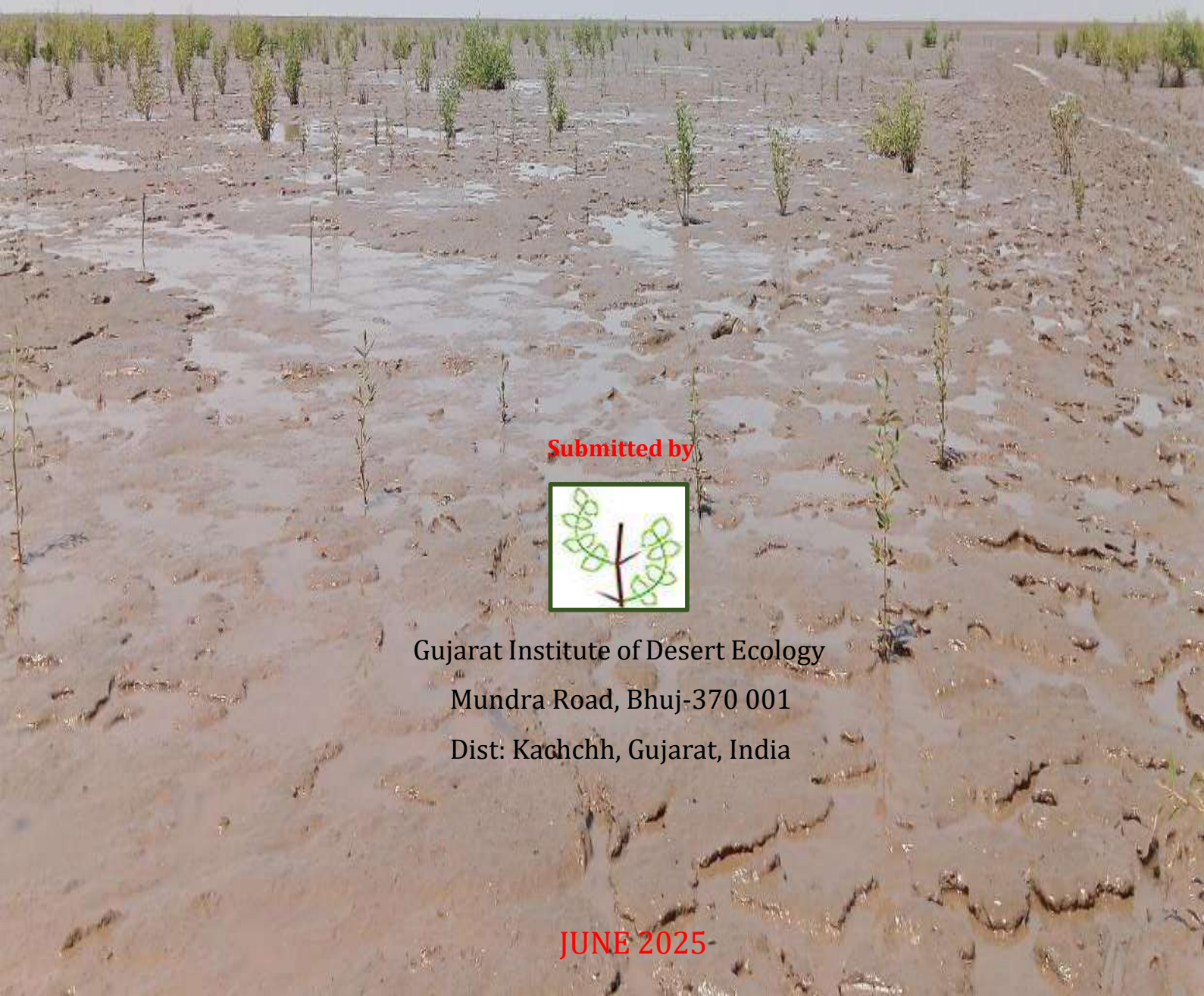
DPA Work order No. EG/WK/ 4751/Part (Marine Ecology Monitoring)/70. Dt. 10.06.2024

Submitted to

Deendayal Port Authority

Gandhidham- 370201

Dist: Kachchh, Gujarat-, India



Submitted by

Gujarat Institute of Desert Ecology

Mundra Road, Bhuj-370 001

Dist: Kachchh, Gujarat, India

JUNE 2025

FINAL REPORT

for the Project entitled

Monitoring of Mangrove Plantation (1600 ha) carried out by Deendayal Port Authority, Kandla

DPA Work order No. EG/WK/4751/Part (Marine Ecology Monitoring)/70. Dt.10.06.2024.

Submitted by

Gujarat Institute of Desert Ecology

Mundra Road, Bhuj-370 001

Dist: Kachchh, Gujarat

Submitted to

DEENDAYAL PORT AUTHORITY
KANDLA

Deendayal Port Authority

Gandhidham, Dist: Kachchh, Gujarat-370201

JUNE -2025

Gujarat Institute of Desert Ecology

Certificate

This is state that the Final Report for project entitled **"Monitoring of Mangrove Plantation (1600 ha) carried out by Deendayal Port Authority, Kandla"** has been prepared in line with the Work order issued by the Deendayal Port Authority Vide. Ref. No. EG/WK/4751/Part (Marine Ecology Monitoring)/70. Dt.10.06.2024.

The work order is for a period of one year (10.06.2024 - 09.06.2025) for the above-mentioned study.

Authorized Signatory

DIRECTOR
Gujarat Institute of Desert Ecology
Bhuj - Kachchh.

Institute Seal

Project Team

Project Coordinator: Dr. V. Vijay Kumar, Director

Project Personnel

Principal Investigator

Dr. B. Balaji Prasath, Senior Scientist

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Team Members

Dr. L. Prabhadevi, Advisor

Dr. Dhara Dixit, Project Scientist-I

Mr. Dayesh Parmar, Senior Scientific Officer

Mr. Ketan Kumar Yogi, Junior Research Fellow

Snapshot of the Project, "Regular Monitoring of Mangrove Plantation (1600 Ha) carried out by Deendayal Port Authority (Statutory requirement)"

S. No	Components of the Study	Remarks
1	Deendayal Port's letter sanctioning the project	EG/ WK/4751/Part/ (Marine Ecology Monitoring)/70 dated 10/06/2024
2	Duration of the project	One year from 10.06.2024 to 09.06.2025
3	Period of the survey carried out for various components	September, 2024 – April, 2025
4	Survey area within the port limit	Sat Saida Bet, Nakti creek and Kantiyajal mangrove plantation sites
5	No of locations sampled within the port limits	06 blocks in Sat Saida Bet 02 blocks in Nakti creek 05 block at Kantiyajal Site
6	Components of the report	
6a	Mangrove density	Sat Saida Bet: Density of mangrove varied from 100 to 4000 and individuals/ha and tree height ranging from 70 - 240cm Nakti creek: Density of mangrove varied from 400 – 1600 individuals/ha and tree height ranges from 100 - 170 cm. Kantiyajal: Density of mangrove varied from 500 - 1600 individuals/ha tree height ranges from 70-140 cm.
6b	Avg. Carbon stock 0-30 cm depth (%)	The Avg. Carbon stock of mangrove plantation varied from 39.87 to 62.81%. The highest Carbon stock potential was at Nakti creek.

6c	Assessment of Carbon values (Mg C ha^{-1})	The Carbon values of mangrove plantation varied from 1,920.93 to 4043.5. The highest carbon values potential was at Sat Saida Bet.
6c	Assessment of CO_2 equivalent	The CO_2 equivalent was maximum 31.65 at Sat Saida Bet while at Nakti creek it was 27.66 and at Kantiyajal it was 24.97.
7	Management	The restoration efforts to be done to improve the sparse mangrove patches with multi-species plantation initiatives along with promotion of natural regeneration through long term efforts.

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1. Introduction

Mangrove forests are important ecosystems that exhibit high productivity and biodiversity. These forests flourish in varying depths of saline waters and with specialized root structures called pneumatophores that provide vital habitat for diverse macro- and micro fauna (Mullarney et al. 2017). Additionally, mangroves can sequester carbon dioxide at rates up to four times that of terrestrial forests per unit area, further proving their importance for reducing global warming (Alongi 2022). Aquatic tourism and fisheries also rely heavily on mangroves making it economically important alongside its carbon sequestration potential. The international scientific community has gradually adopted the importance of economic ecological functions and services provided by mangroves. However, these ecosystems face unsustainable use and destruction which leads to poorly restored coverage of mangroves (Sidik et al. 2023). To address these issues, researchers have concentrated on developing restoration methods through plantation and conservation programs aimed at sustaining mangroves ecological and economic aspects.

India accounts for roughly 3.3 % of the world's total mangrove cover, equating to 0.15% of the total land area, which signifies a meagre fraction. Mangrove forests are located on the coasts of 9 Indian states and four Union Territories. The country's total area is estimated to be around 4992 Km^2, with nearly 57 % of this figure sitting on the east coast, 31 % on the west, and 12 % in the Andaman and Nicobar Islands (FSI, 2021). The three types of mangrove ecosystems in India include: insular located on the Andaman and Nicobar Islands and continental, which consist of two further classified as estuarine deltaic found on the country's east coast and backwater on the western side (Shah and Ramesh 2022). India possesses the most significant number of true mangrove species accounting for 46, which includes 42 species and 4 natural hybrids belonging to 14 groups and 22 genera. The east coast is home to 40 mangrove species which belong to 14 families and 22 genera. The west coast is populated by 27 species from 16 genera and 11 families, while the Andaman and Nicobar Islands host the richest diversity of mangroves in India – 38 species from 13 families and 19 taxa (Ragavan et al. 2016). Mangrove forests can be defined by their unparalleled primary productivity which is the rate of organic carbon conversion from carbon dioxide respiration outpacing all other forms of biomass in nearly all terrestrial habitats (Harishma et al. 2020). The living biomass and sediments are rich in nutrients sequester what's known as "blue carbon", which can be stored for

centuries. The phrase “blue carbon” was coined in 2009 to highlight the importance of conserving and restoring marine and coastal ecosystems for climate change mitigation and other ecosystem services. However, “blue carbon” encompasses various definitions, and its original definition included all organic material accumulated by marine organisms, as well as the potential for managing marine ecosystems to reduce greenhouse gasses and assist mitigation and conservation efforts of climate change (Lovelock and Duarte 2019).

Although accounting for a small portion of tropical forests, it notes that the position of mangroves at the land-sea interface gives them the ability to impact the carbon cycle of the coast significantly. The contribution of coastal and marine ecosystems, including mangroves, is more effective than terrestrial systems in mitigating climate change through carbon sequestration and storage (Choudhary et al. 2024). The management of blue carbon ecosystems is disregarded concerning climate change policies and is usually missing from national carbon accounts and international carbon payment systems. There are two main accepted methods for estimating the biomass of mangroves: field measurements and remote sensing with a GIS-based approach. Petrokofsky et al. (2012) consider field measurements to be accurate and dependable while validation between remote sensing data and field data is necessary. Active protection and restoration initiatives have recently been carried out through field data collection to support the satellite data, enhancing the modelling of the global carbon cycle. Furthermore, these coastal ecosystems provide a wide range of services necessary for climate change adaptation, such as the protection of coastlines and nutrition for people globally (IUCN, 2017). Carbon sequestration by mangroves ecosystems can be included in national accounts in the international scope.

In conclusion, as woody habitats mangroves serve as crucial carbon sinks in coastal regions. In addition, Mangrove forests serve as natural barriers against storms, erosion, and rising sea levels, directly guarding coastal regions and amplifying local economies receive economies' benefits. This function is even more important in climate change due to the increasing frequency and intensity of extreme weather. In addition, healthy mangrove ecosystems aid in mitigating water pollution, which is essential for maintaining clean water, stabilizing sediments, and filtering debris. Thus, conserving and restoring mangroves is not simply an environmental obligation but one of the unique and

effective measures to strategically safeguard coastal populations. Protect ecosystems and conserve them, which now builds the case for more advanced and active integrated coastal policies with greater focus on ecological systems and human welfare. The Deendayal Port Authority (DPA) has actively engaged in mangrove plantation initiatives following the directives of the Ministry of Environment, Forests, and Climate Change (MoEFCC), Government of India. The monitoring of the mangrove plantation carried out by the DPA has been undertaken by the Gujarat Institute of Desert Ecology (hereafter GUIDE) regularly as per the specification in the work order (EG/WK/4751/part Marine Ecology Monitoring)/70 dated 10.04.24. This report describes the monitoring results of the mangrove plantation managed by the DPA at Nakti creek, Kantiyajal and Sat Saida Bet from 2024 to 2025.

2. Rationale of the project

The Deendayal Port Authority (DPA) is one of India's most developed ports as it has one of the largest cargo capacities in India. DPA is located in the strategic region of Gujarat on the upper north-western coast of India and is one of the largest creek-based ports in the country. It is situated at the Gulf of Kachchh at the southern point and is regarded as one of India’s twelve major ports. The most significant of this location is its semi-diurnal tidal range of around 6 to 7 meters. This enables DPA to have a powerful pull in trade since the significant tidal difference helps with navigation in the port-channel docking areas, thereby increasing maritime trade activity. For the past seven years, DPA has continuously been constructed and upgraded further enhancing its prime geographic ports and the natural resources. The Port area is complimented by a unique creek ecosystem containing diverse life forms like veracious mangrove regions of about 193.1 km^2 and extensive mudflats around 312.9 km^2. Kandla region contains a network of intricate creeks and saltwater mudflats which have sparse range of halophytic mangrove vegetation interspersed with brackish landforms.

The area within 10 kilometres of the port is predominantly developed and includes salt works, human settlements, and port infrastructure to the north and west. Eastern and southern peripheries are marked by ecological features like creek systems, mangrove formations, and mudflats, which indicate the region's ecological value. DPA has had considerable movements of materials, machines, and personnel alongside extensive construction activity as part of its infrastructural development expansion. Such activity

has almost certainly changed the ecological composition of the area. To site these issues and reduce environmental degradation, DPA has undertaken considerable projects, from time to time towards the conservation of the mangroves and other plants and the protection of their coastal habitats within the borders of its property. The authority has also focused on expanding conservation efforts to improve mangrove cover because of the important ecosystem services provided by these plants such as protection of coastline, habitat for fauna and flora, and carbon dioxide storage.

From 2005 to 2024, DPA has managed a remarkable mangrove plantation project covering an area of 1,600 hectares carefully through various implementing agencies at Sat Saida Bet and Nakti creek in Kandla and Kantiyajal in Bharuch district (Figure 1). The DPA has entrusted the task of evaluating the status of 1600 ha of mangrove plantation in these locations to the GUIDE, Bhuj. The detailed report on the mangrove plantation evaluation includes periodic monitoring and reporting so that DPA obtains a comprehensive detailed evaluation of the advancement and ecological effect of the mangrove plantations, which allows for adequate management decisions concerning the preservation of these vulnerable coastal ecosystems.

3. Objectives of the Study

The evaluation and health assessment of the mangrove ecosystem are the primary scopes of this research. Focus is also given to addressing and managing ecosystem loopholes. The further findings will support the formulation of precise management propositions. To attain the above purposes the following objectives were formulated:

- To conduct an extensive survey of the 1600ha planted mangrove area in Sat Saida Bet, Nakti creek in Kachchh and in Kantiyajal, Bharuch district.
- To assess the level of the plantation and also the health of the mangroves and growth of the species.
- To estimate the carbon stock that could potentially be stored in the soil under the mangrove plantation and its carbon sink value about climate change impacts.

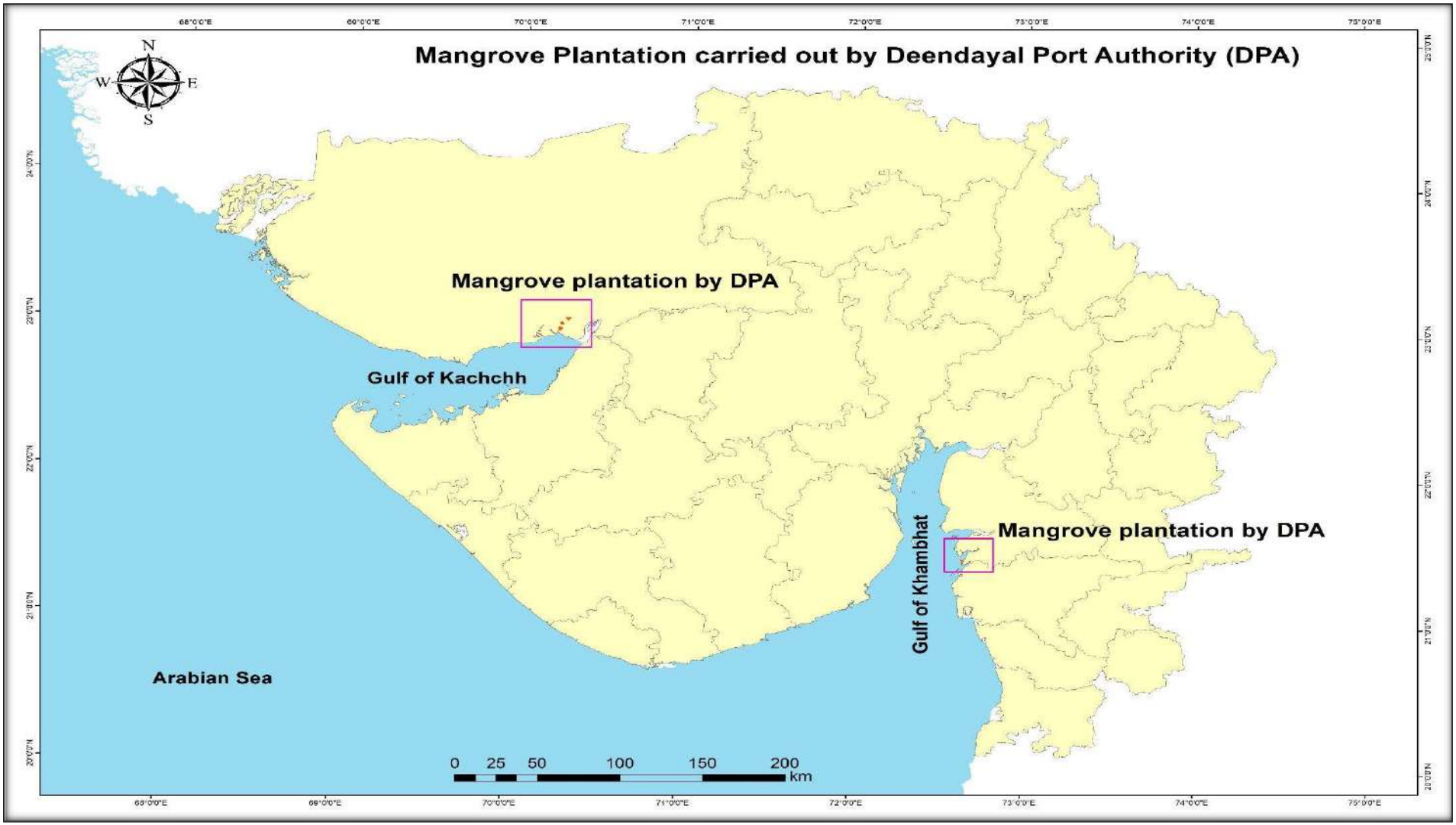

Figure 1: Mangrove plantation carried out by DPA at Sat Saida Bet and Nakti creek in Kachchh district and Kantiyajal in Bharuch district

4. Study Area

The region of Deendayal Port is examined in terms of its ecology, infrastructure, and geography which comprise the environmental setting. Additionally, the port's coordinates are located at 22°59'39.77''N, 70°13'20.14''E and its average altitude lies 20 feet above mean sea level. Moreover, the average rainfall was 466 mm (in 2021) and its climate features an annual maximum temperature of 42.8°C and an average minimum of 21.3°C.The area has high relative humidity – at 60% for the rest of the year, 80% during the southwest monsoon (June to September), and down to 50% in November-December. The average wind speed is reported at 4.65 m/s and is highest in June at 10.61 m/s. Droughts occur frequently every five years, in two out of five-year cycles (Figure 2).

The coastal area is characterized by flat marsh land featuring dense mangrove growth, mudflats, creek systems, salt marshes, halophytes, salt pans, and swamps. The only freshwater infusions accompany coastal flooding during monsoon months due to flash floods. There are no perennial or seasonal rivers and the region lacks any form of: irrigation, Cape Town water, Gandhidham taluka receives rainfall, or 15-20 erratic days a year. Besides the National Highway 8A, Gandhidham Railway Station, Bhuj airport (~60 km northwest), Tuna village (12 km North), and Gandhidham Town (12 km northwest) are the other key infrastructural features of the region. Survey of India's top sheets covering the area are 41J1, 41I4 and the port region falls under seismic zone V which has a high risk of earthquakes. There are no major rivers, streams, reserved forests, significant historical locations, or modern dams in the vicinity. These unique surroundings form the ecological balance and infrastructural development of Deendayal Port. The plantation site coordinates are (N 21°27'01.1'', to 21°26'54.24'' and E 72°40'36.04, to 72°38'58.22'') positioned to take advantage of the exuberantly developing mangrove patch which is in the Kantiyajal region of Bharuch District, Gujarat. Both summer and winter have set tropical temperature ranges of 25 °C to 42 °C and an easterly wind of 8 km/h. The area experiences low humidity of 35% as well. Strong tidal currents can be observed in the adjacent marine area, where high tidal coefficients are measured. These factors combine with the warm temperature of shallow waters to dictate the pace of marine life and fishing activities in the region year-round (Figure 3).

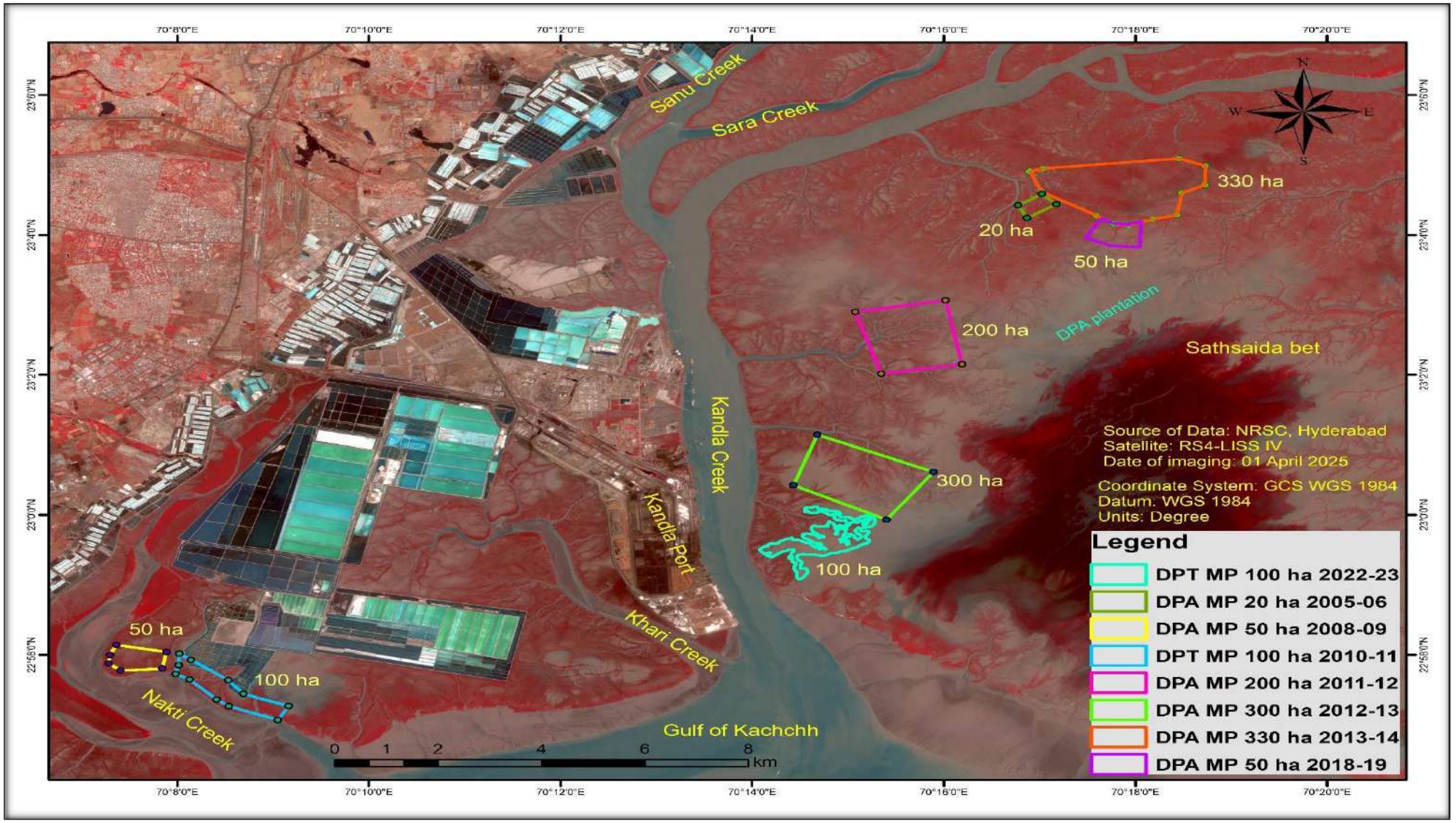

Figure 2: Location of Mangrove Plantation sites at Sat Saida Bet and Natki Creek in Kandla district

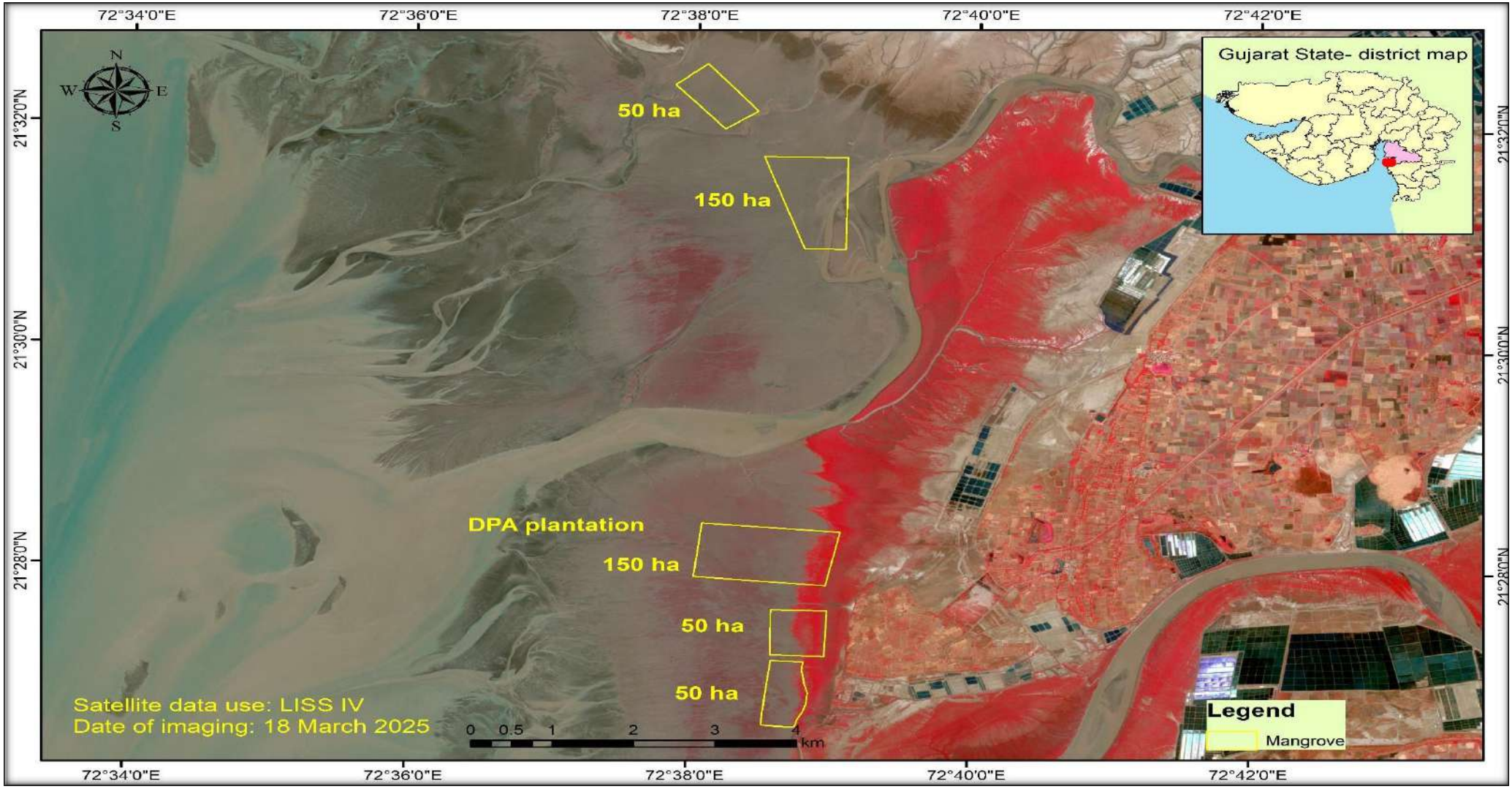

Figure 3: Location of Mangrove Plantation sites at Kantiyajal in Bharuch district

5. Details of the plantation sites

This study examined the status of mangroves at Sat Saida bet and Nakti creek in the Kandla (Kachchh) district and Kantiyajal in the Bharuch district covering more than ten blocks spanning 1400 ha, where plantation activities were conducted from 2005 to 2021. Nevertheless, this analysis (2021-2023) adds another 200 ha of plantations at Sat Saida bet (100 ha) and Kantiyajal (100 ha), which increases the area of the study to 1600ha. The focus of this study for the years 2024-2025 is to assess the actual density of the mangrove plantations developed in these areas. Together with evaluating the carbon sequestration potential of these mangrove ecosystems which are key in reducing climate change impacts through capturing and storing carbon dioxide from the atmosphere. In addition, the study attempts to recommend possible actions for the protection of these ecosystems to safeguard mangrove habitats enabling a healthy and resilient environment. The descriptions of the mangrove plantation work implemented over time by the DPA are found in Fig – 2 & 3 and Table 1. This data will help to illustrate the progress made and the ongoing need for conservation initiatives in these vital ecosystems.

Table 1. Details of the implemented mangrove plantation activities by DPA

Location	Year of Plantation	Area (ha)	Species planted	Implementing Agency
Sat Saida Bet, Kachchh district	2005-2006	20	*A. marina*	Gujarat Institute of Desert Ecology, Bhuj
	2011-2012	200	*A. marina*	Forest Department, GoG
	2012-2013	300	*A. marina*	Forest Department, GoG
	2013-2014	330	*A. marina*	Forest Department, GoG
	2018-2019	50	*A. marina*	Gujarat Ecology Commission
	2022-2023	100	*A. marina*	Gujarat Ecology Commission

Nakti Creek, Kachchh district	2008-2009	50	*A. marina*	M/s. Patel Construction Co, Gandhidham
	2010-2011	100	*A. marina* *R. mucronata* *C. tagal*	Gujarat Ecology Commission
Kantiyajal, Bharuch District	2015-2016	150	*A. marina*	Gujarat Ecology Commission
	2016-2017	150	*A. marina* *R. mucronata*	Gujarat Ecology Commission
	2018-2019	50	*A. marina*	Gujarat Ecology Commission
	2021-2022	50	*A. marina*	Gujarat Ecology Commission
		50	*A. marina*	Gujarat Ecology Commission
Total Area (ha)		**1600**		

5.1 Plantation at Sat Saida bet (1000 ha)

The mangrove ecosystem of Sat Saida bet with six blocks has been investigated in 1000 hectares (Table 1 and Figure 4 to Figure 9) of mangrove area between 2005 - 2023 which includes studies done by Gujarat Institute of Desert Ecology (2005-2006), Forest Department of Gujarat (2011-2014), and Gujarat Ecology Commission (2018-2023). Sat Saida bet is located on the eastern shore of Kandla creek of Gulf of Kachchh. The unique Island of 253.8 km^2 area is located opposite to Deendayal port. It has sparse and dense mangroves, mudflats, and halophytic vegetation. Surrounded by Kandla creek and its branches in the west, Navlakhi creek and its branches on the east and Sara and Phang creek on its north, Sat Saida bet is a highly potential site for mangrove plantation with its vast mudflat. Many major, medium and minor creek systems of Kandla and Navlakhi creeks ramify into this Island in varying length and dimension, supplying tidal water to the interior regions. Southern border of the Island represents the innermost end of Gulf of Kachchh with very few minor creek systems. It is familiar that mudflats with favourable tidal amplitude are suitable for mangrove plantation. So, DPA chose Sat Saida Bet area to execute the mangrove plantation activities.

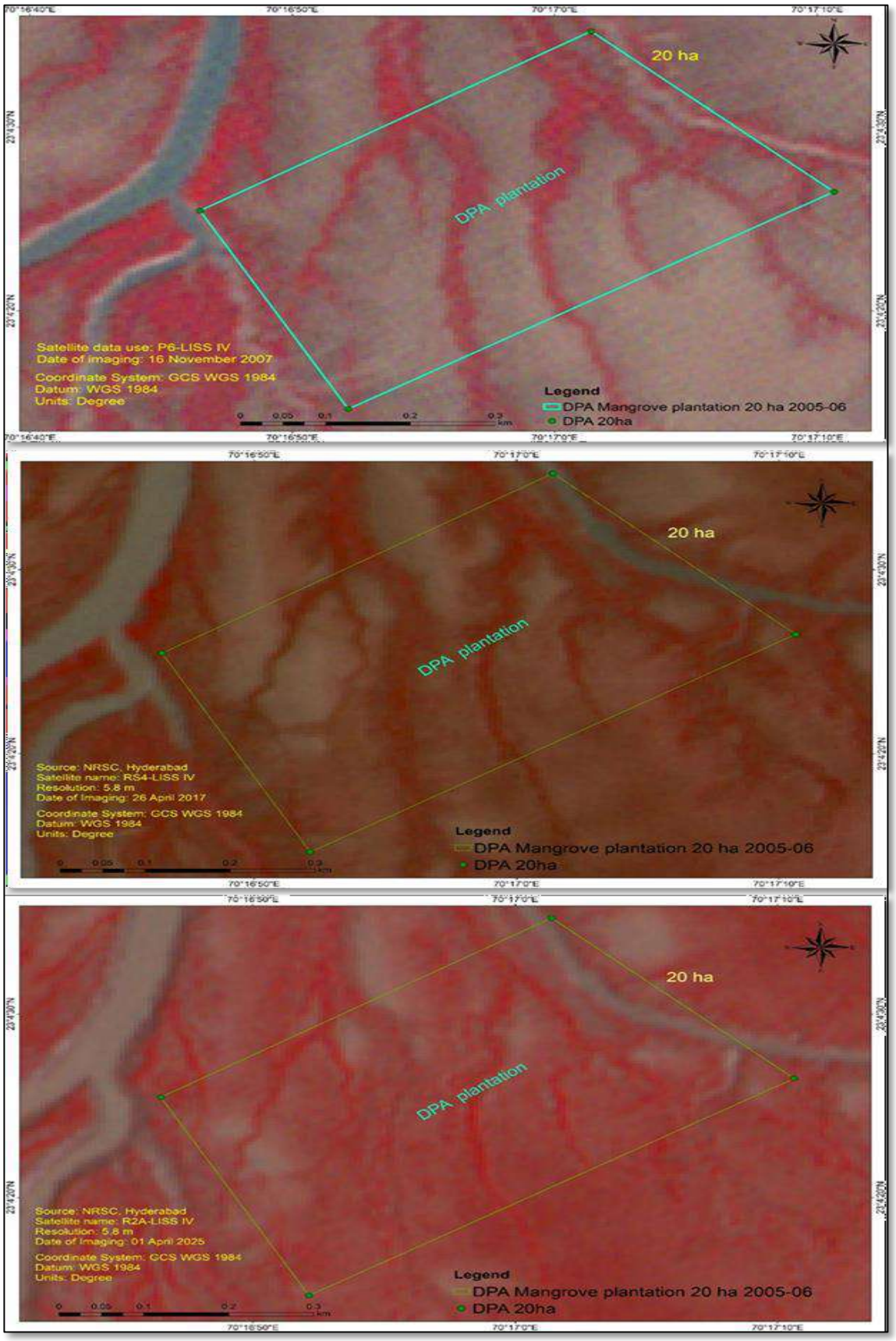

Figure 4: Satellite imageries of the 20 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

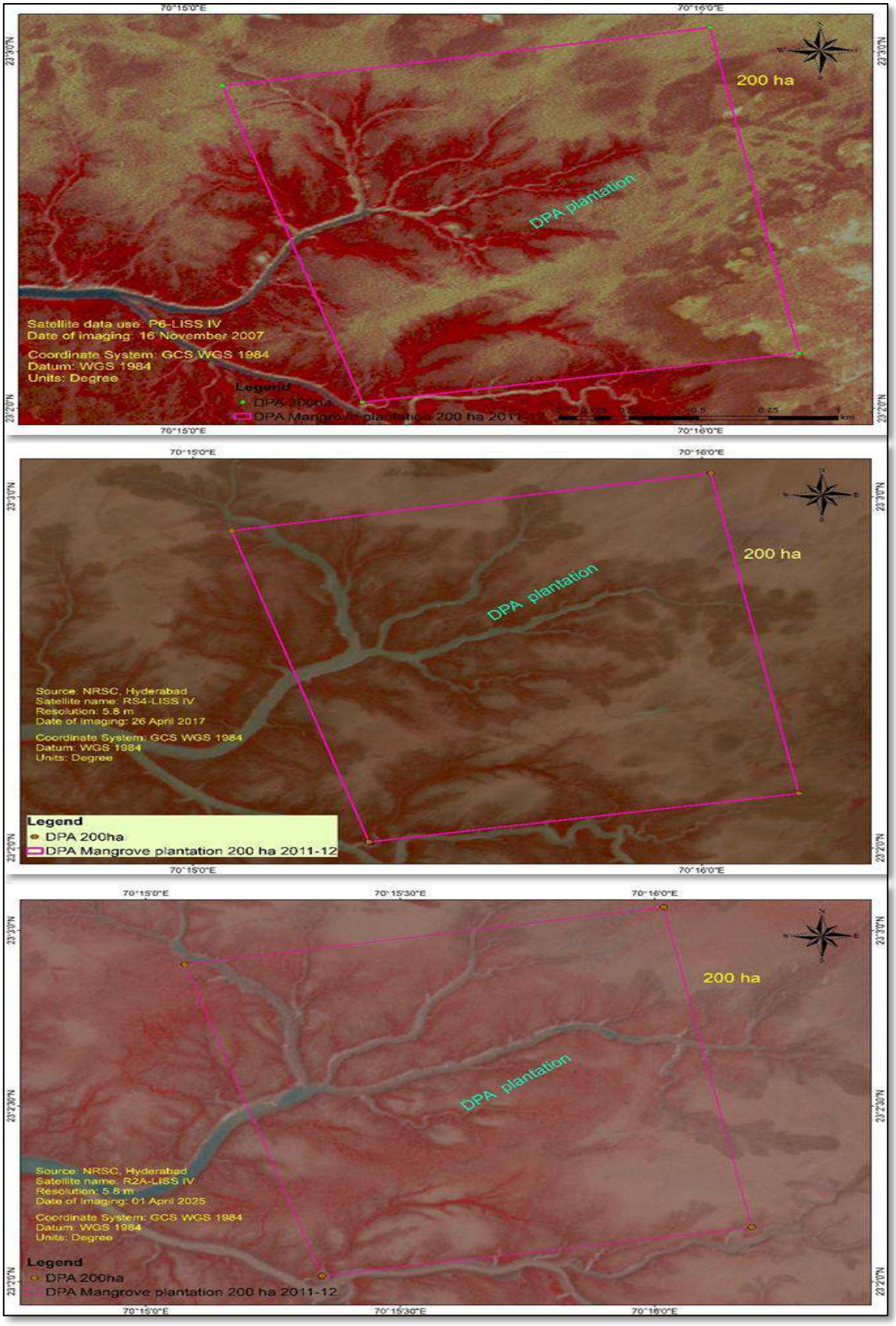

Figure 5: Satellite imageries of the 200 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

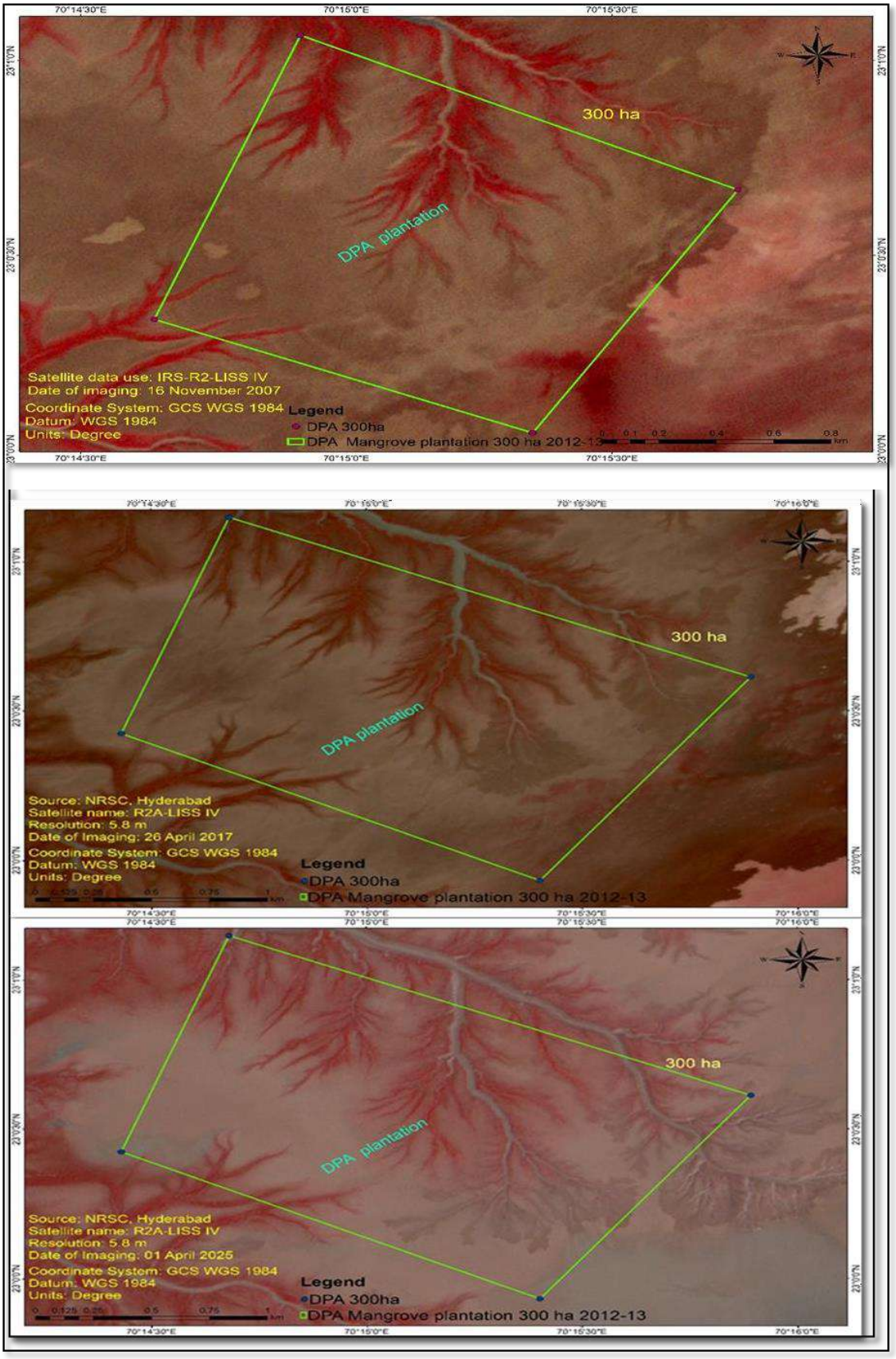

Figure 6: Satellite imageries of the 300 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

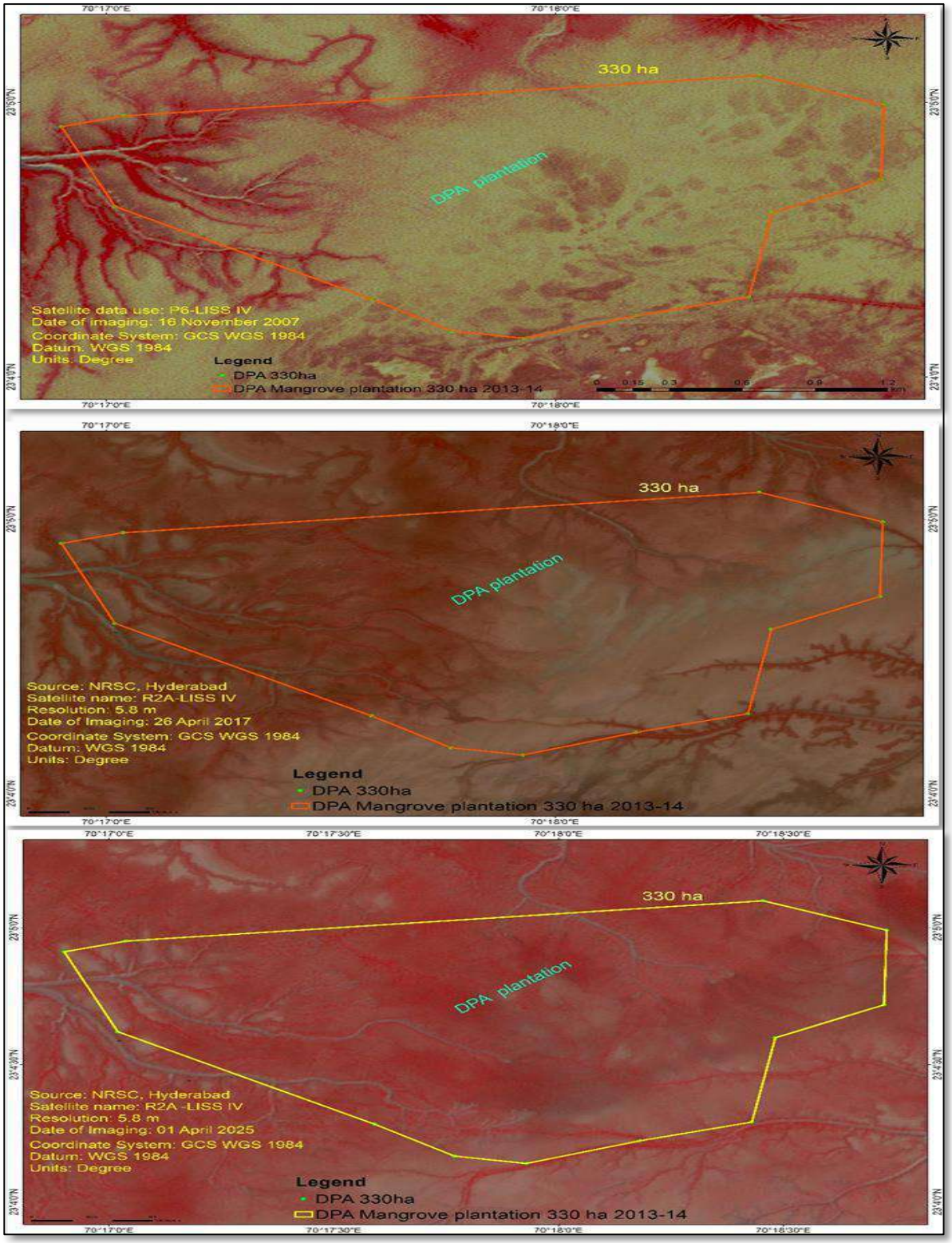

Figure 7: Satellite imageries of the 330 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

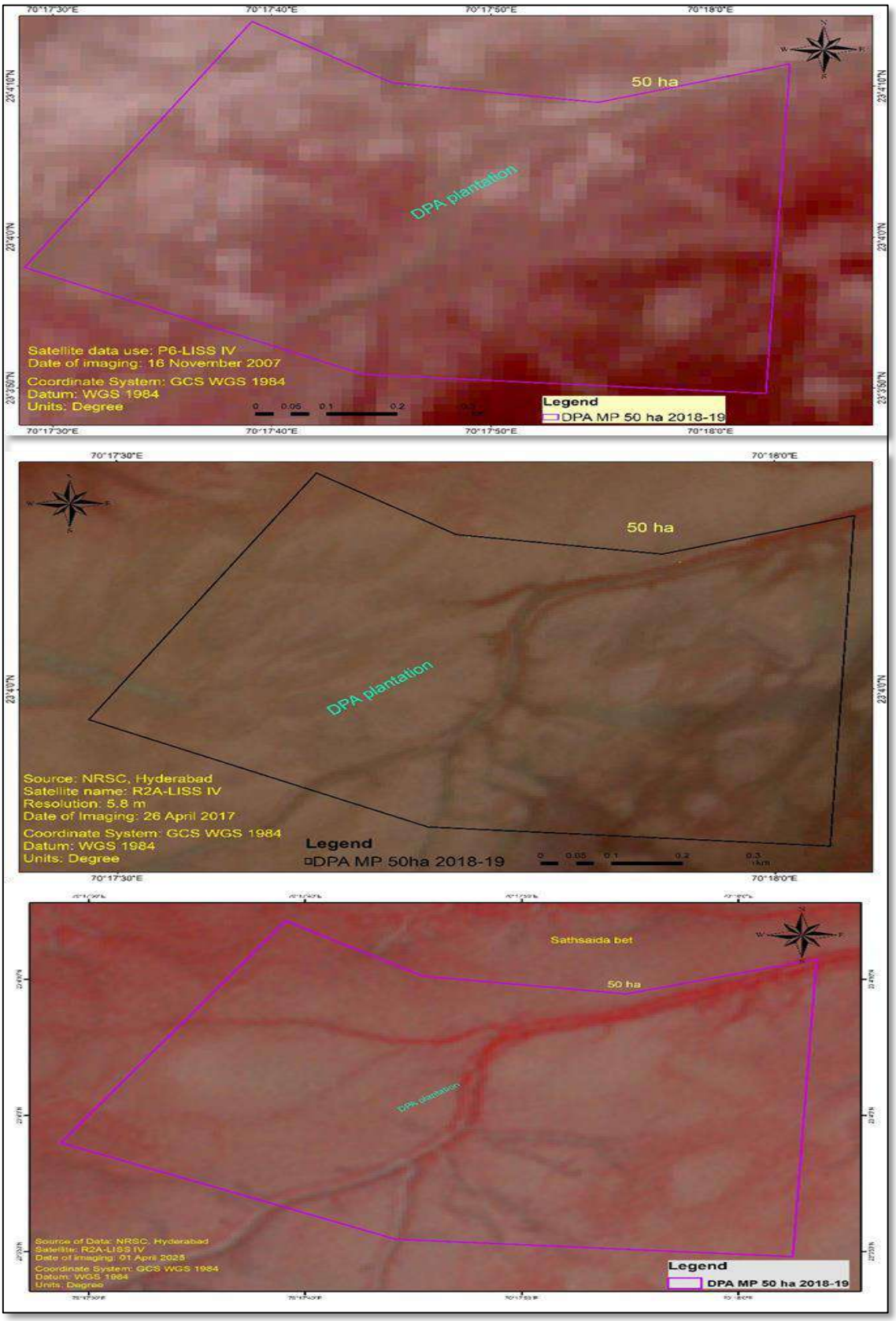

Figure 8: Satellite imageries of the 50 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

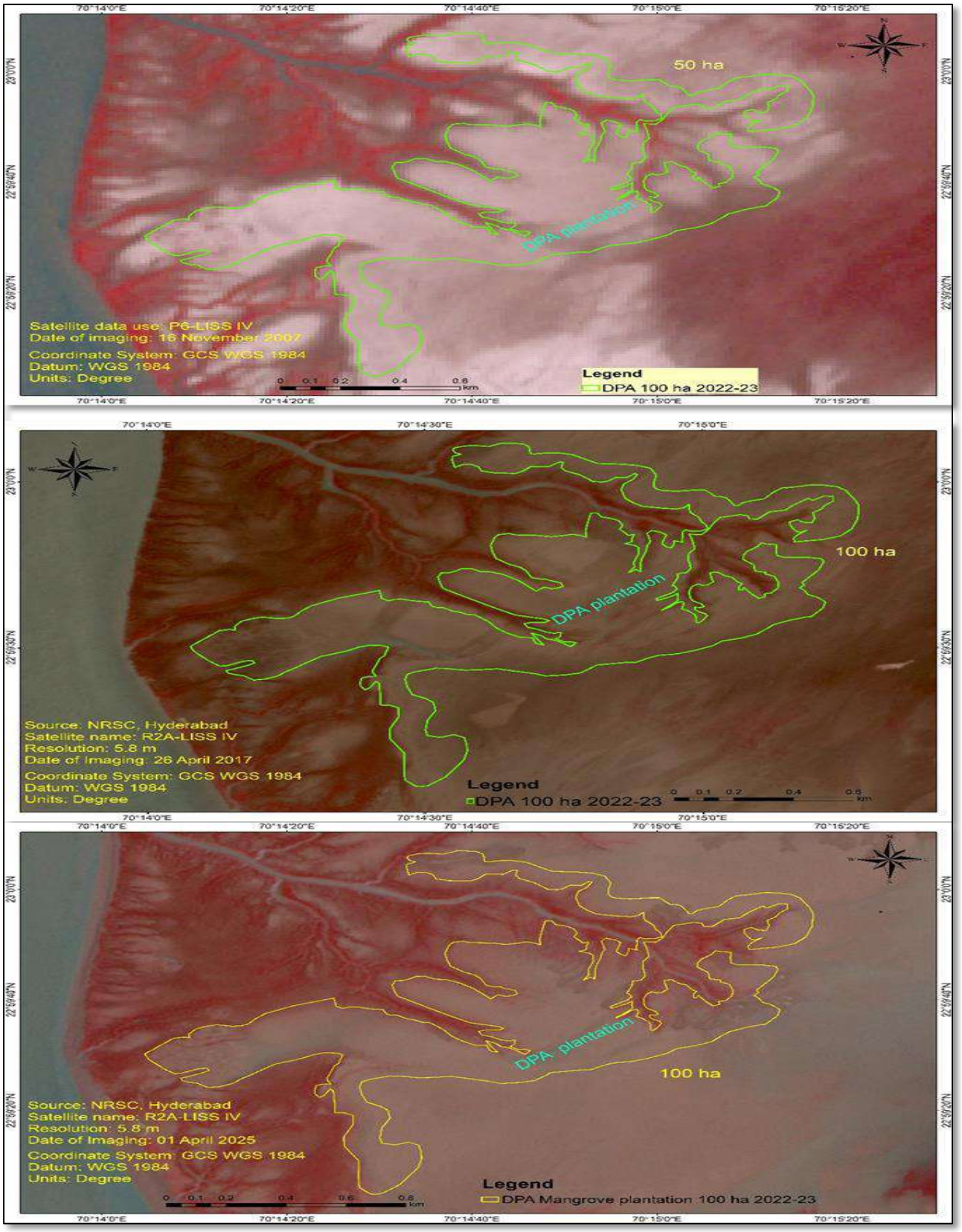

Figure 9: Satellite imageries of the 100 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

5.2 Mangrove plantation at Nakti creek (150 ha)

A detailed area of 150 hectares of mangrove plantation, consisting of two distinct parts, was constructed in Nakti Creek; one more significant block of 100 hectares and a smaller block of 50 hectares. Additionally, this project was divided amongst multiple organizations for collaborative efforts towards maintaining the coastal habitat. The outset of the project was started by M/s Patel Construction Co. based out of Gandhidham, which started working on the project around 2008 to 2009. The second phase was executed by the Gujarat Ecology Commission from 2010 to 2011. The description of these attempts is included in Table 1, and Figures 10, 11. Both construction phases required attention to overcoming challenges related to biodiversity, so the project focused on three main techniques: replanting saplings from nurseries, creating otla beds, and using direct seed dibbling. The venture aimed to reclaim biodiversity alongside protecting the success of the mangrove plantation. Therefore, researchers decided to plant *Avicennia marina and Rhizophora mucronata*, a salt tolerant mangrove species that plays a vital role in controlling erosive forces and provides essential habitat for flora and fauna along the coast.

Unlike the former one, the more significant block which is 100 hectares on the other side of the creek had more variety in the species of mangrove to increase ecological complexity and diversity of different ecosystems. Furthermore, this section contained A. *marina, Rhizophora mucronata,* and *Ceriops tagal*. The addition of these species was intentional and improved the overall ecological balance and the overall health of the mangrove ecosystem. The project intends to restore the mangrove habitat using various plant species. However, the goal is also to strengthen, local coastal ecosystems, biodiversity, and the sustainable health of the coastal environment. This type of broad strategy regarding mangrove planting highlights the critical role that various indigenous species have in tackling the problem of coastal erosion while simultaneously sustaining both marine and terrestrial fauna and flora.

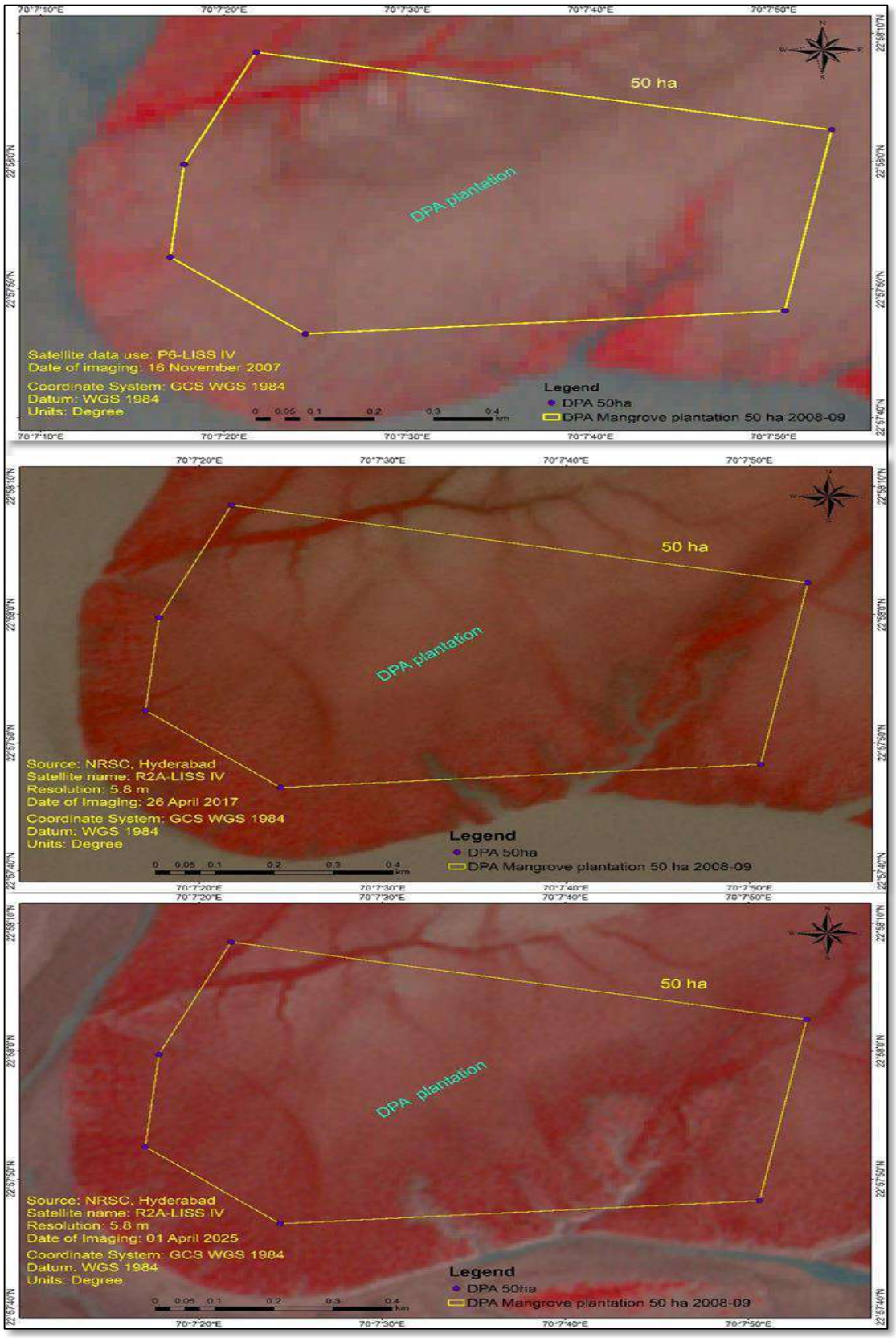

Figure 10: Satellite imageries of the 50 Ha plantation site at Nakti Creek (2007, 2017, and 2025)

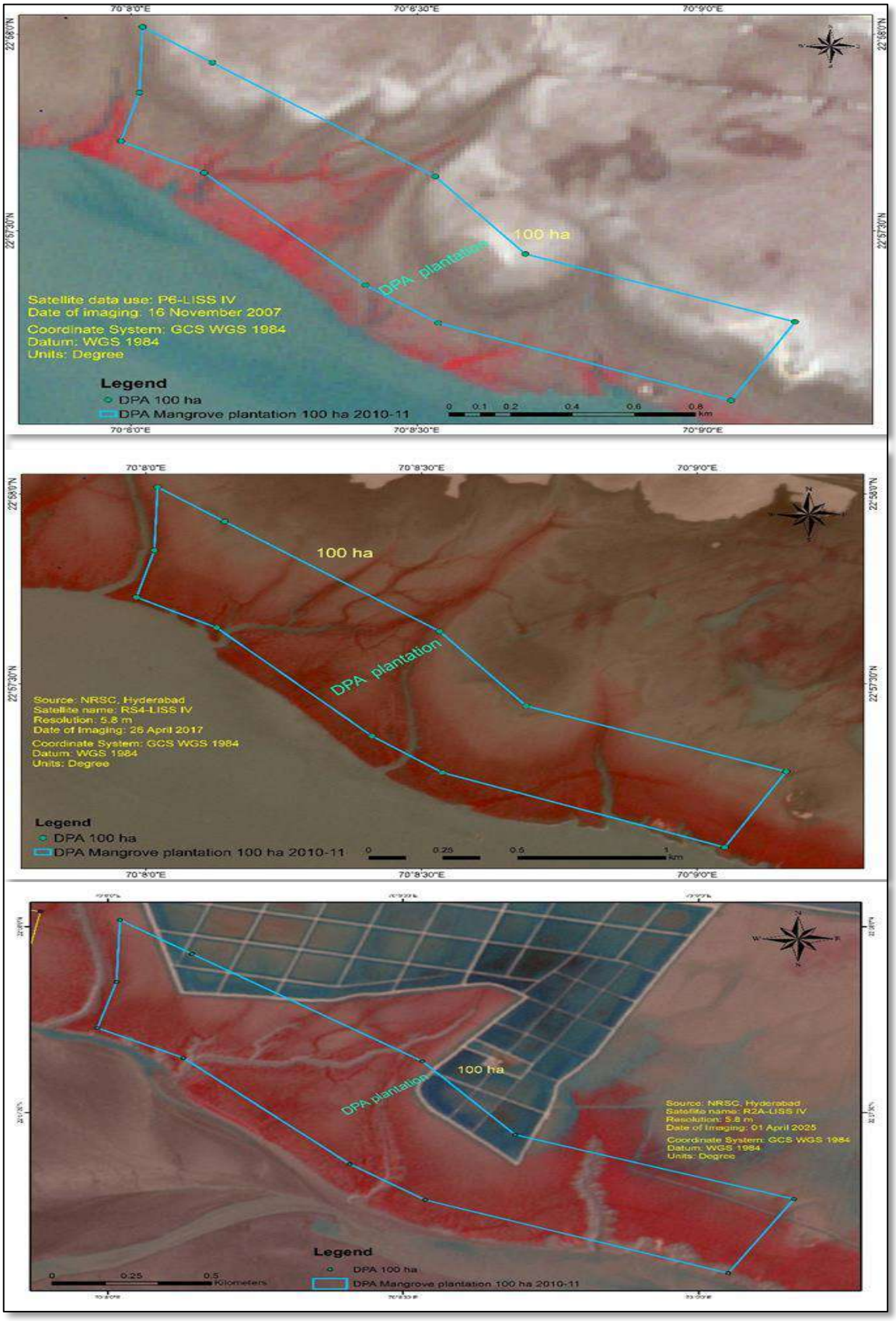

Figure 11: Satellite imageries of the 100 Ha plantation site at Nakti Creek (2007, 2017, and 2025)

5.3 Mangrove plantation at Kantiyajal (450 ha)

The mangrove ecosystem of Kantiyajal with Four blocks has been investigated in 450 hectares (Table 1 and Figure 12 to Figure 16) of mangrove area between 2015 - 2022 including studies done by Gujarat Ecology Commission (GEC). The GEC has been concentrating on the increase of local biodiversity by carrying out mangrove plantation activities in Kantiyajal area of Bharuch District. The commission undertook planting of grey mangroves *Avicennia marina* from 2015 to 2016, planting 150 hectares. A. marina is alongside coastlines and acts as a natural barrier, serving core ecological functions like habitat creation. It was a significant milestone in ecological restoration because of its importance to coastal region. During the subsequent year (2016-2017), they continued with *A. marina* planting but this time they added another key mangrove species *Rhizophora mucronata*. By replanting 150 hectares of land, the region demonstrated a commitment to a highly diverse ecological landscape and a robust environment. In the third block, 2018-2019, only 50 hectares of *A. marina* were planted. However in the fourth block, 2021-2022 mangrove plantation period, *A. marina* planting increased to 100 hectares. That indicates renewed focus towards ecological conditions, and restorations, which allows for more extensive plantation efforts. Dunes, coastal and other erosion are broader spread issues which the plantation programs would help together with losing ecosystem diversity. These steps are critical in retaining local biodiversity which showcases some of the lesser known features to be preserved in the Kantiyajal region of Bharuch District during ongoing efforts to manage balance in its unique ecological network.

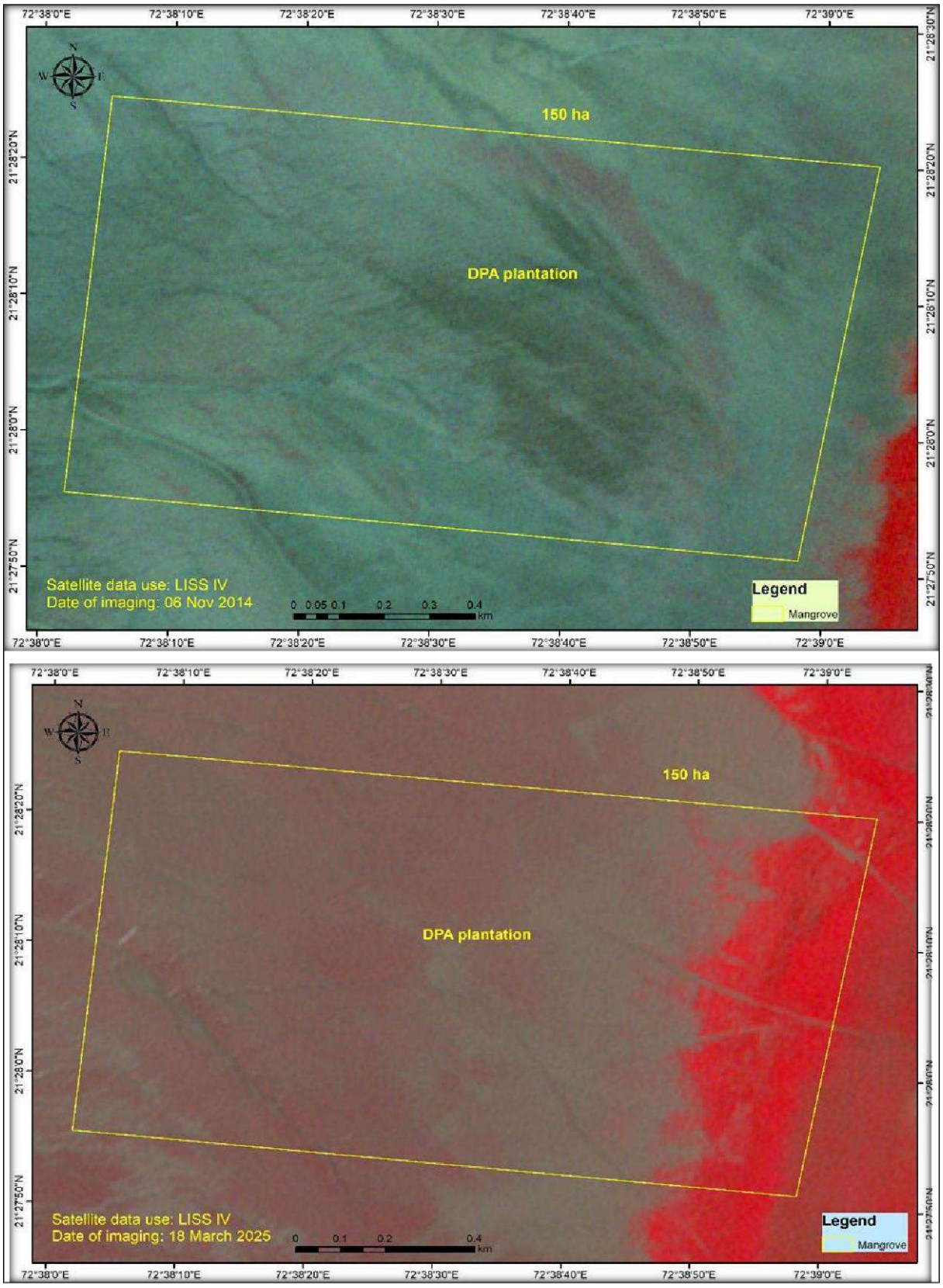

Figure 12: Satellite imageries of the 150 Ha block-1 plantation site at Kantiyajal (2014 and 2025)

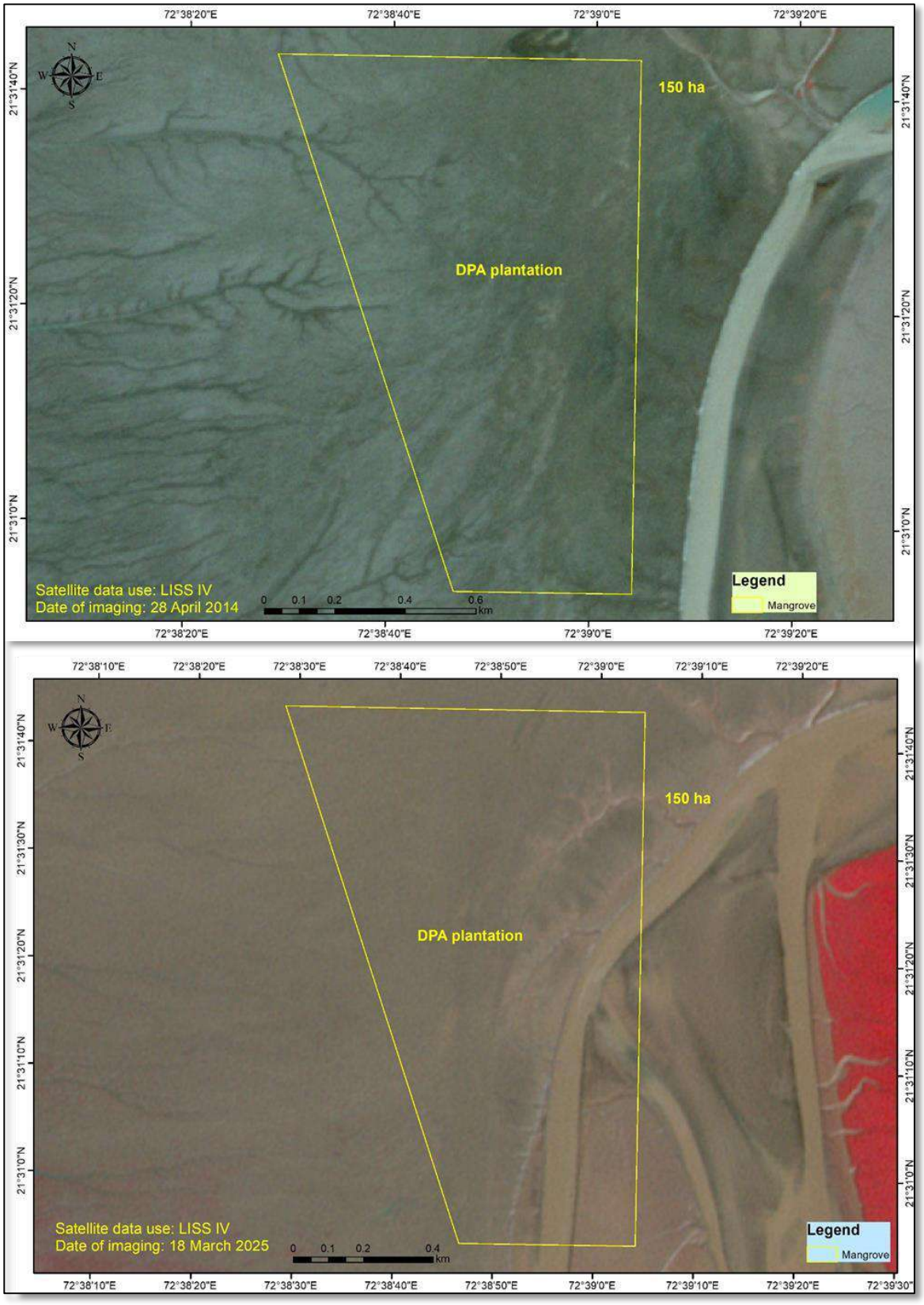

Figure 13: Satellite imageries of the 150 Ha block-2 plantation site at Kantiyajal (2014 and 2025)

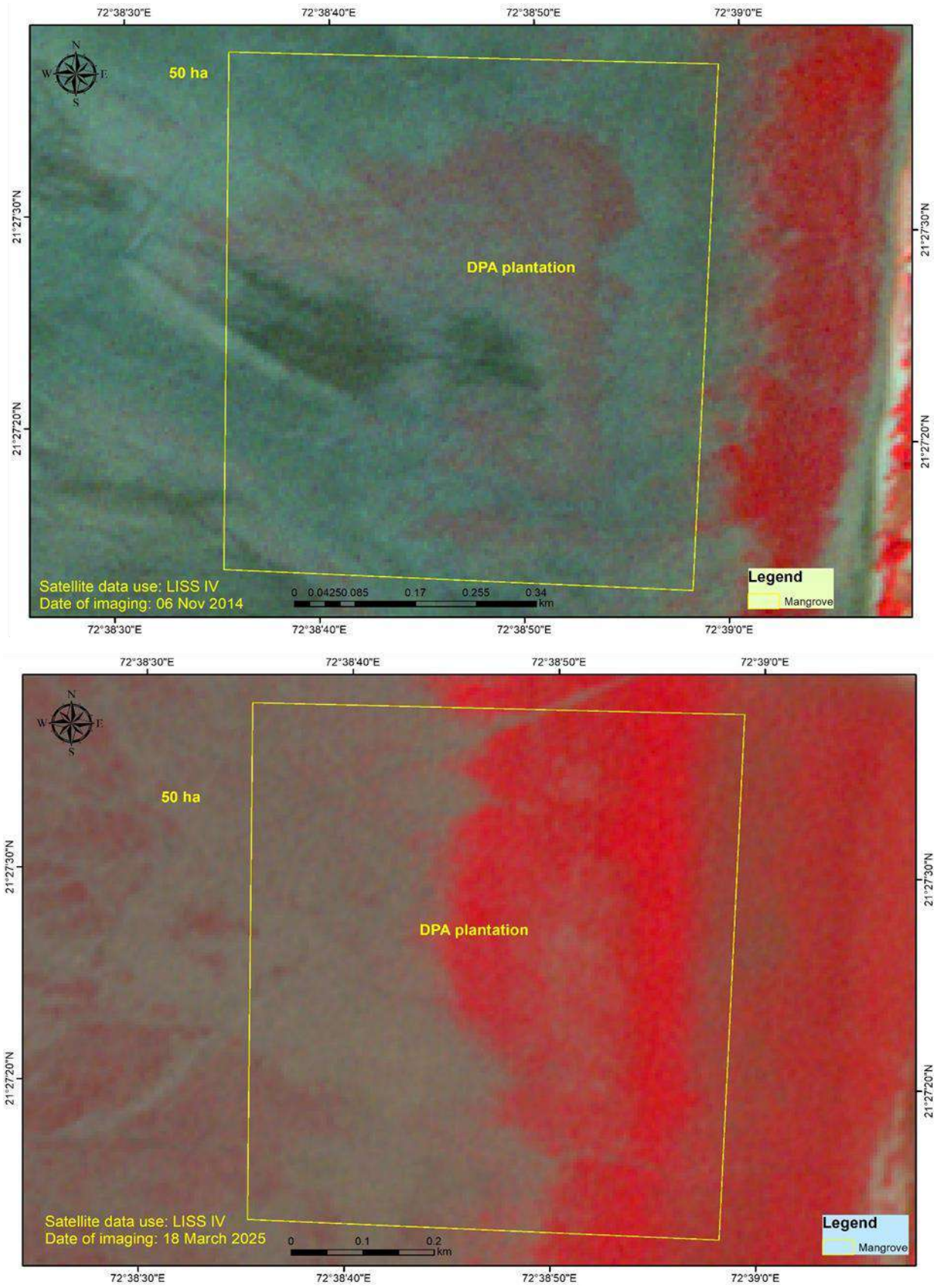

Figure 14: Satellite imageries of the 50 Ha block-3 plantation site at Kantiyajal (2014 and 2025)

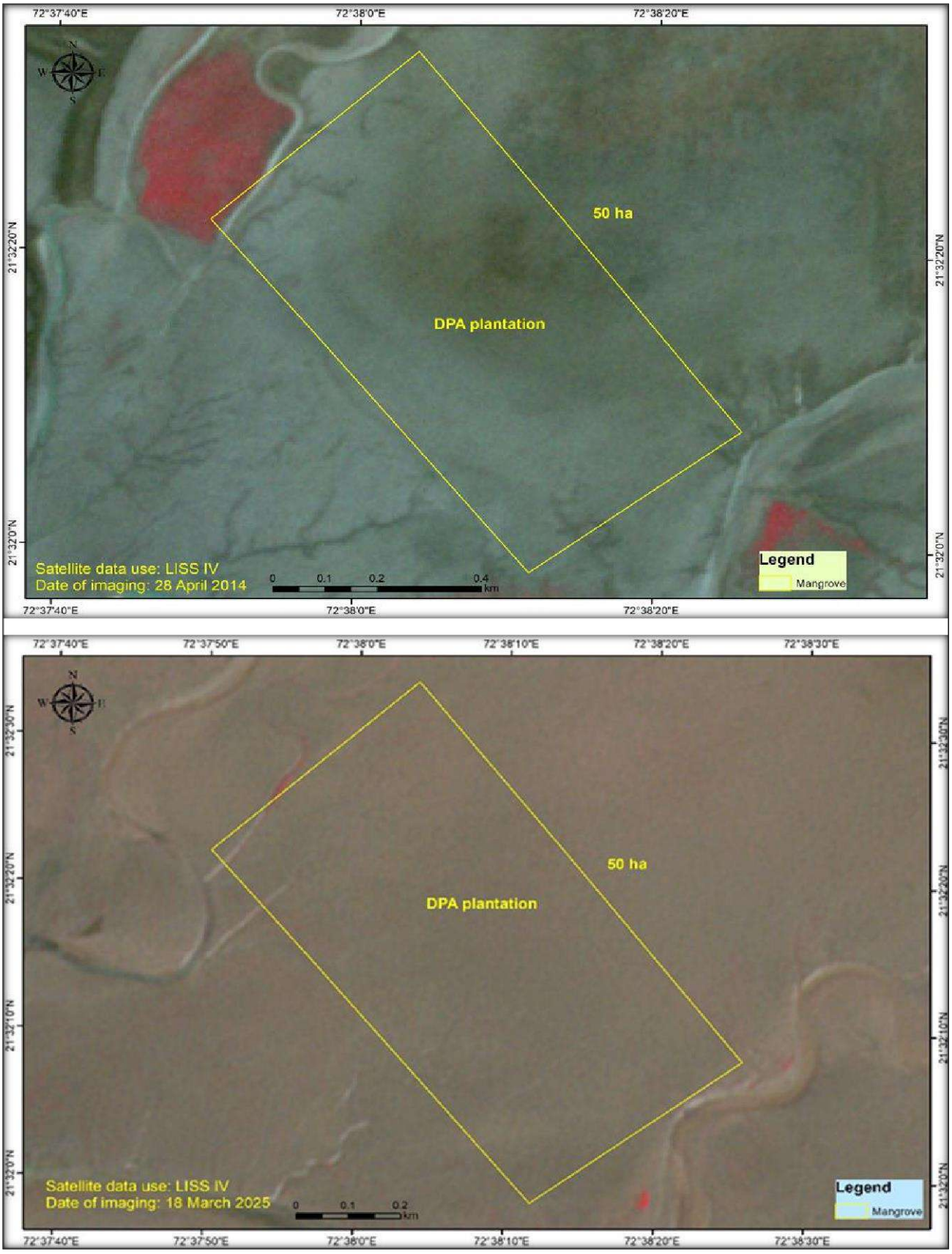

Figure 15: Satellite imageries of the 100 (50-1) Ha block-4 plantation site at Kantiyajal (2014 and 2025)

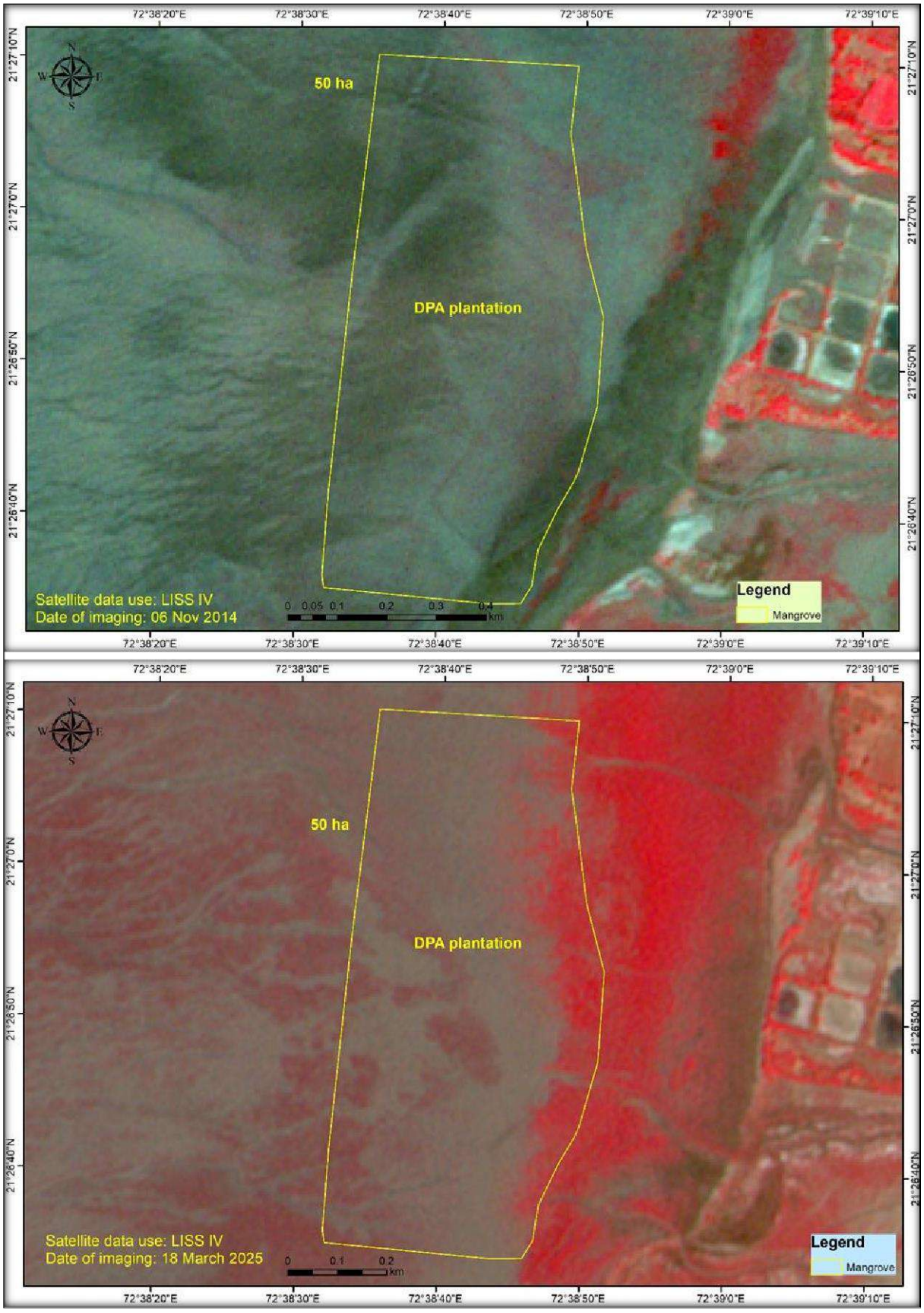

Figure 16: Satellite imageries of the 100 (50-2) Ha block-5 plantation site at Kantiyajal (2014 and 2025)

5.4 Regular mapping through GIS & RS

Mangrove plantations in 1600 ha was regularly monitored and mapped using RS and GIS facilities as part of the conservation and management efforts. The difference in mangrove density was assessed through ArcGIS (version 9.3) and ERDAS (version 9.3) and areas having restoration priority was identified for plantation activity. The table 2 provides a comprehensive overview of sampling sites within a 1,600-hectare mangrove plantation in Gujarat, India, detailing specific blocks and sampling points across three locations: Sat Saida Bet and Nakti Creek in Kachchh district, and Kantiyajal in Bharuch district. Each site is divided into several blocks base on year of plantation in three different areas, with each block containing multiple sampling and GIS points identified by precise geographic coordinates. This structure enables systematic ecological monitoring by allowing researchers to track environmental changes across different spatial scales and habitats within the plantation. The detailed coordinates facilitate accurate mapping and comparison of ecological data, supporting effective management and conservation of these vital mangrove ecosystems.

Table 2. Comprehensive Details of GIS and Sampling Sites within the 1600-Hectare Mangrove Plantation in 2025

Sat Saida Bet, Kachchh district				Nakti Creek, Kachchh district				Kantiyajal, Bharuch District			
HA	Sampling point	Longitude	Latitude	HA	Sampling point	Longitude	Latitude	HA	Sampling point	Longitude	Latitude
	Block -1				Block -1				Block -1		
20	1	70° 17' 3"	23° 4' 25"	50	1	70° 7' 22"	22° 57' 55"	150	1	72° 38′ 52.63″	21° 31′ 38.34″
	2	70° 16' 53"	23° 4' 25"		2	70° 7' 46"	22° 57' 57"		2	72° 38′ 41.87″	21° 31′ 31.73″
					3	70° 7'37.07"	22°57'50.13"		3	72° 38′ 41.31″	21° 31′ 19.26″
									4	72° 38′ 44.87″	21° 31′ 8.35″
									5	72° 38′ 52.66″	21° 31′ 8.14″
									6	72° 38′ 53.9″	21° 30′ 57.95″
									7	72° 38′ 47.47″	21° 30′ 54.83″
	Block -2				Block -2				Block -2		
200	1	70° 15' 13"	23° 2' 37"	100	1	70° 8' 17"	22° 57' 34"	150	1	72° 38′ 55.72″	21° 28′ 15.14″
	2	70° 15' 11"	23° 2' 46"		2	70° 8' 18"	22° 57' 30"		2	72° 38′ 59.27″	21° 28′ 5.57″

	3	70° 15' 22"	23° 2' 44"		3	70° 8' 22"	22° 57' 35"		3	72° 38′ 46.93″	21° 28′ 4.47″
	4	70° 15' 18"	23° 2' 21"		4	70° 8' 31"	22° 57' 28"		4	72° 38′ 34.92″	21° 28′ 8.45″
	5	70° 15' 29"	23° 2' 25"		5	70° 8' 32"	22° 57' 23"		5	72° 38′ 29.21″	21° 28′ 13.88″
	6	70° 15' 40"	23° 2' 34"						6	72° 38′ 26.62″	21° 27′ 58.01″
	7	70° 15' 52"	23° 2' 40"						7	72° 38′ 50.13″	21° 27′ 56.08″
	8	70° 15' 49"	23° 2' 48"								
	9	70° 15' 40"	23° 2' 43"								
	10	70° 15' 27"	23° 2' 36"								
	Block -3				**Block -3**				**Block -3**		
300	1	70° 15' 41"	23° 0' 40"					**50**	1	72° 38′ 46.3″	21° 27′ 4.29″
	2	70° 15' 43"	23° 0' 35"						2	72° 38′ 41.64″	21° 26′ 52.77″
	3	70° 15' 38"	23° 0' 29"						3	72° 38′ 44.8″	21° 26′ 41.13″
	4	70° 15' 34"	23° 0' 37"								
	5	70° 15' 31"	23° 0' 44"								
	6	70° 15' 26"	23° 0' 47"								
	7	70° 15' 22"	23° 0' 46"								
	8	70° 15' 5"	23° 0' 47"								
	9	70° 15' 7"	23° 0' 54"								
	10	70° 15' 1"	23° 0' 55"								

	11	70° 14' 55"	23° 0' 55"								
	12	70° 14' 52"	23° 0' 50"								
	13	70° 14' 49"	23° 0' 53"								
	14	70° 14' 47"	23° 0' 57"								
	15	70° 14' 42"	23° 1' 1"								
Block -4				Block -4				Block -4			
330	1	70° 17' 38"	23° 4' 30"					50	1	72° 38′ 51.29″	21° 27′ 32.55″
	2	70° 17' 50"	23° 4' 24"						2	72° 38′ 51.43″	21° 27′ 22.37″
	3	70° 17' 25"	23° 4' 31"						3	72° 38′ 49.22″	21° 27′ 17.0″
	4	70° 17' 10"	23° 4' 37"								
	5	70° 17' 55"	23° 4' 13"								
	6	70° 17' 42"	23° 4' 23"								
	7	70° 17' 15"	23° 4' 45"								
	8	70° 17' 27"	23° 4' 38"								
	9	70° 17' 35"	23° 4' 41"								
	10	70° 17' 42"	23° 4' 41"								
	11	70° 17' 47"	23° 4' 38"								
	12	70° 17' 54"	23° 4' 34"								
	13	70° 17' 16"	23° 4' 53"								
	14	70° 17' 24"	23° 4' 50"								
	15	70° 17' 31"	23° 4' 52"								
Block -5				Block -5						Block -5	

50	1	70°17'12.44"	23° 4'20.00"					50	1	72° 38′ 3.7″	21° 32′ 25.84″
	2	70°17'11.03"	23° 4'13.28"						2	72° 38′ 8.14″	21° 32′ 11.76″
	3	70°17'21.64"	23° 4'12.93"						3	72° 38′ 22.07″	21° 32′ 8.35″
Block -6				Block -6						Block -6	
100	1	70° 14' 18"	22° 59' 34"								
	2	70° 14' 31"	22° 59' 34"								
	3	70° 14' 40"	22° 59' 46"								
	4	70° 14' 56"	22° 59' 46"								

6. Results

The mangrove monitoring study results of the three sites, Nakti creek Kantiyajal and Sat Saida bet during 2025 are presented below.

6.1 Monitoring of mangrove plantation at Sat-Saida Bet

The 20 ha mangrove plantation was carried out at the Sat-Saida Bet near DPA port, Kandala. This plantation was carried out during the year 2005-06 by Gujarat institute of Desert Ecology, executed this plantation with the help of community participation. The results showing a high tree density of 2,200 trees per hectare. The average tree height is reported as 139.09 cm, while the average girth is 10.36 cm indicating relatively young or slender trees. The average canopy width is 2.3 meters, suggesting moderate foliage coverage. Overall, this area appears to be densely populated with slim, possibly young trees, and the height value should be double-checked for accuracy (Plate 1).

Plate 1: Mangrove plantation 20 Ha at Sat Saida Bet site Block- 1 during a visit in 2025

The Plate 2 and figure 17 and 18 shows information from ten quadrants (Q1-Q10) within a 200-hectare area, including tree density, average height, and girth, ocular diameter of the trunk and canopy cover. Densities have quite a range of 1,200 to 3,800 trees per quadrant. Tree heights and girths do not differ tremendously, but the canopy cover is rather balanced with some quadrants such as Q5 having fairly high canopy values compared to all other quadrants density, while other quadrants like Q7 and Q10 with very high density having lower canopy values. This implies that greater tree density does not always result in increased canopy cover due to competition for resources affecting the tree growth and canopy expansion. Collectively, the data reveals the diversity in the structure of forests throughout the area sampled.

Plate 2: Mangrove plantation 200 Ha at Sat Saida Bet site Block- 2 during a visit in 2025

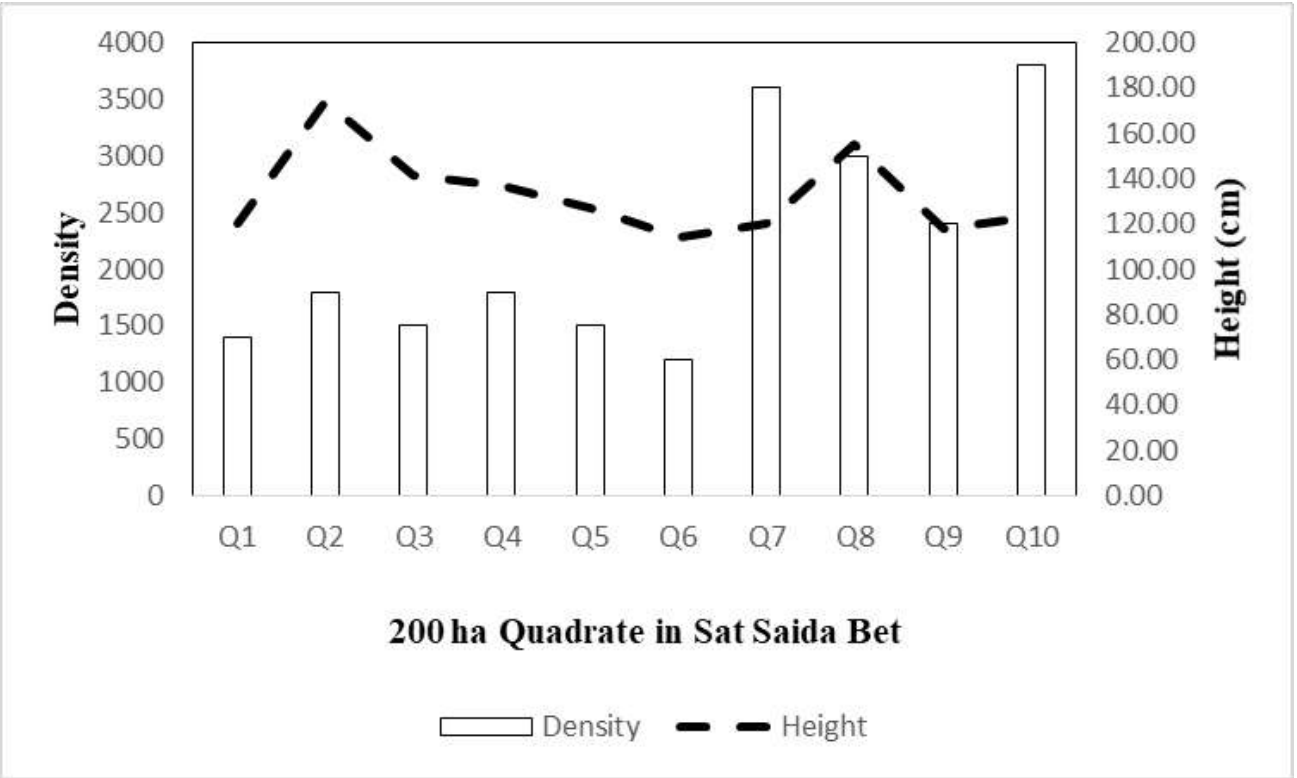

Fig.17 Details of density (No) and height of mangroves in 200 ha plantation area in 2011-2012 at Sat Saida Bet.

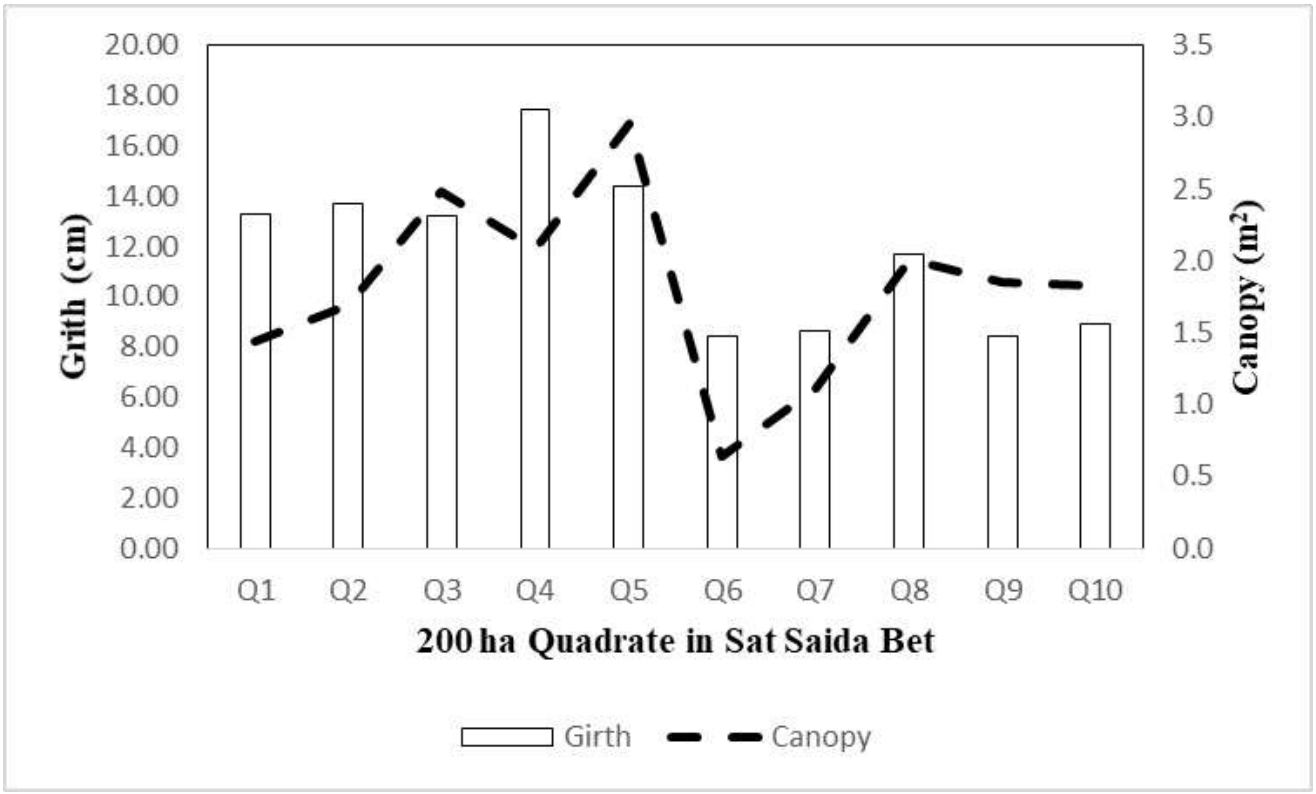

Fig. 18 Details of Canopy and Basal Girth of mangroves in 200 ha plantation area in 2011-2012 at Sat Saida Bet.

The monitoring result information related to a 300-hectare site presented in the figure 19 and 20 and plate 3 demonstrates that density of trees in this area ranges from 1300 to 2600 individuals at its peak in Q5 and lowest in Q8. Average height of the trees is from 128 to142 cm with the highest in Q6 whereas girth ranges from 11.73 to 15 cm, maxima in Q3. Canopy cover usually increases with value of height and is at its max Q6 of 2.01 and min of 1.61 m^2. The data can be interpreted that degree of density does not correlate with amount of height or girth.

Plate 3: Mangrove plantation 300 Ha at Sat Saida Bet site Block- 3 during a visit in 2025

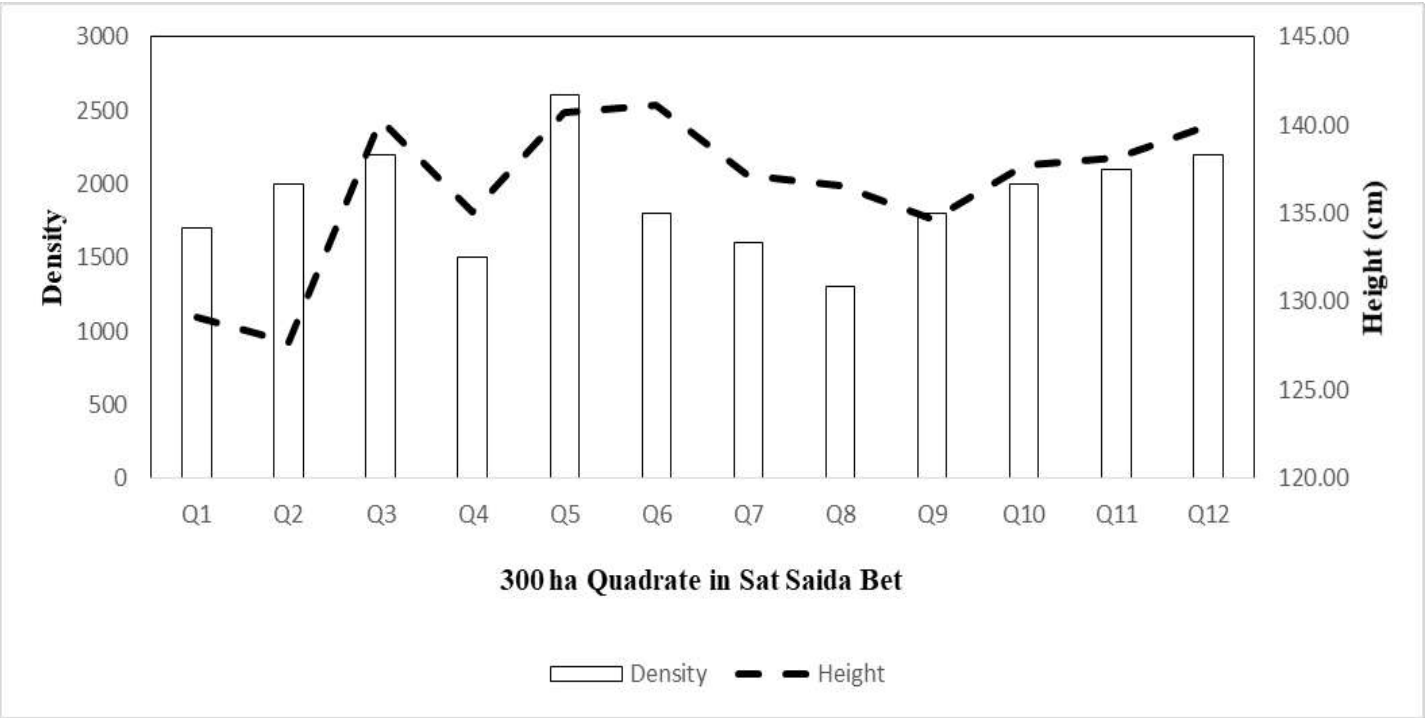

Fig.19 Details of density (No) and height of mangroves in 300 ha plantation area in 2012-2013 at Sat Saida Bet.

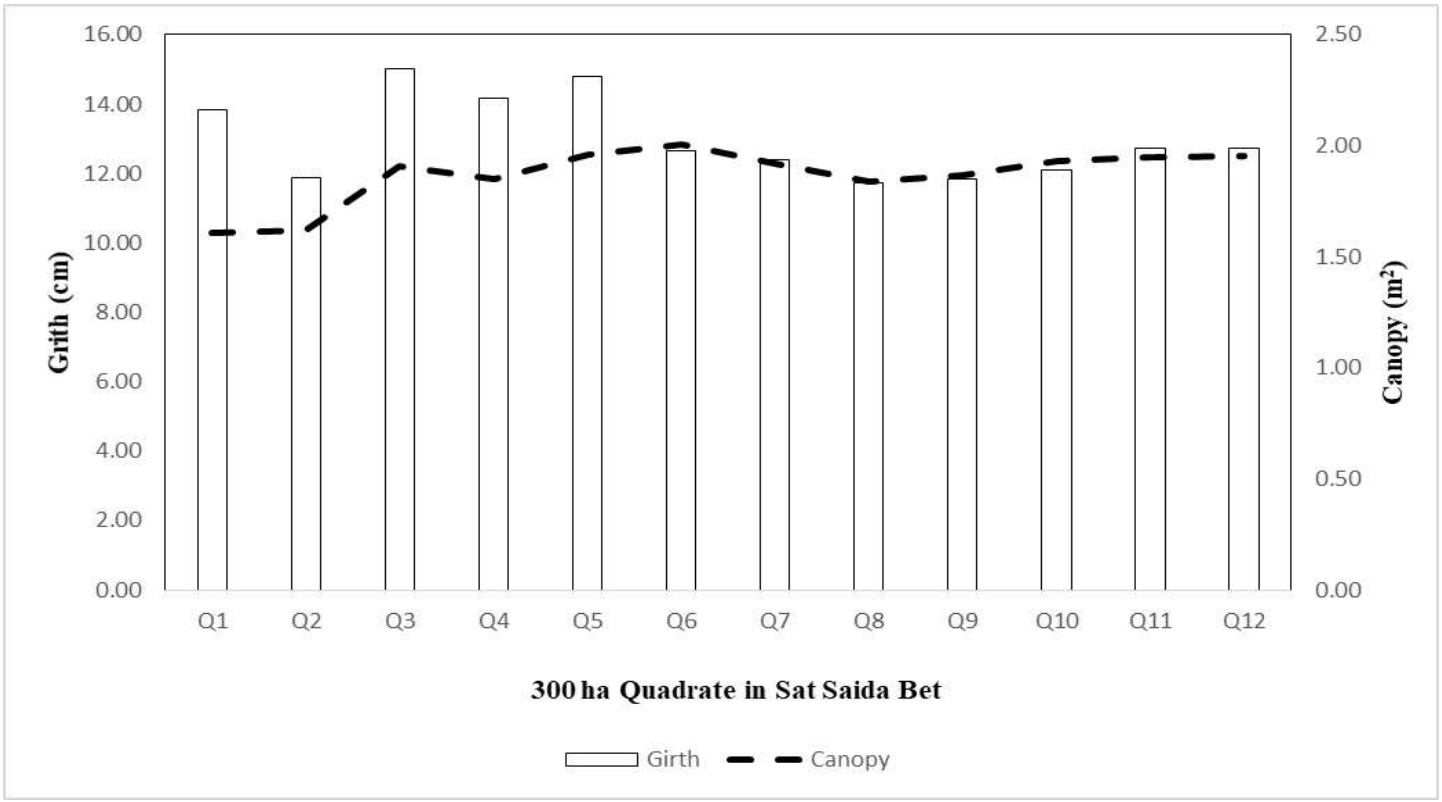

Fig.20 Details of Canopy and Basal Girth of mangroves in 300 ha plantation area in 2012-2013 at Sat Saida Bet.

The plate 4 and figure 21 and 22 shows the data on tree measurements across fourteen (Q1 to Q14) quadrants within an area of 330 ha detailing density, height, girth and canopy spread. The density seems to vary in a very wide range of 1300 to 4000 trees/ha, with a greater density often relating to lesser girth and canopy size which indicates that there is competition for resources. The height of the trees measured ranges from 127cm to 185cm, the girth ranges from 8 to 15 cm and the canopy spread from 1.08 to 3.12 m^2. It is worth mentioning that quadrants which contain lower density like Q5 and Q11 tend to have their girth and canopy size greatly expanded hence suggesting that trees which are in sparser regions are able to grow broader and larger in canopies.

Plate 4: Mangrove plantation 330 Ha at Sat Saida Bet site Block- 4 during a visit in 2025

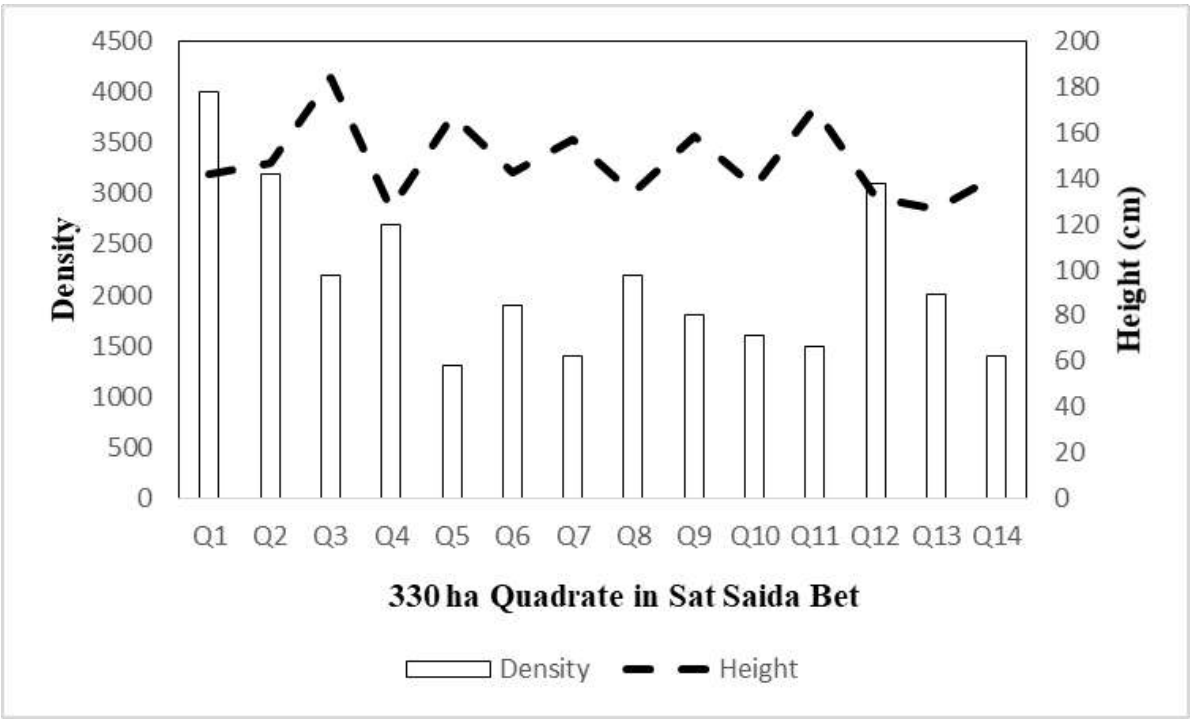

Fig. 21 Details of density (No) and height of mangroves in 330 ha plantation area in 2013-2014 at Sat Saida Bet

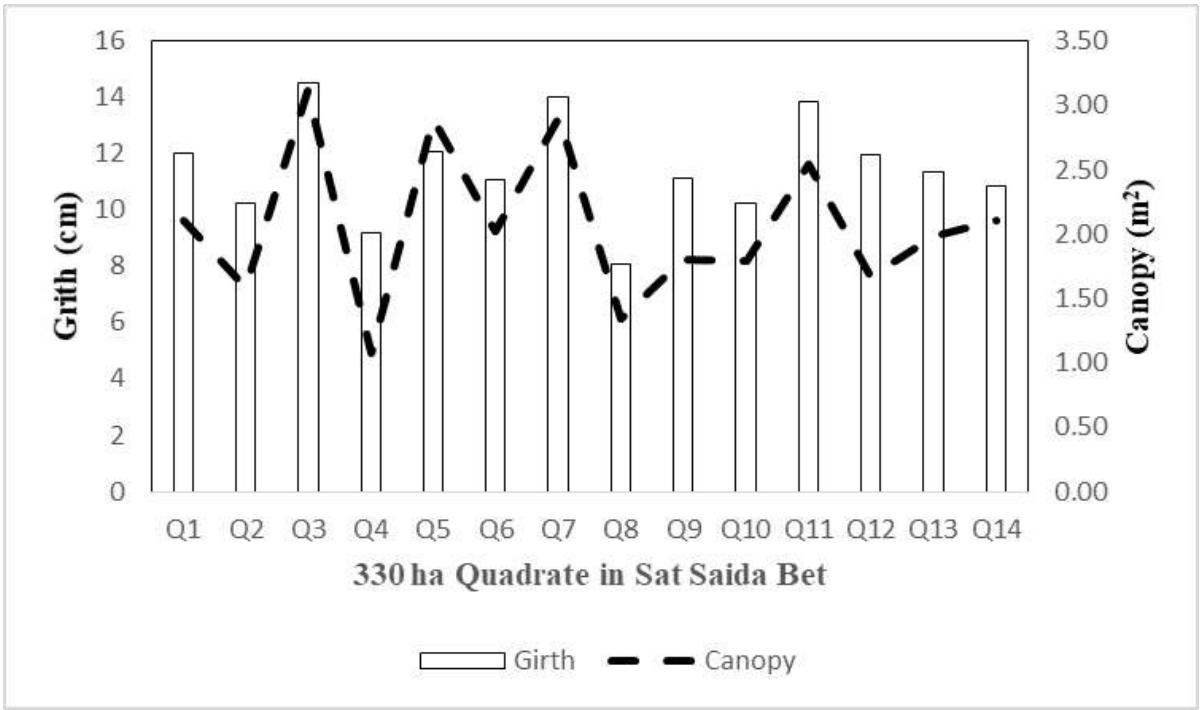

Fig. 22 Details of Canopy and Basal Girth of mangroves in 330 ha plantation area in 2013-2014 at Sat Saida Bet.

The figures 23 and 24; plate 5 illustrate that in a 50 hectare area in Sat Saida Bet, Q1 sustains the highest tree density at 2200 trees as well as the tallest average height of 133.64 and also has the largest average girth of 15.18 and broadest average canopy of 1.8 indicating a more mature. In addition, Q2 and Q3 have even lower densities of 900 and 1200 trees respectively alongside progressively smaller average height, girth, and canopy values suggesting these areas are relatively younger, less established, or more disturbed in comparison to Q1.

Plate 5: Mangrove plantation 50 Ha at Sat Saida Bet site Block- 5 during a visit in 2025

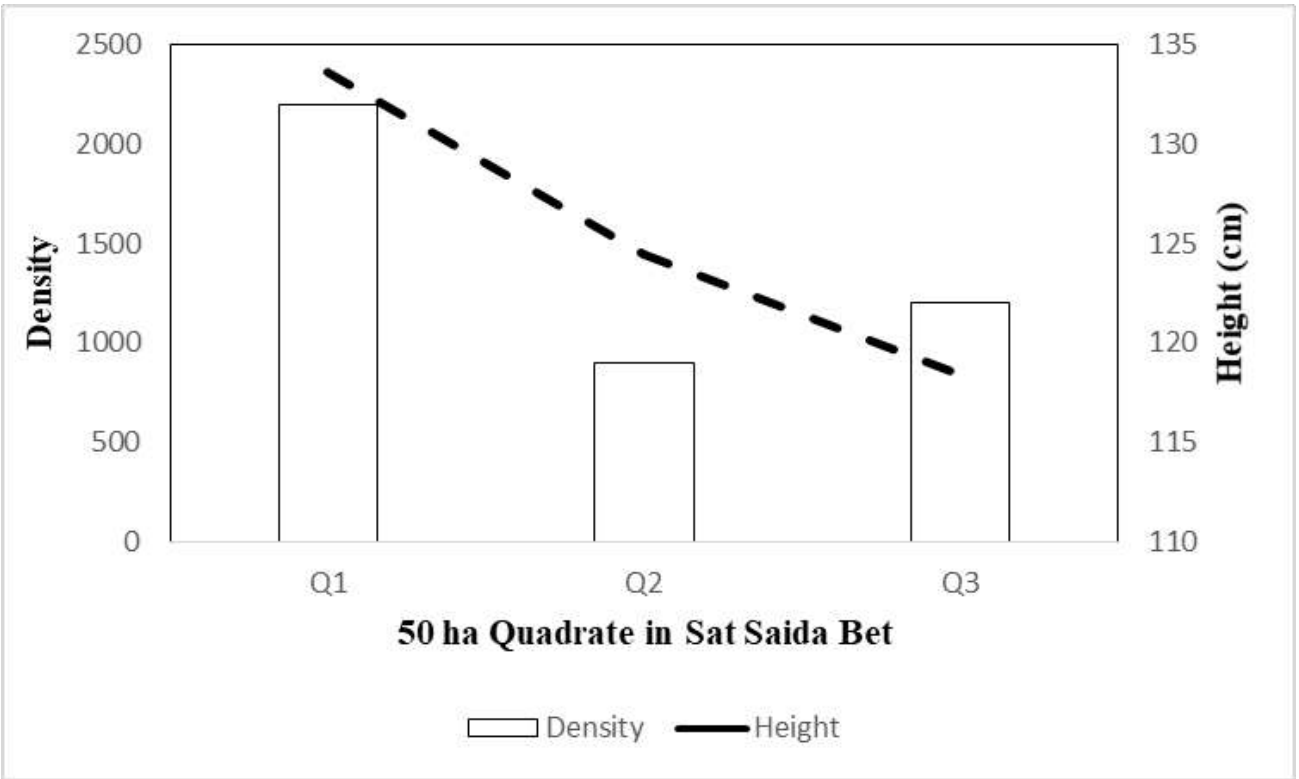

Fig.23 Details of density (No) and height of mangroves in 50 ha plantation area in 2018-2019 at Sat Saida Bet.

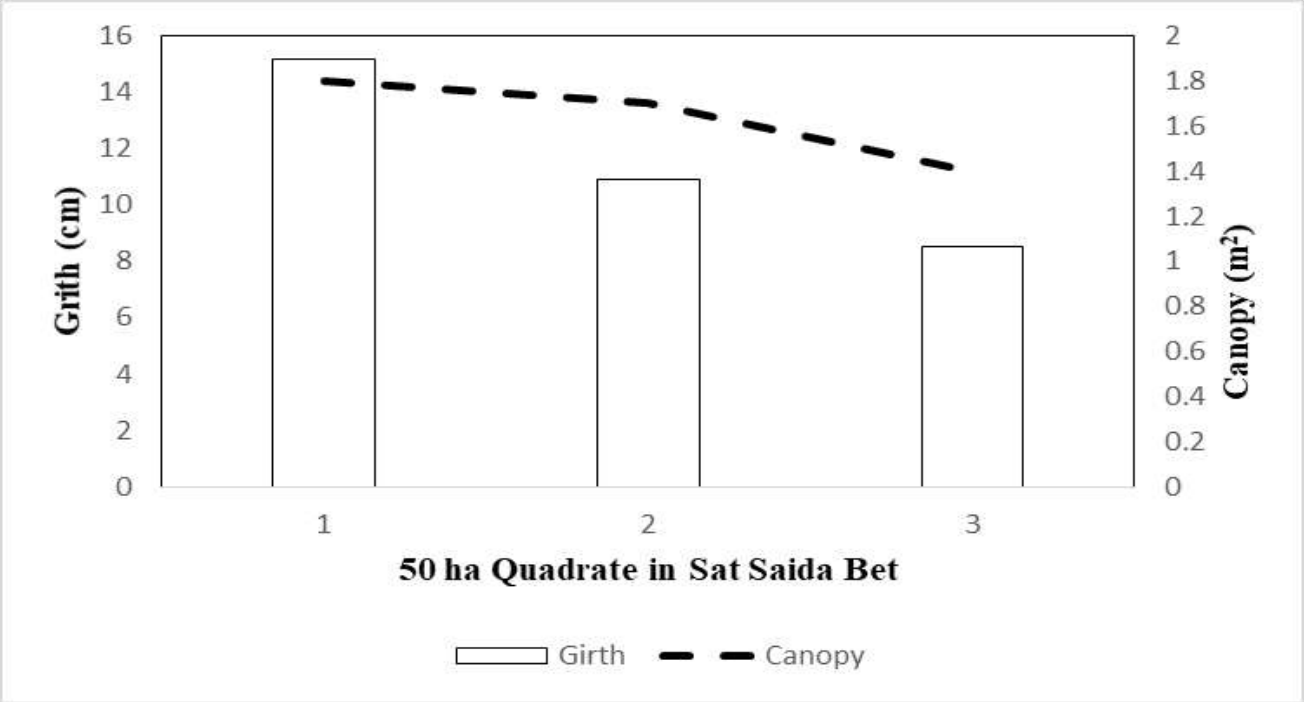

Fig. 24 Details of Canopy and Basal Girth of mangroves in 50 ha plantation area in 2018-2019 at Sat Saida Bet.

The tree population data regarding their density, height, girth, and canopy spread is presented through five quadrants (Q1–Q5) in a 100-hectare range. Q1 has the highest trees that measure 224 cm as well as having the largest girth of 17 cm and the highest canopy cover of 5.60 m^2; though having moderate density of 1000. On the contrary, Q2 displays the lowest density of 100, shortest trees of 100 measuring the smallest girth of 7 cm, and the lowest canopy of 0.72 m^2 which points towards undeveloped sparse vegetation. Q4 has the highest density (1300) average tree height of (115), girth (8), moderate canopy of (1.15) indicating denseness but less mature trees. Q3 and Q5 display median ranges for all parameters. It can also be seen from the data that forest structure is most characteristic in Q1 which shows a stand of fewer taller trees, as opposed to Q4 which has more, but smaller trees. (Plate 6; Figure 25 and 26). There are few natural grow trees are observed.

Plate 6: Mangrove plantation 100 Ha at Sat Saida Bet site Block- 6 during a visit in 2025

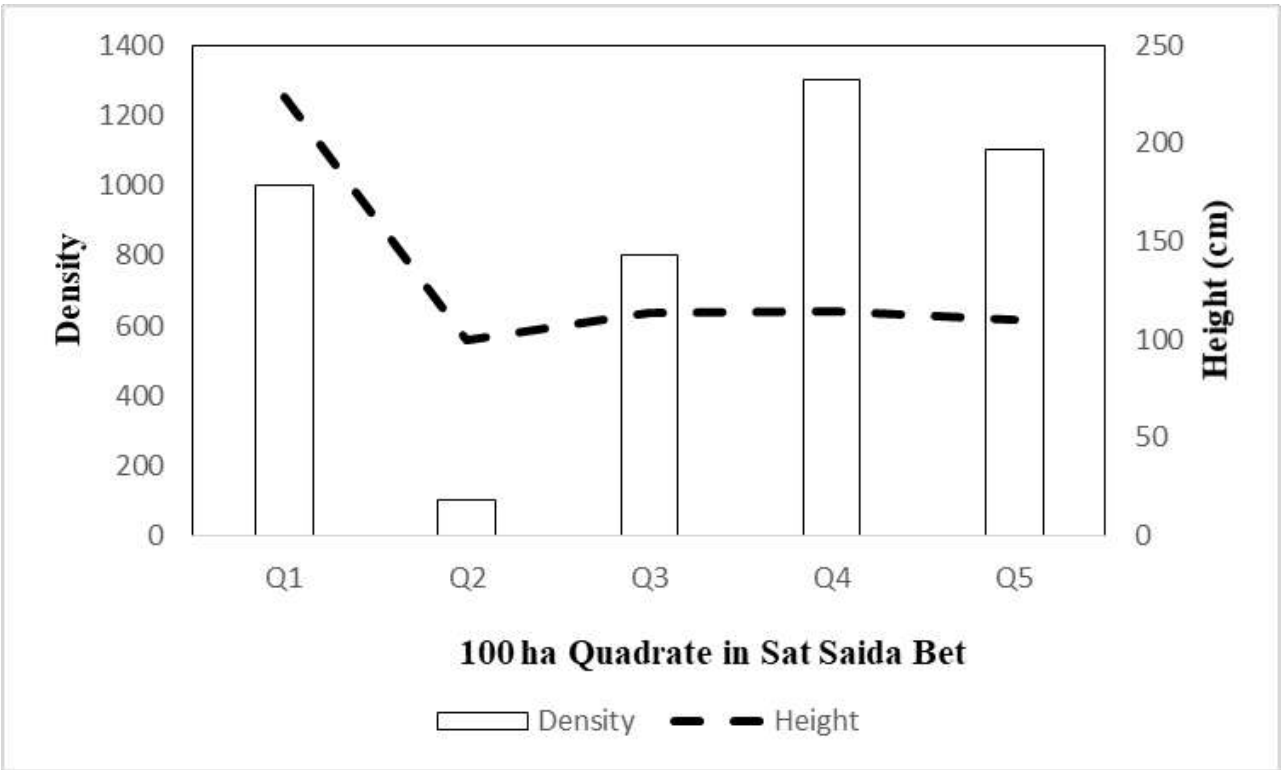

Fig. 25 Details of density (No) and height of mangroves in 100 ha plantation area in 2022-2023 at Sat Saida Bet

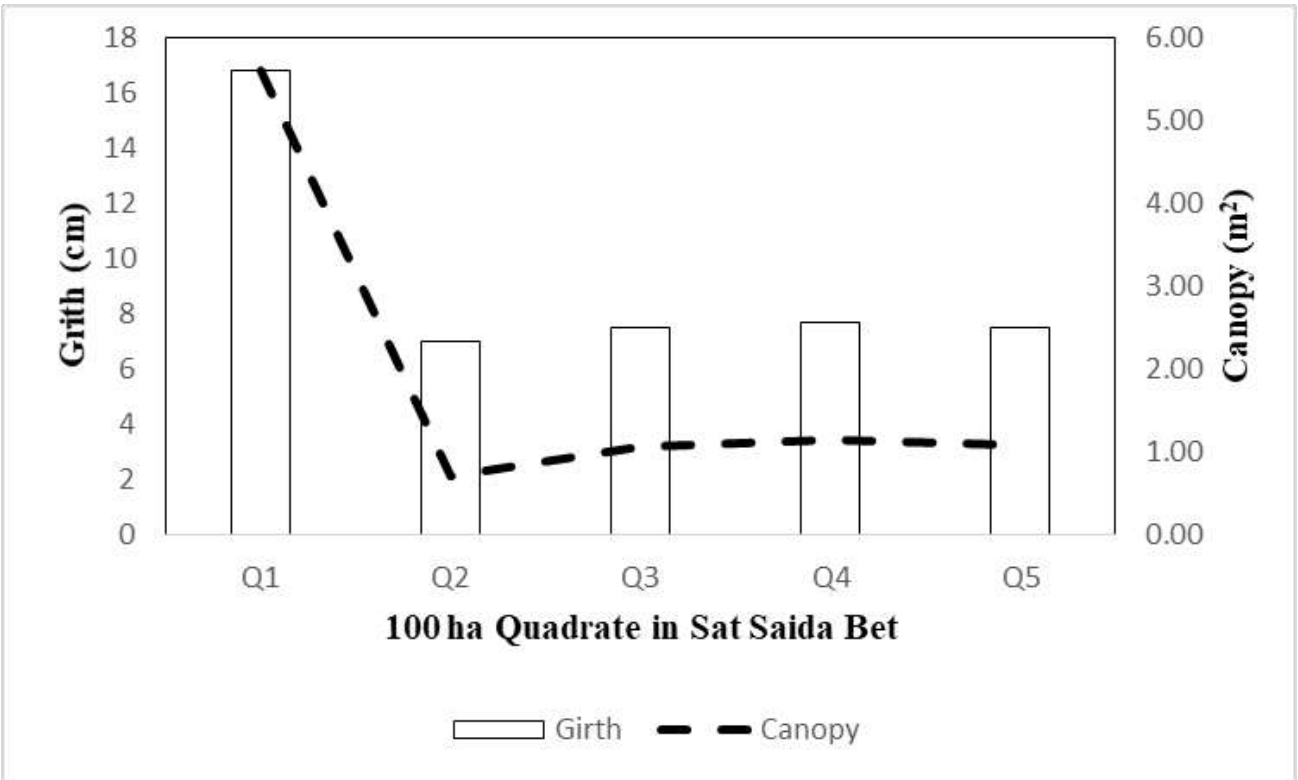

Fig. 26 Details of Canopy and Basal Girth of mangroves in 100 ha plantation area in 2022-2023 at Sat Saida Bet.

6.2 Monitoring of mangrove plantation at Nakti Creek

The figure 27 and 28; Plate 7 summarizes the structural characteristics of mangroves in a 50-hectare plantation at Nakti Creek during 2008-2009, comparing two quadrants (Q1 and Q2). Q1, with a higher density of 1500 trees per hectare, shows smaller average tree height (175 cm), basal girth (9 cm), and canopy spread (2.0 m). In contrast, Q2, with a lower density of 500 trees per hectare, has mangroves that are taller (182 cm), have thicker trunks (11 cm girth), and wider canopies (3.7 m).

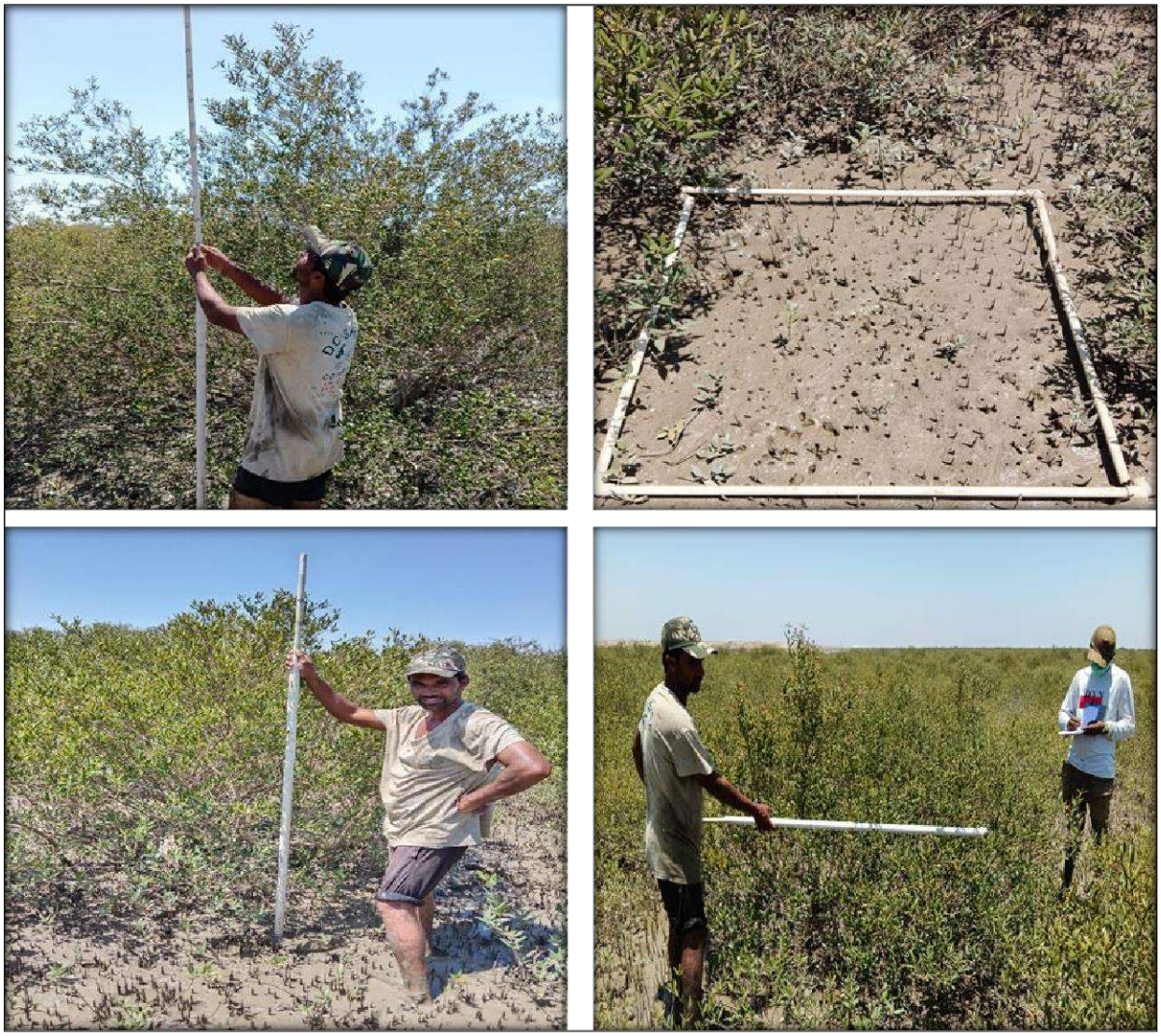

Plate 7: Mangrove plantation 50 Ha at Nakti Creek site Block- 1 during a visit in 2025

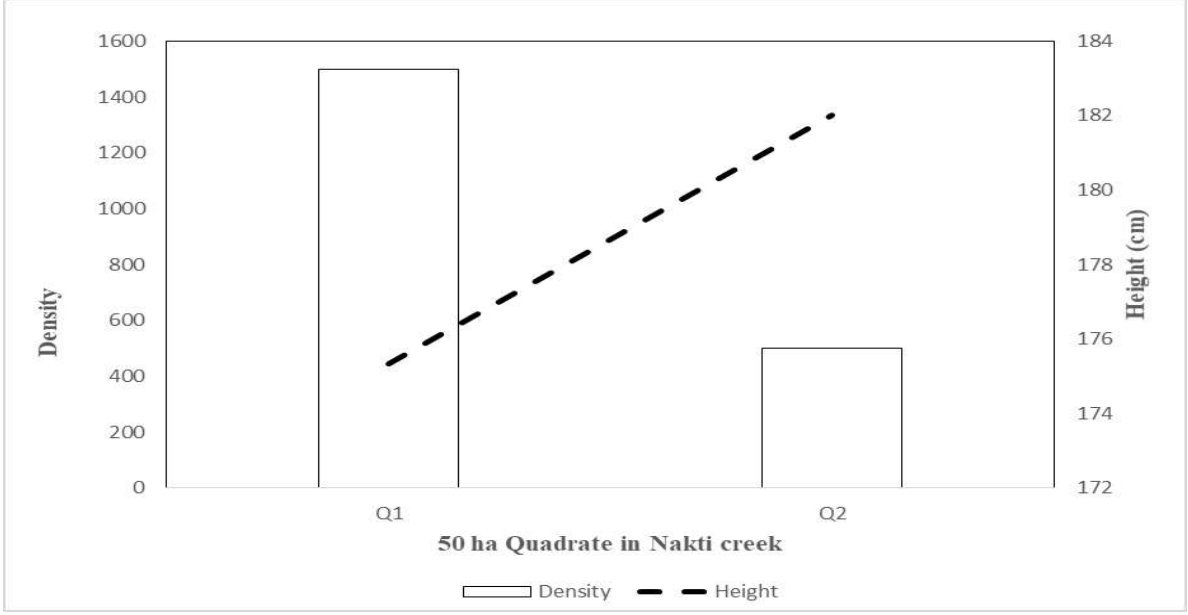

Fig. 27 Details of density (No) and height of mangroves in 50 ha plantation area in 2008-2009 at Nakti Creek.

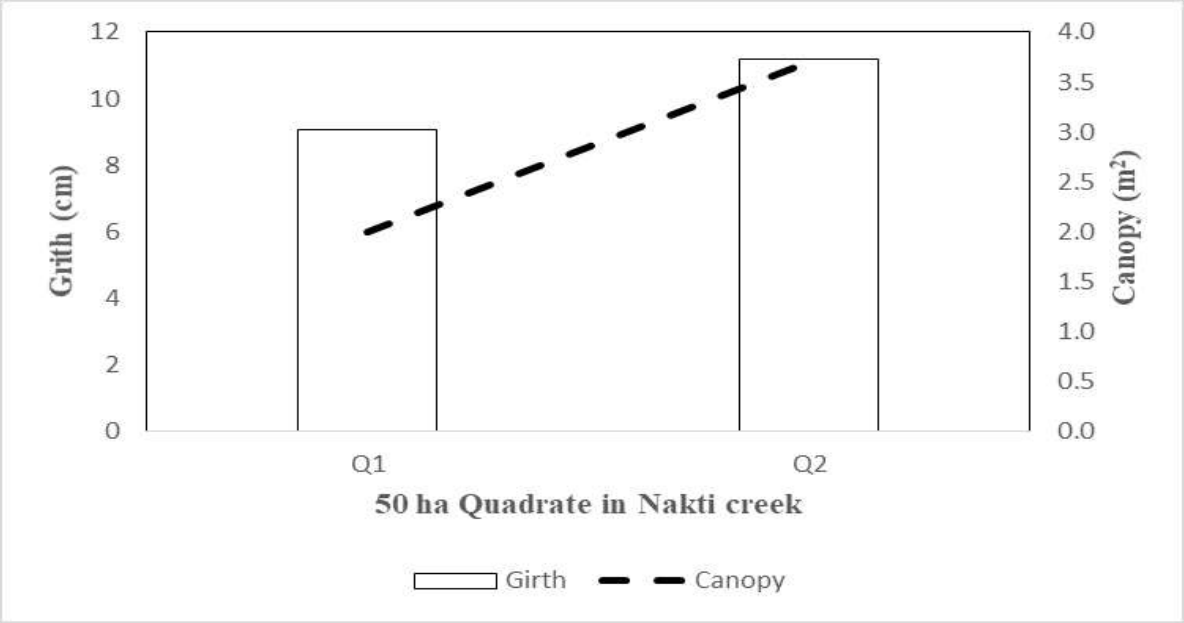

Fig. 28 Details of Canopy and Basal Girth of mangroves in 50 ha plantation area in 2008-2009 at Nakti Creek.

The Figure 29 illustrates the variations in tree density, height, girth and canopy size in five quadrants (Q1-Q5) over a 100 hectare mangrove plantation area in 2010-2011, which shows remarkable differences across that space. Q2 contains the greatest tree density (1600/Ha) along with a height that is above average (156 m) and broad canopy (3.8 m). Q5 contains the lowest density trees (1000/Ha), but reaches remarkable height (171 m) signifying that lesser competition might allow stretched growth. Moderate density in Q3 possessing the thickest trunks (15 cm girth) along with 3.5 m wide canopy could identify older or stouter trees. Q1 without exception has lower values for each of the parameters which suggests younger trees or less competitive stands, whereas Q4 shows intermediate figures 30 and plates 8.

Plate 8: Mangrove plantation 100 Ha at Nakti Creek site Block- 2 during a visit in 2025

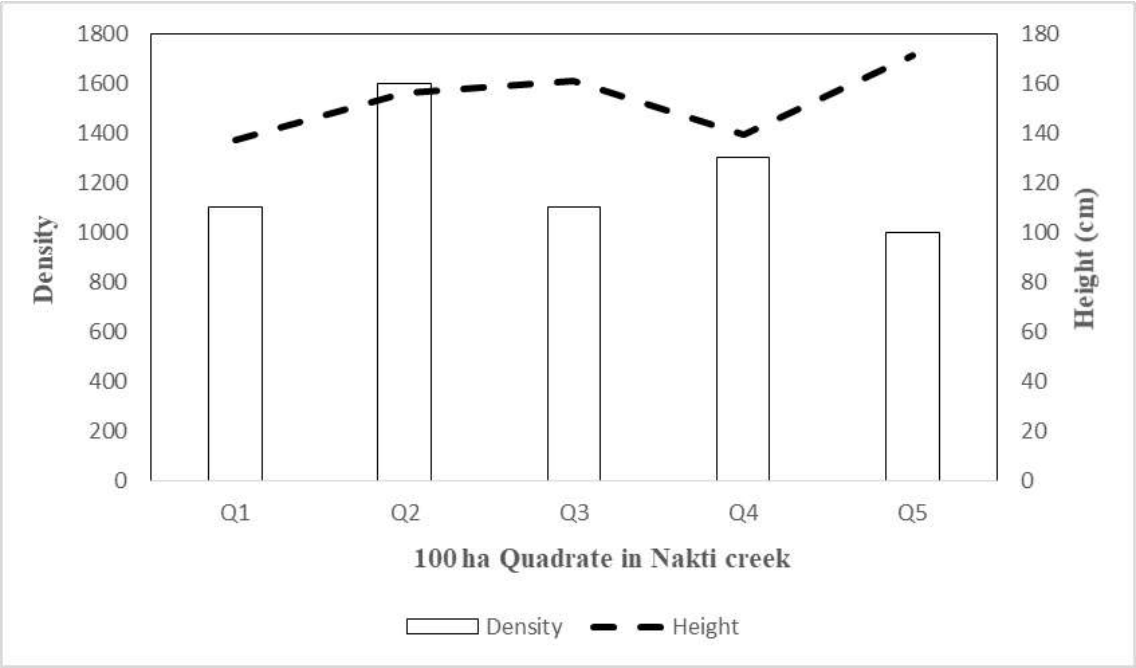

Fig.29 Details of density (No) and height of mangroves in 100 ha plantation area in 2010-2011 at Nakti Creek

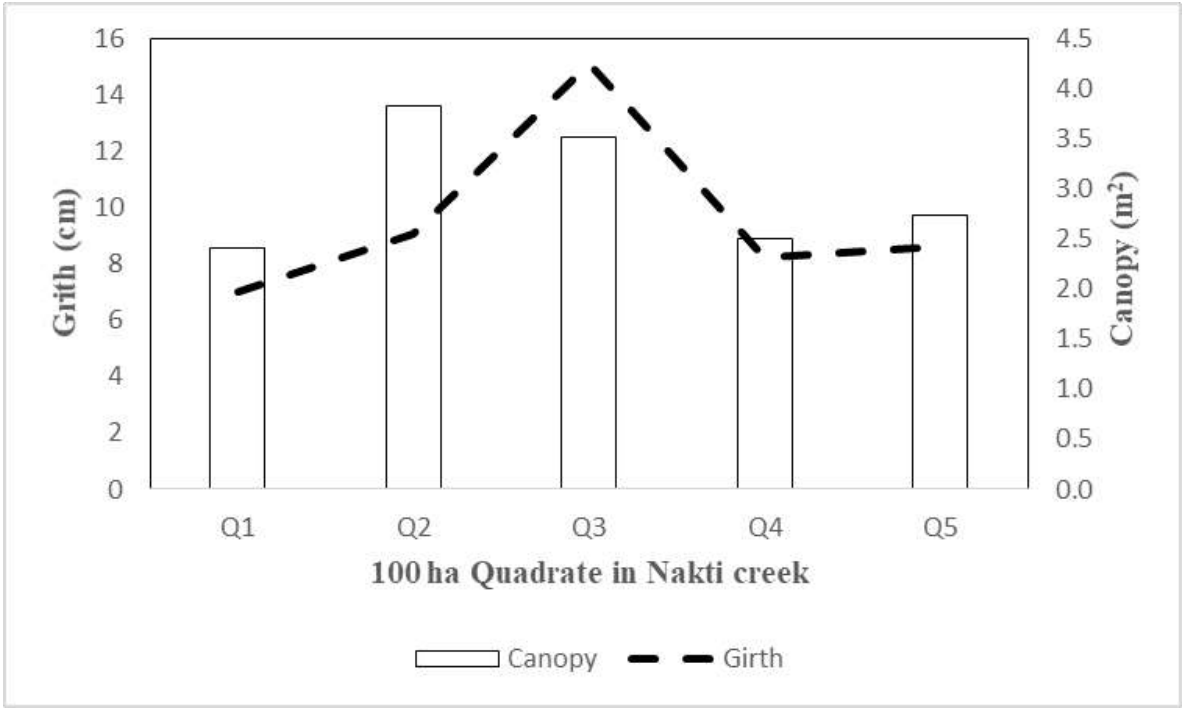

Fig.30 Details of Canopy and Basal Girth of mangroves in 100 ha plantation area in 2010-2011 at Nakti Creek.

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6.3 Monitoring of mangrove plantation at Kantiyajal

The plate 9 and figure 31 and 32 illustrates the data of tree density, mean height, girth and canopy size of individual quadrants from seven quadrants (Q1 – Q7) that lie within a 150-hectare area at kantiyajal mangrove plantation area. The values exhibit considerable: densities were found between 500 and 1200, height ranged from 108 to 152 cm, girth was between 7 and 12 cm, and canopy span varied from 0.51 to 2.29 m^2, Q2 contains the highest trees (152) but Q2 has the moderate canopy (1.24 m^2). Furthermore, Q1 and Q5 have the greater canopies (2.29 and 2.07 m^2) but have average heights. Such data can be used to study forest structure, tree growth, and the habitat diversity in the surveyed region.

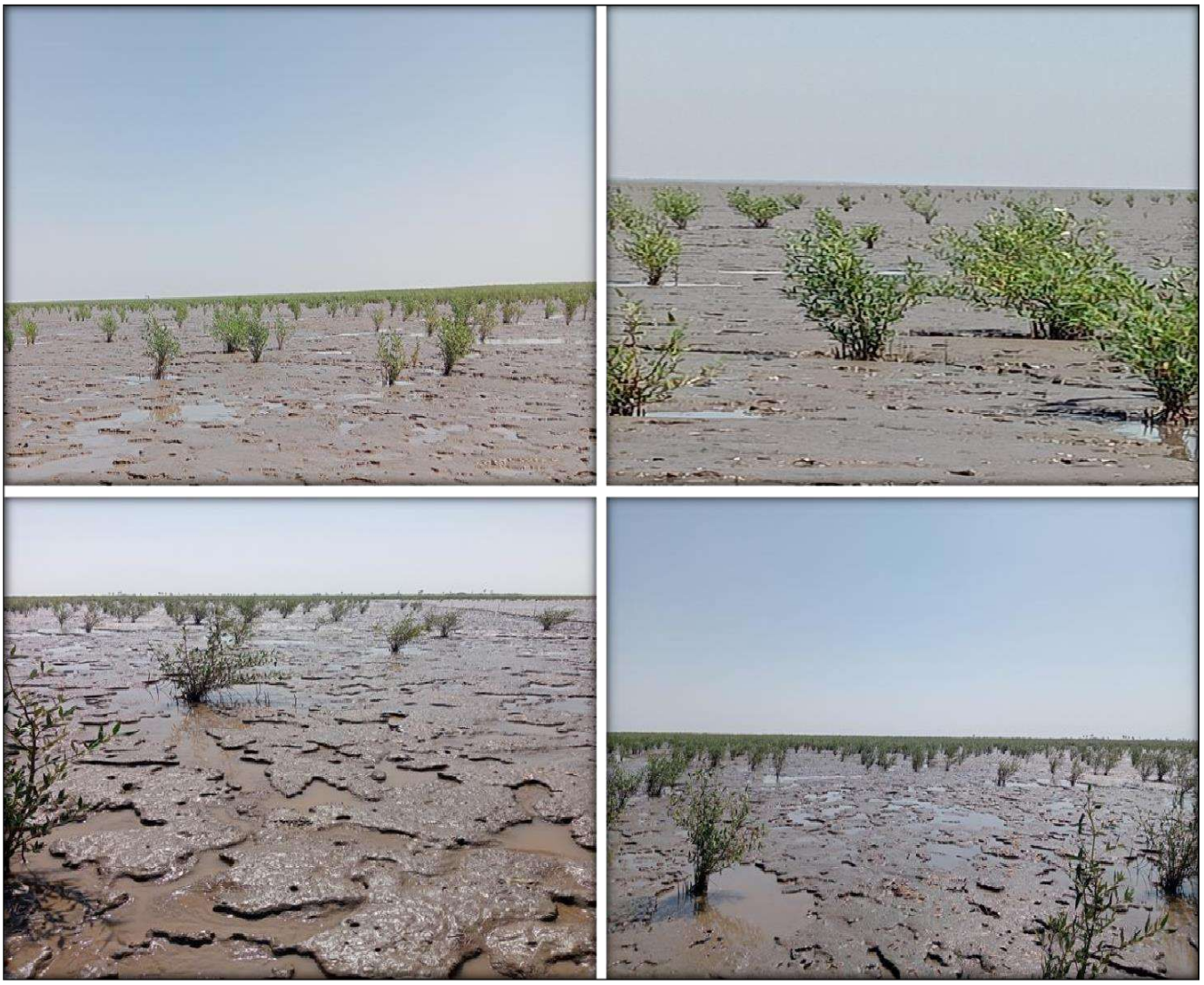

Plate 9: Mangrove plantation 150 Ha at Kantiyajal site Block- 1 during a visit in 2025

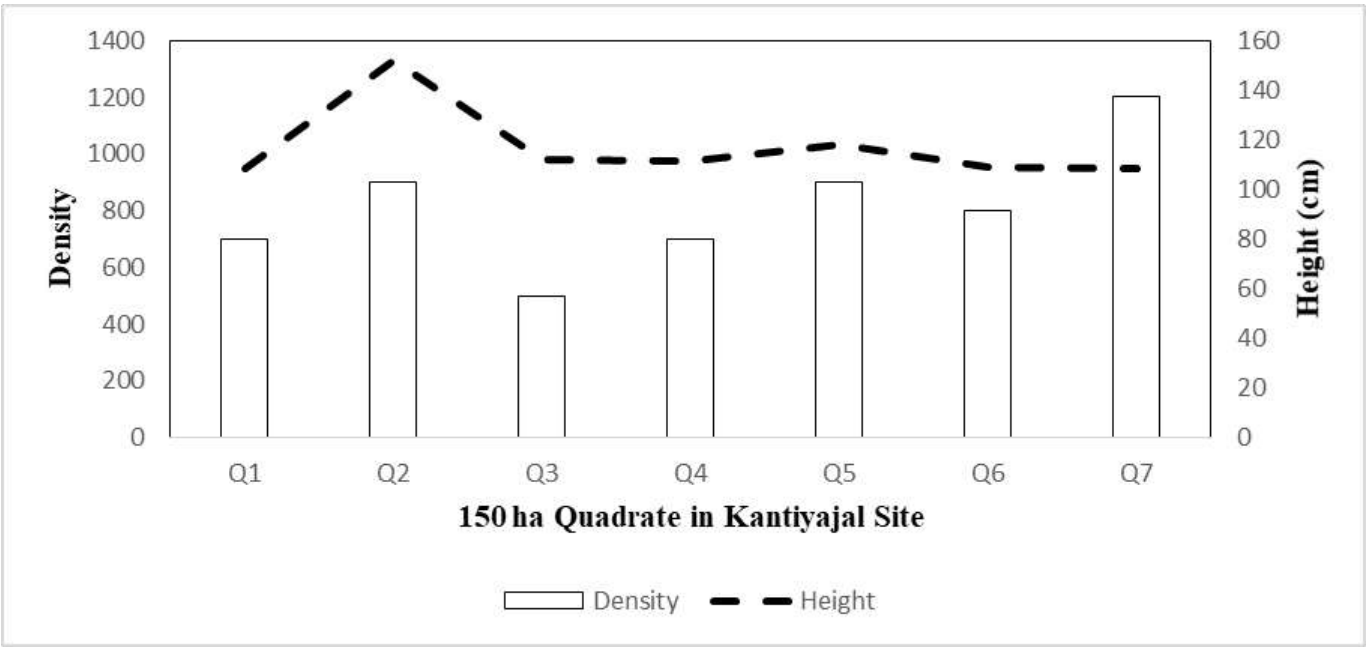

Fig.31 Details of density (No) and height of mangroves in 150 ha plantation area in 2015-2016 at Kantiyajal site

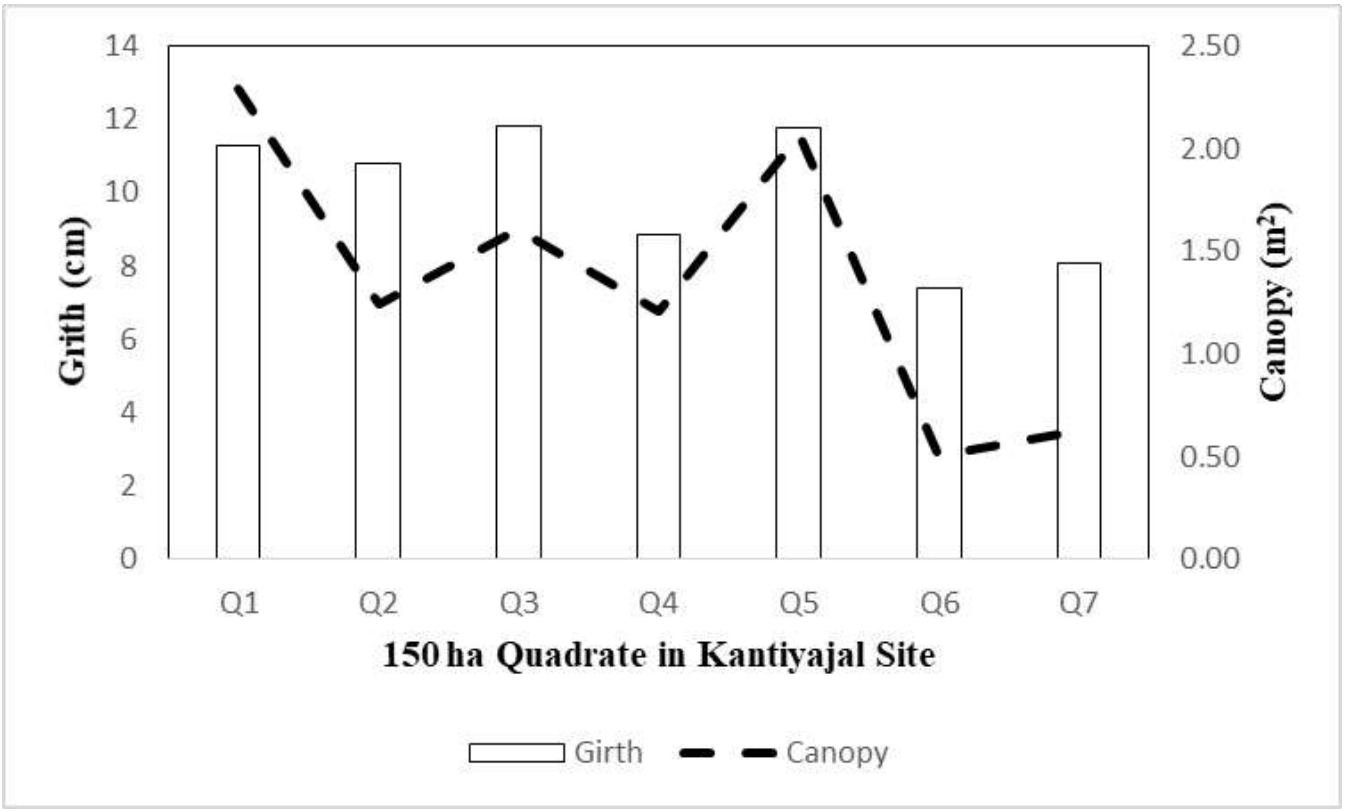

Fig.32 Details of Canopy and Basal Girth of mangroves in 150 ha plantation area in 2015-2016 at Kantiyajal site

The plate 10 shows the area where 150 ha were mangrove planted from 2016 to 2017. Since this area were many sparse mangroves with a height of less than 70 cm and a girth of less than 8 cm. The densities values also very low compare to other site were significant between 500 and 800 plants/ ha.

Plate 10: Mangrove plantation 150 Ha at Kantiyajal site Block- 2 during a visit in 2025

Plate 11: Mangrove plantation 50 Ha at Kantiyajal site Block- 3 during a visit in 2025

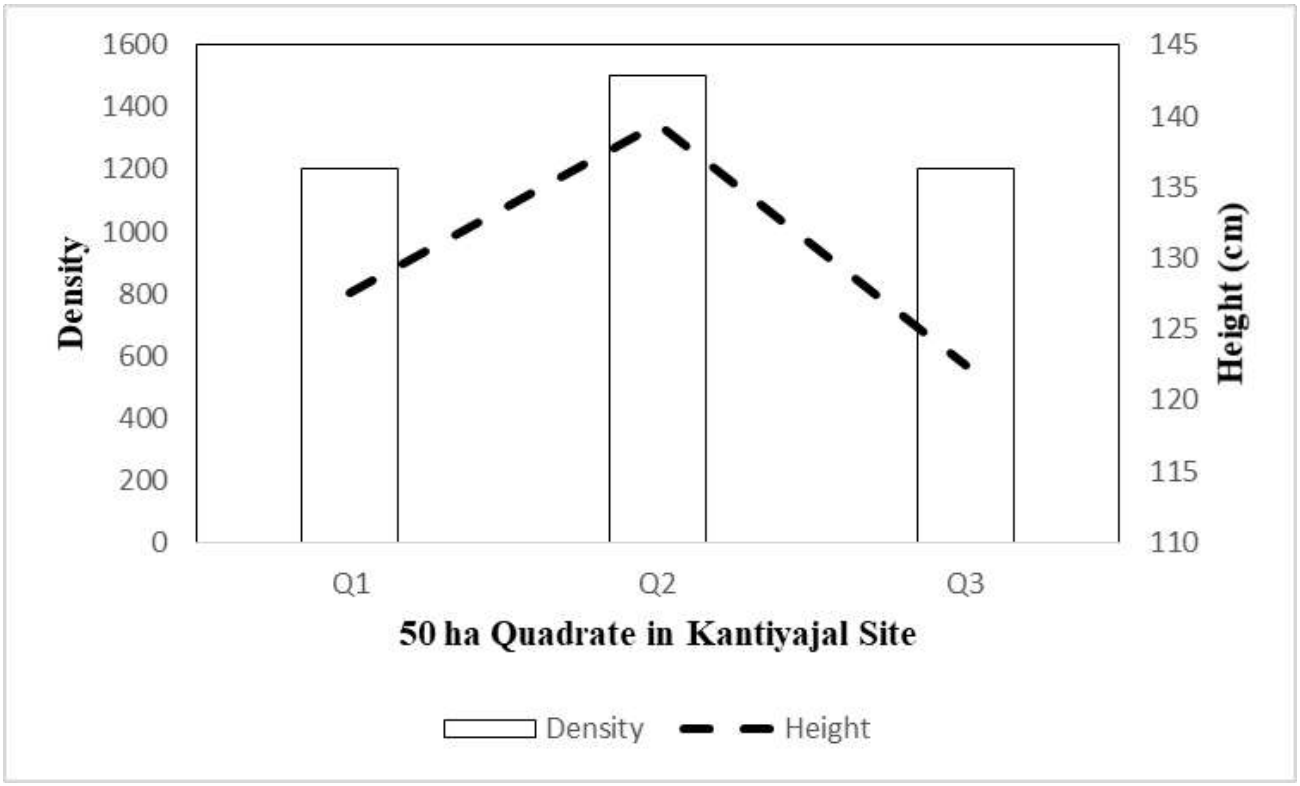

Fig.33 Details of density (No) and height of mangroves in 50 ha plantation area in 2018-2019 at Kantiyajal site

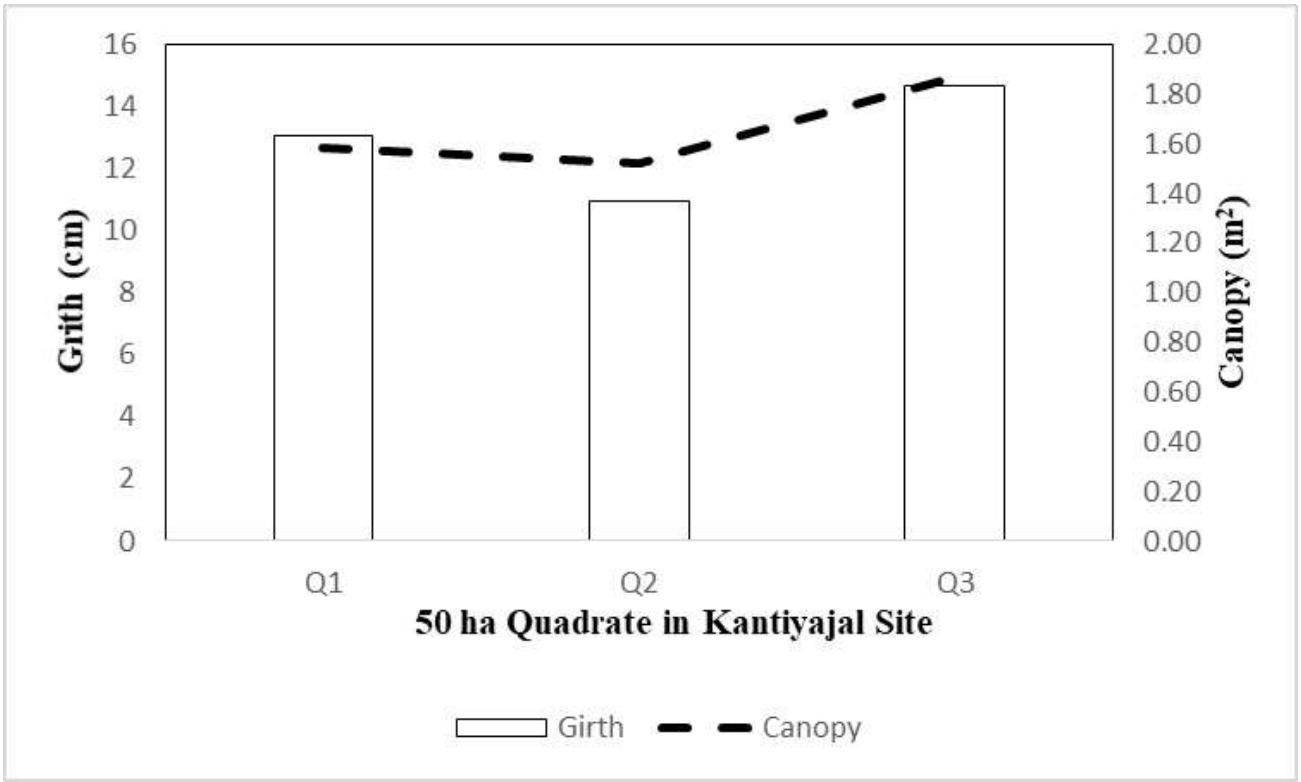

Fig.34 Details of Canopy and Basal Girth of mangroves in 50 ha plantation area in 2018-2019 at Kantiyajal site

The plate 12 shows that 50 mangrove plantation area planted area 2021 to 2022. The area was sparse so many mangrove less than 50 cm height and girth less than 6 cm. The values exhibit considerable, densities were found less than 300.

Plate 12: Mangrove plantation 100 (50-1) Ha at Kantiyajal site Block- 4 during a visit in 2025

The plate 13 and figure 35 and 36 presents data for three quarters (Q1, Q2, Q3) over a 50-hectare area in mangrove plantation 100 (50-2) Ha area in 2021-2022 at Kantiyajal site , showing tree density, average height, girth, and canopy size. In Q1, the density is 600 trees/ha, height is 116 cm, girth is 7 cm, and canopy is 3.4 m^2. In Q2, density increases to 700, height slightly decreases to 113 cm, girth remains 7 cm, but canopy drops sharply to 0.8 m^2. By Q3, density peaks at 1000, height rises to 123 cm, girth increases to 7.40 cm, and canopy recovers to 1.7 m^2. Overall, the data suggests fluctuations in tree characteristics, with density and height generally increasing, but canopy size showing significant variation across quarters.

Plate 13: Mangrove plantation 100 (50-2) Ha at Kantiyajal site Block- 5 during a visit in 2025

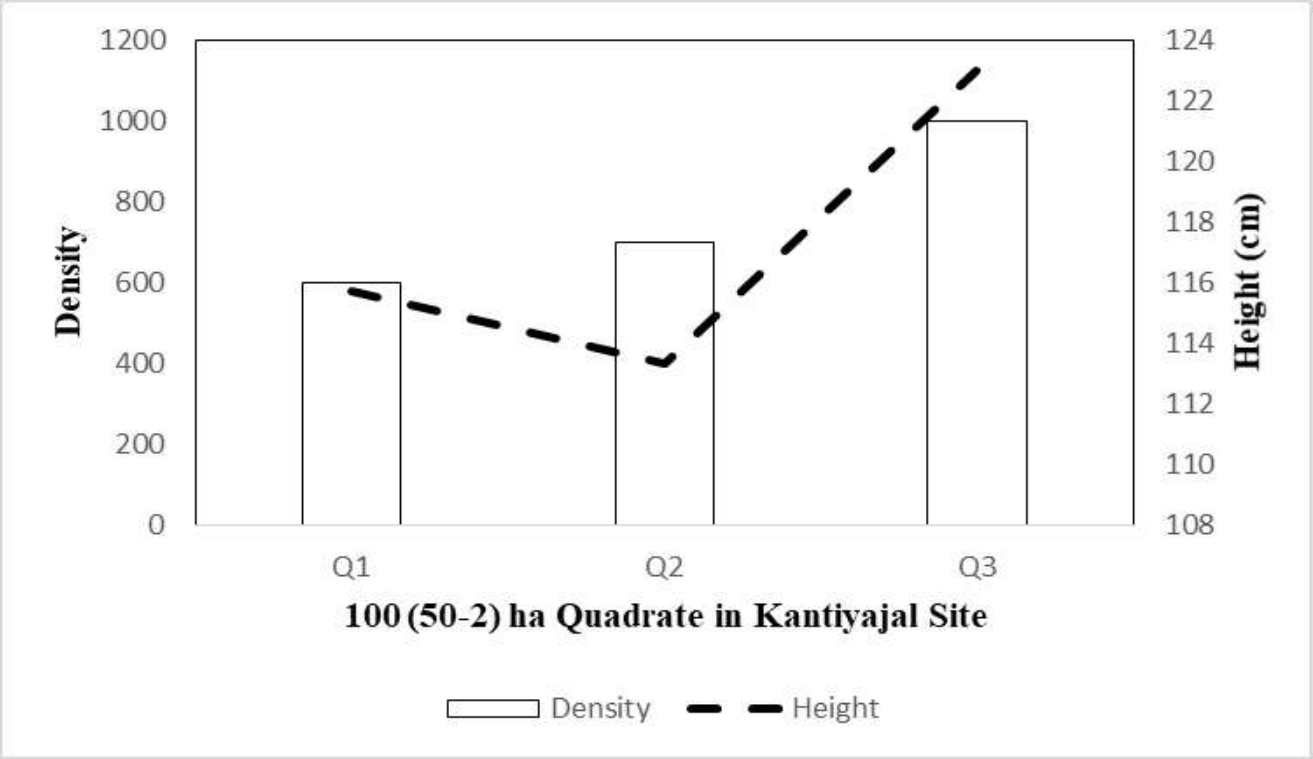

Fig.35 Details of density (No) and height of Mangrove 100 (50-2) Ha plantation area in 2021-2022 at Kantiyajal site

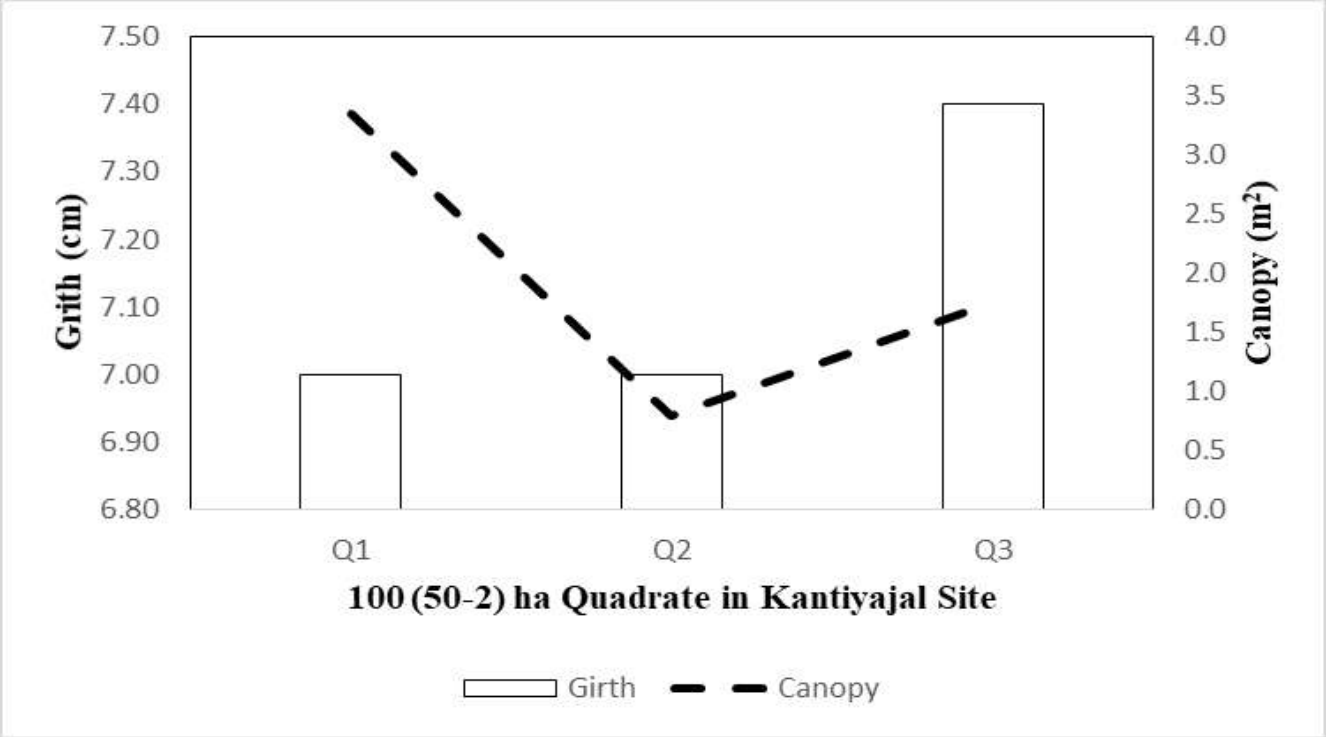

Fig.36 Details of Canopy and Basal Girth of Mangrove 100 (50-2) Ha plantation area in 2021-2022 at Kantiyajal site

7. Regeneration and recruitment class

The study conducted in various plantation blocks reveals crucial insights into the density of younger-class mangroves, particularly in their natural regeneration and recruitment phases. The findings indicate significant variations in the density of these young mangroves across different locations, highlighting both favourable and less favourable conditions for their establishment. The regeneration class, which encompasses newly established mangrove seedlings, exhibited the highest average density in the 50-hectare plantation block of Nakti Creek, with an impressive 1, 50,000 plants per hectare. This suggests highly favourable conditions for seedling establishment, potentially due to optimal salinity levels, sediment availability, and reduced anthropogenic disturbances. Conversely, the lowest density of regeneration-class mangroves was recorded in the 20-hectare plantation block of Sat-Saida Bet, where only 20,000 plants per hectare were observed. The lower density of younger-class mangroves in this particular plantation block may be influenced by multiple ecological and environmental factors. While limited seed dispersal and suboptimal hydrodynamic conditions are common constraints affecting mangrove regeneration, the structural dynamics of this block present an additional challenge to new growth. Since this plantation is relatively old, a few mature and large trees have been observed within the area. The presence of such well-established trees creates natural competition for resources such as sunlight, nutrients, and space. Larger trees tend to develop extensive root systems that dominate the nutrient supply in the soil, reducing the availability of essential elements required for the germination and survival of younger mangroves. Additionally, the shading can limit the penetration of sunlight to the forest floor which can hamper the successful establishment of younger classes' mangroves (Fig.37).

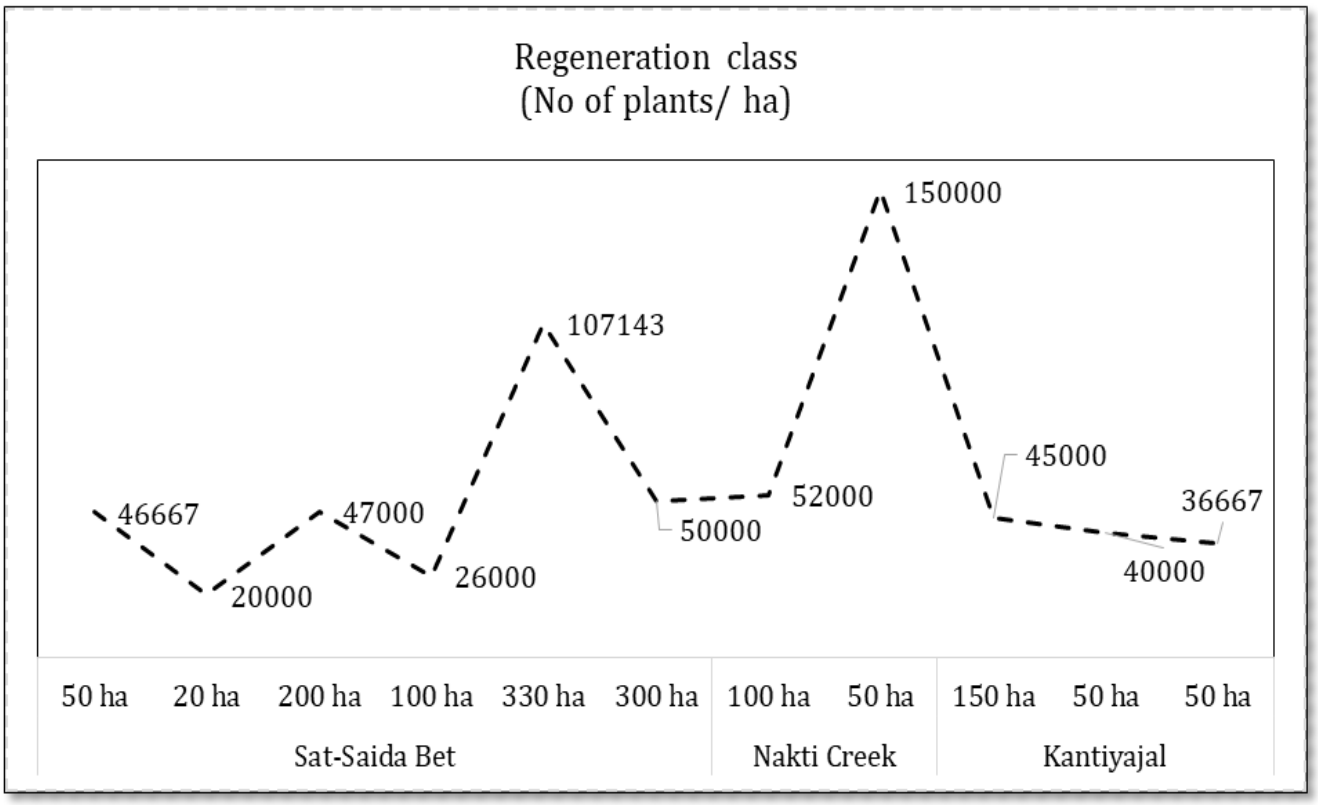

Fig. 37: Regeneration class mangroves in surveyed areas of plantations

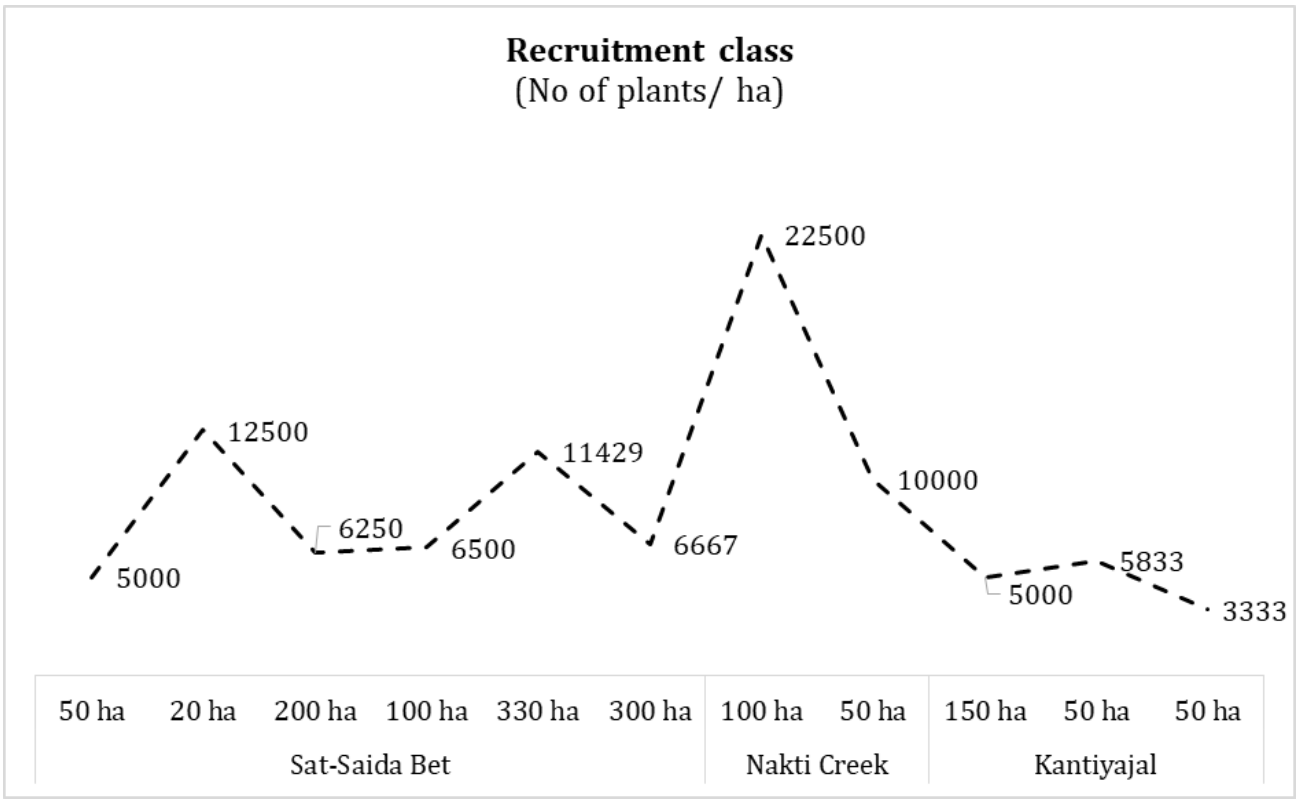

Fig. 38: Recruitment class mangroves in surveyed areas of plantations

The recruitment class, which consists of slightly older juvenile mangroves transitioning towards maturity, showed similar trends in density distribution. The highest density of 22,500 plants per hectare was recorded in the 100-hectare plantation block of Nakti Creek, reinforcing its role as a crucial site for mangrove establishment and growth. In contrast, the lowest recruitment density was observed in the 50-hectare plantation block of Kantiyajal, with only 3,333 plants per hectare. This lower density might be linked to factors such as hydrodynamic variability, nutrient availability, or mainly grazing pressures of camels in the area of plantation.

The presence of younger mangroves in these plantation blocks plays a fundamental role in ecological stabilization. These juvenile trees contribute significantly to sediment trapping and soil stabilization, reducing coastal erosion and enhancing overall shoreline resilience. Moreover, their ability to capture and retain sediments ensures the maintenance of water quality in adjacent coastal ecosystems by filtering out pollutants and excess nutrients. The ongoing regeneration and recruitment processes in these areas indicate a promising trajectory for mangrove forest development, emphasizing the importance of conservation efforts and sustainable management practices (Fig.38).

8. Soil biomass carbon

Mangrove soils are regarded as some of the most important carbon sinks, with carbon storage surpassing the biomass present above ground. These ecosystems are among the most sophisticated systems for the capture and retention of carbon because of the vast deposits of organic-rich sediments that form and the slow decomposition of matter in their waterlogged, saline and anoxic soil. The capability of mangroves to accumulate and sequester carbon in their biomass and sediments categorizes them into significant 'blue carbon' ecosystems that help slow down climate change. The carbon stock in mangrove soils is subject to change due to the presence of some, or all, species of mangrove, the age of the forest, and many soil characteristics. Through the long term capture of atmospheric carbon, mangroves play an important role in global climate regulation.

8.1 Soil biomass carbon stock potential at Sat saida Bet mangrove site

This table 3 shows data regarding soil carbon stock from two sampling blocks at three different depths in a 20-hectare *Avicennia marina* mangrove plantation at Sat Saida Bet. The soil parameters which include total organic carbon (TOC), and bulk density were measured to assess the amount of carbon stocked in the soil. Results indicate that the

carbon stock at a depth of 0-30 cm from the surface is about **29.63** (%) for the total area, which implies that the studied mangrove soils could be considered as an important carbon sink. The almost same values from different blocks and depths imply that soil conditions are relatively the same and carbon capture is efficient throughout the plantation which highlights the importance of the mangroves under climate change impact mitigation through blue carbon storage.

Table: 3 Soil Carbon stock in Sat Saida Bet mangrove plantation site- 20 ha (*A. marina*)

Sampling Blocks	**Depth (cm)**	**TOC (%)**	**Bulk Density (g/cm³)**	**Carbon stock (%)**	**Carbon stock in 0-30 cm (%)**
SC-1	10	0.42	1.27	5.33	30.77
	20	0.39	1.18	9.20	
	30	0.41	1.32	16.24	
SC-2	10	0.33	1.33	4.39	28.48
	20	0.33	1.32	8.71	
	30	0.41	1.25	15.38	
Average Carbon Stock (%)					**29.63**

The table 4 provides specified measurements of soil carbon from four sampling blocks (SC-3, SC-4, SC-5, and SC-6) within a 200-hectare region, with samples taken from 10, 20, and 30 cm depth intervals. For each block and depth, values are given for Total Organic Carbon, Bulk Density, Carbon Stock (%), and the estimated Carbon Stock in the top 30 cm of soil (%). Results indicate that carbon stock accumulations show increases with depth and there are distinct differences among blocks: SC-3 and SC-6 have the highest carbon stocks per hectare while SC-5 has the lowest. Average carbon stock for all the blocks is 43.78 % which suggests that relatively moderate levels of soil carbon is stored on in this 200-hectare region. The fact that these are average values points to the explanation of the local soil and environmental conditions, as well as changes and management interventions sought via spatial planning within the area facilitated CO_2 soil sequestration.

Table: 4 Soil Carbon stock in Sat Saida Bet mangrove plantation site- 200 ha (*A. marina*)

Sampling Blocks	Depth (cm)	TOC (%)	Bulk Density (g/cm³)	Carbon stock (%)	Carbon stock in 0-30 cm (%)
	10	0.69	1.30	8.97	
	20	0.74	1.27	18.80	
SC - 3	30	0.56	1.22	20.50	48.27
	10	0.56	1.25	7.00	
	20	0.65	1.27	16.51	
SC-4	30	0.57	1.22	20.86	44.37
	10	0.57	1.39	7.92	
	20	0.50	1.35	13.50	
SC-5	30	0.35	1.41	14.81	36.23
	10	0.65	1.33	8.65	
	20	0.62	1.30	16.12	
SC-6	30	0.54	1.32	21.38	46.15
Average Carbon Stock (%)					**43.78**

The values of soil carbon stock for 300 ha five sampling blocks (SC-7 to SC-11) at three different depths (10 cm, 20 cm, and 30 cm). Most blocks to the seem to have an increase in TOC percentage with an increase in depth, including with the carbon stock that is calculated. The values of bulk density remain fairly uniform with the exception of being between 1.18 and 1.35 g/cm³. Carbon stock over 30 cm differs between blocks with SC-11 having the highest value measured at 48.27 % and SC-7 having the lowest value at 28.31 %, measuring an average of 36.14 % across all blocks. This shows uneven distribution of carbon in soil which is important in determining the condition of the soil as well as its ability to retain carbon in the selected location (Table 5).

Table: 5 Soil Carbon stock in Sat Saida Bet mangrove plantation site- 300 ha (*A. marina*)

Sampling Blocks	Depth (cm)	TOC (%)	Bulk Density (g/cm³)	Carbon stock (%)	Carbon stock in 0-30 cm (%)
	10	0.24	1.32	3.17	
	20	0.39	1.28	9.98	
SC-7	30	0.38	1.33	15.16	28.31

	10	0.41	1.27	5.21	
	20	0.45	1.32	11.88	
SC-8	30	0.39	1.23	14.39	31.48
	10	0.51	1.18	6.02	
	20	0.47	1.30	12.22	
SC-9	30	0.48	1.33	19.15	37.39
	10	0.38	1.35	5.13	
	20	0.44	1.25	11.00	
SC-10	30	0.48	1.33	19.15	35.28
	10	0.50	1.28	6.40	
	20	0.60	1.33	15.96	
SC-11	30	0.68	1.27	25.91	48.27
Average Carbon Stock (%)					**36.14**

The table 6 showed soil carbon stock data 330ha for four sampling blocks (SC-12 to SC-15) with three depth increments (10 cm, 20 cm, and 30 cm). The mean carbon stock for all blocks stands at 57.54 %. These significant levels of stored carbon illustrate how important these soils are for carbon sequestration, especially in mitigating climate change through the storage of atmospheric carbon in soil. The differences among blocks and depths also suggest different inputs of organic matter, soil practices, or other environmental parameters which highlight the need for more targeted soil carbon management plans for specific locations.

Table: 6 Soil Carbon stock in Sat Saida Bet mangrove plantation site- 330 ha (*A. marina*)

Sampling Blocks	**Depth (cm)**	**TOC (%)**	**Bulk Density (g/cm^3)**	**Carbon stock (%)**	**Carbon stock in 0-30 cm (%)**
	10	0.44	1.28	5.63	
	20	0.68	1.30	17.68	
SC-12	30	0.71	1.20	25.56	48.87
	10	0.79	1.25	9.88	
	20	0.75	1.20	18.00	
SC-13	30	0.81	1.18	28.67	56.55
	10	0.84	1.39	11.68	
	20	1.11	1.37	30.41	
SC-14	30	1.08	1.25	40.50	82.59
	10	0.50	1.25	6.25	
SC-15	20	0.50	1.28	12.80	42.16

	30	0.60	1.27	22.86	
Average Carbon Stock (%)					**57.54**

The data displays soil carbon stock quantifications for 50 Ha from two sampling blocks (SC-16 and SC-17) at three distinct depths: 10 cm, 20 cm, and 30 cm. It describes total organic carbon (TOC) percentage, bulk density, and the carbon stock values calculated for each depth. From all samples taken, average carbon stock is calculated to be 50.02 % for the top 30 cm of soil. This indicates a moderate to high amount of soil carbon storage which improves soil fertility, structure, and helps mitigate climate change. These results capture the need of careful soil management to bolster soil carbon stocks considered vital for agricultural and environmental sustainability (Table. 7).

Table: 7 Soil Carbon stock in Sat Saida Bet mangrove plantation site- 50 ha (*A. marina*)

Sampling Blocks	**Depth (cm)**	**TOC (%)**	**Bulk Density (g/cm^3)**	**Carbon stock (%)**	**Carbon stock in 0-30 cm (%)**
SC-16	10	0.72	1.32	9.50	40.2
	20	0.56	1.28	14.34	
	30	0.41	1.33	16.36	
SC-17	10	0.60	1.27	7.62	59.85
	20	0.75	1.22	18.30	
	30	0.87	1.30	33.93	
Average Carbon Stock (%)					**50.02**

An assessment of the carbon stocks on soil in the Sat Saida Bet mangrove plantation (100 ha, dominated by *Avicennia marina*) shows considerable carbon sequestration potential over three sampled blocks (SC-18, SC-19, SC-20) at 10, 20, and 30 cm depths. Soil up to30 cm in depth has an average carbon stock of 40.31 % and individual block values range from 29.88 to 46.04 %. Especially, TOC (%) in the bulk of samples increase with depth which indicates that major carbon accumulation happens across the entire soil profile. In any case, the high bulk density values also spatially imply carbon storage capacity, thus superposing the observation. In any case, the findings of the study demonstrate the

importance of mangroves in enhancing soil carbon stocks and combating climate change through blue carbon sequestration. (Table. 8).

Table: 8 Soil Carbon stock in Sat Saida Bet mangrove plantation site- 100 ha (*A. marina*)

Sampling Blocks	Depth (cm)	TOC (%)	Bulk Density (g/cm^3)	Carbon stock (%)	Carbon stock in 0-30 cm (%)
SC-18	10	0.35	1.35	4.73	29.88
	20	0.44	1.33	11.70	
	30	0.38	1.18	13.45	
SC-19	10	0.50	1.18	5.90	45.01
	20	0.56	1.30	14.56	
	30	0.62	1.32	24.55	
SC-20	10	0.53	1.32	7.00	46.04
	20	0.63	1.23	15.50	
	30	0.59	1.33	23.54	
Average Carbon Stock (%)					**40.31**

The mean carbon stock value from different sized plantations at the Sat Saida Bet mangrove site was 42.90 % at 30 cm depth with a range of 29.63 % - 57.54 % proportional to plantation area which is shown in Table 9. This difference is most likely attributed to the age of the plantations, species composition, site conditions and the management practices which are all known to influence the rate of carbon accumulation in mangrove ecosystems. Mangroves have an international reputation for their capability to store carbon in the soil and above it, and therefore play an important role in fighting climate change because they sequester huge amount of carbon and store it over long periods of time. This average figure can be used as a starting point to track carbon shifts at the site, and adds to the reasoning for conserving and managing mangrove ecosystems in the region for natural carbon emission mitigation.

Table 9 Average Carbon Stock at Sat saida Bet mangrove site

Plantation (ha)	Avg. Carbon stock 0-30 cm depth (%)
20	29.63
200	43.78
300	36.14
330	57.54
50	50.02
100	40.31
Avg.	**42.90**

8.2 Soil biomass carbon stock potential at Nakti creek mangrove site

The soil carbon stock at the Nakti creek mangrove plantation site (50 ha), dominated by *Avicennia marina* was analyzed through two sampling blocks (TC-1 and TC-2) at depths of 10 cm, 20 cm, and 30 cm. For TC-1, the carbon stock increased with depth: 12.01 % (10 cm), 18.80 % (20 cm), and 32.87 % (30 cm), totalling 63.68 (%). Similarly, TC-2 showed stocks of 9.44 % (10 cm), 17.27 % (20 cm), and 45.24 % (30 cm), totalling 71.95 (%). The average carbon stock across both blocks was 67.82 (%), for the entire 50-hectare site (Table 10).

Table: 10 Soil Carbon stock in Nakti creek mangrove plantation site- 50 ha (*A. marina*)

Sampling Blocks	Depth (cm)	TOC (%)	Bulk Density (g/cm^3)	Carbon stock (%)	Carbon stock in 0-30 cm (%)
TC-1	10	0.78	1.54	12.01	63.68
	20	0.74	1.27	18.80	
	30	0.83	1.32	32.87	
TC-2	10	0.71	1.33	9.44	71.95
	20	0.68	1.27	17.27	
	30	1.16	1.30	45.24	
Average Carbon Stock (%)					**67.82**

The present's data on soil carbon stock from different sampling blocks in a 100-hectare mangrove plantation with *Avicennia marina, Rhizophora mucronata*, and *Ceriops tagal* species. It includes total organic carbon (TOC) percentage, bulk density. TOC at three depths (10, 20, 30 cm) for each block alongside their respective carbon stock, leading up to carbon stock per hectare within 30 cm of soil, which was estimated. The results indicate variability among blocks, with TC-4 yielding the highest carbon stock at 77.64 % and TC-6 yielding the lowest at 45.1 %. Overall, the mean carbon stock across blocks stood at 57.8 %. This demonstrates the capacity of mangrove soils in relation to carbon sequestration and emphasizes the importance of the contribution of these ecosystems in climate change mitigation (Table 11).

Table: 11 Soil Carbon stock in Nakti creek mangrove plantation site- 100 ha (*A. marina*, *R. mucronata, C. tagal*)

Sampling Blocks	Depth (cm)	TOC (%)	Bulk Density (g/cm^3)	Carbon stock (%)	Carbon stock in 0-30 cm (%)
TC-3	10	0.3	1.18	3.54	
	20	0.93	1.23	22.88	
	30	0.78	1.27	29.72	56.14
TC-4	10	1.01	1.25	12.63	
	20	0.98	1.30	25.48	
	30	1.08	1.22	39.53	77.64
TC-5	10	0.75	1.18	8.85	
	20	0.72	1.25	18.00	
	30	0.87	1.32	34.45	61.3
TC-6	10	0.38	1.32	5.02	
	20	0.69	1.30	17.94	
	30	0.60	1.23	22.14	45.1
TC-7	10	0.62	1.37	8.49	
	20	0.59	1.32	15.58	
	30	0.63	1.35	25.52	49.59
Average Carbon Stock (%)					**57.8**

The mean carbon stock at Nakti creek site is calculated by taking the percentage of 30 cm depth on the soil and comparing it to the two sizes of plantations (50 ha and 100 ha) and mangrove carbon reserve. It indicates that the 50-hectares carbon reserve plantation has a higher average Carbon stock (67.82 %) compared to 100-hectare plantation's (57.8 %),

with an overall average of 62.81 % .This implies that the smaller plantations at this site store more carbon per unit area than the larger ones which can be attributed to differences in age or management practices. The study demonstrates the need for such data to optimize understanding of mangrove carbon capture (Table 12).

Table 12 Average Carbon Stock at Nakti creek mangrove site

Plantation (ha)	Avg. Carbon stock 0-30 cm depth (%)
50	67.82
100	57.8
Avg.	**62.81**

8.3 Soil biomass carbon stock potential at Kantiyajal mangrove site

The Kantiyajal mangrove plantation site (150 ha of *Avicennia marina*) exhibited considerable variation of soil carbon stock within its two sampling blocks. Block KC-1 tended to have average carbon stocks of 39.91 (%) and was gradually increasing in contribution with depth to: 5.62% (10cm), 12.51% (20cm), and 21.78% (30cm) whereas KC-2 demonstrated greater sequestration at 63.78 (%) due to deeper-layer storage (7.58% at 10cm, 18.35% at 20cm, and 37.85% at 30cm). This variability demonstrates greater carbon density of KC-2 (bulk density 1.43-1.45 g/cm^3; KC-1 1.37-1.39 g/cm^3) which is likely due to accumulation of organic matter in mangrove sediments (Table 13). The average carbon stock of the *A. marina* plantation was 51.85 (%) (150ha).

Table: 13 Soil Carbon stock in Kantiyajal mangrove plantation site- 150 ha (*A.marina*)

Sampling Blocks	Depth cm	TOC (%)	Bulk Density (g/cm^3)	Carbon stock (%)	Carbon stock in 0-30 cm (%)
KC-1	10	0.41	1.37	5.62	39.91
	20	0.45	1.39	12.51	
	30	0.53	1.37	21.78	
KC-2	10	0.53	1.43	7.58	63.78
	20	0.66	1.39	18.35	

	30	0.87	1.45	37.85	
Average Carbon Stock (%)					**51.85**

The soil carbon stock at the Kantiyajal mangrove plantation site (150 ha), dominated by *Avicennia marina* and *Rhizophora mucronata*, was analyzed through two sampling blocks (KC-3 and KC-4) at depths of 10 cm, 20 cm, and 30 cm. For KC-3, the carbon stock increased with depth: 3.99% (10 cm), 10.01% (20 cm), and 18.23% (30 cm), totalling 32.23 (%). Similarly, KC-4 showed stocks of 6.03% (10 cm), 13.44% (20 cm), and 16.07% (30 cm), totalling 35.54 (%). The average carbon stock across both blocks was 33.88 (%), for the entire 150-hectare site (Table 14).

Table: 14 Soil Carbon stock in Kantiyajal mangrove plantation site- 150 ha (*A. marina* and *R. mucronata*)

Sampling Blocks	**Depth cm**	**TOC (%)**	**Bulk Density (g/cm^3)**	**Carbon stock (%)**	**Carbon stock in 0-30 cm (%)**
KC-3	10	0.30	1.33	3.99	32.23
	20	0.35	1.43	10.01	
	30	0.45	1.35	18.23	
KC-4	10	0.44	1.37	6.03	35.54
	20	0.47	1.43	13.44	
	30	0.38	1.41	16.07	
Average Carbon Stock (%)					**33.88**

The soil carbon stock assessment in the 50-hectare Kantiyajal mangrove plantation site dominated by *Avicennia marina* reveals notable variation across sampling blocks and soil depths. In block KC-5, soil carbon stock values increased with depth, from 3.53 % at 10 cm; 9.57% at 20 cm and 23.37 % at 30 cm, indicating substantial carbon accumulation in deeper layers. Similarly, KC-6 showed a rise from 1.89% at 10 cm; 7.23 at 20 cm and 13.97% at 30 cm. The average soil carbon stock across the site was 29.78 (%) (Table 15).

Table: 15 Soil Carbon stock in Kantiyajal mangrove plantation site- 50 ha (*A. marina*)

Sampling Blocks	Depth cm	TOC (%)	Bulk Density (g/cm³)	Carbon stock (%)	Carbon stock in 0-30 cm (%)
KC-5	10	0.24	1.47	3.53	36.47
	20	0.33	1.45	9.57	
	30	0.53	1.47	23.37	
KC-6	10	0.14	1.35	1.89	23.09
	20	0.26	1.39	7.23	
	30	0.35	1.33	13.97	
Average Carbon Stock (%)					**29.78**

The soil carbon stock at the Kantiyajal mangrove plantation site (100 ha), dominated by *Avicennia marina*, was analyzed through two sampling blocks (KC-7 and KC-8) at depths of 10 cm, 20 cm, and 30 cm. For KC-7, the carbon stock increased with depth: 7.15% (10 cm), 15.85% (20 cm), and 25.89% (30 cm), totalling 48.89 (%). Similarly, KC-8 showed stocks of 3.72% (10 cm), 11.02% (20 cm), and 24.36% (30 cm), totalling 39.1(%). The average carbon stock across both blocks was 43.99(%), for the entire 150-hectare site (Table 16).

Table: 16 Soil Carbon stock in Kantiyajal mangrove plantation site- 100 ha (50 ha and 50 ha) (*A. marina*)

Sampling Blocks	Depth cm	TOC (%)	Bulk Density (g/cm³)	Carbon stock (%)	Carbon stock in 0-30 cm (%)
KC-7	10	0.50	1.43	7.15	48.89
	20	0.57	1.39	15.85	
	30	0.63	1.37	25.89	
KC-8	10	0.26	1.43	3.72	39.1
	20	0.38	1.45	11.02	
	30	0.56	1.45	24.36	
Average Carbon Stock (%)					**43.99**

The soil carbon stock at the Kantiyajal mangrove plantation site reflects the critical role of mangroves in carbon sequestration, with the average carbon stock at 30 cm depth (%) across different plantation areas (totalling 450 hectares) calculated to be 39.87%, based on observed values of 51.85%, 33.88%, 29.78%, and 43.99% for individual plots. This substantial soil organic carbon pool highlights the effectiveness of mangrove plantations in trapping and storing carbon, as mangrove soils are known to accumulate and retain carbon due to their ability to trap sediments and maintain anaerobic conditions that slow decomposition processes (Table 17).

Table.17 Average Carbon Stock at Kantiyajal mangrove site

Plantation (ha)	Avg. Carbon stock 0-30 cm depth (%)
150	51.85
150	33.88
50	29.78
100 (50 +50)	43.99
Avg.	**39.87**

9. Details of carbon Sequestration at the plantation sites

Each block randomly selected 10 trees that were >7 cm dbh and in good health plants. The allometric equations pertaining to *A. marina* (Vikarant et al., 2013) were used in estimating above ground biomass (AGB), below ground biomass (BGB), and tree biomass. The total tree biomass carbon was then converted into CO2 equivalent by multiplying it with a factor of 3.67 (Kauffman and Donato, 2012; Kathiresan et al., 2021). The data from 2025 from across Sat Saida Bet, Nakti Creek and Kantiyajal shows that there is a notable difference in biomass and carbon values across different hectare (HA). Sat Saida Bet tends to show greater tree biomass and carbon values as well as in larger plots like 330 HA, with CO_2 equivalents peaking at 6042.32 Mg C ha^{-1}, indicating greater carbon sequestration potential than the rest of the regions, while Nakti Creek has moderate biomass and carbon storage. Despite Nakti Creek showing the 100 HA plot having a quite high tree biomass and carbon value of 1887.81 Mg C ha^{-1}. Kantiyajal does has some blocks with high tree biomass like to 50 HA at 2849.60 Mg C ha^{-1}, but they still have lower carbon

values because it makes the area appear to contain less dense or younger vegetation (Table 17).

This finding confirms once more the spatial differences in carbon sequestration capacity across these sites and emphasizes area size and specific local ecological conditions as prime determinants of carbon storage potential in mangrove and coastal ecosystems.

Table. 17 Details of Carbon Sequestration at 1600ha mangrove plantation site

Sat Saida Bet during 2025					
Hectare (HA)	**Above Ground Biomass**	**Below Ground Biomass**	**Tree Biomass**	**Carbon values (Mg C ha^{-1})**	**CO_2 equivalent**
20 HA	3.83	2.63	6.61	3875.96	24.25
200 HA	4.99	3.30	8.50	5053.82	31.21
300 Ha	6.07	3.89	10.23	5301.18	37.54
330 Ha	4.32	2.92	7.41	6042.32	37.54
50 Ha	5.16	3.39	8.77	2849.60	27.21
100 Ha	2.88	2.06	5.04	1138.56	32.17
Average	**4.54**	**3.03**	**7.76**	**4043.57**	**31.65**
Nakti creek during 2025					
50	3.16	2.23	5.50	2904.33	20.18
100	5.66	3.67	9.57	1887.81	35.13
Average	**4.41**	**2.95**	**7.535**	**2396.07**	**27.66**
Kantiyajal during 2025					
150	3.56	2.47	6.17	1335.92	22.64
50	6.07	3.89	10.23	3627.13	37.54
100(50-2)	2.27	1.68	4.01	799.75	14.73
Average	**3.97**	**2.68**	**6.80**	**1,920.93**	**24.97**

10. Phyto-sociological observation

Halophytes are an example of a specialized plant that can live in areas with high salinity. They can be divided into three categories based on their growth conditions: obligate halophytes, which depend entirely on a saline environment; facultative halophytes which can exist in both saline non-saline environments; and habitat indifferent halophytes which have some degree of preference for their environment. In the course of the comprehensive survey, we identified four prominent species of halophytes within the designated DPA mangrove plantation sites. These were: *Salicornia brachiata, Aeluropus lagopoides, Salvadora persica,* and *Sesuvium portulacastrum*. At the plantation site, we recorded an interesting form of relationship between halophyte species and mangrove associated plants. Numerous halophyte associated species recorded for the first time during the field trips began the quest to understanding these intricate ecosystems. Also observed were mudskippers, bivalves, crabs, gastropods and many fish that contribute to the ever changing ecological relationships at the plantation sites. This abundance of both plant life and animal life is why we believe that halophytes are important for the condition of the entire ecosystem along the coast. The working commingling of halophytes and mangrove associated ecosystems forms a zone of high productivity and biodiversity.

The roots of mangrove trees house many microorganisms that aid plants in osmoregulation and dealing with both heat and salt stress. The vegetation and fauna flora of such ecosystems enables nutrient cycling to occur and supports higher trophic levels in the biological community. It also helps in the conservation of natural diversity and the stability of the environment. Furthermore, halophytes boost soil structure by capturing salts and favourable rhizobacteria, which contribute to the salt tolerance of supplementary flora. Taking care of and acclimatizing coastal areas that are abundant in these halophytes is important for the ecological sustainability of fish resources, protection of coastal zone against natural calamities, and climate mitigation through efficient carbon sequestration (Plate 14).

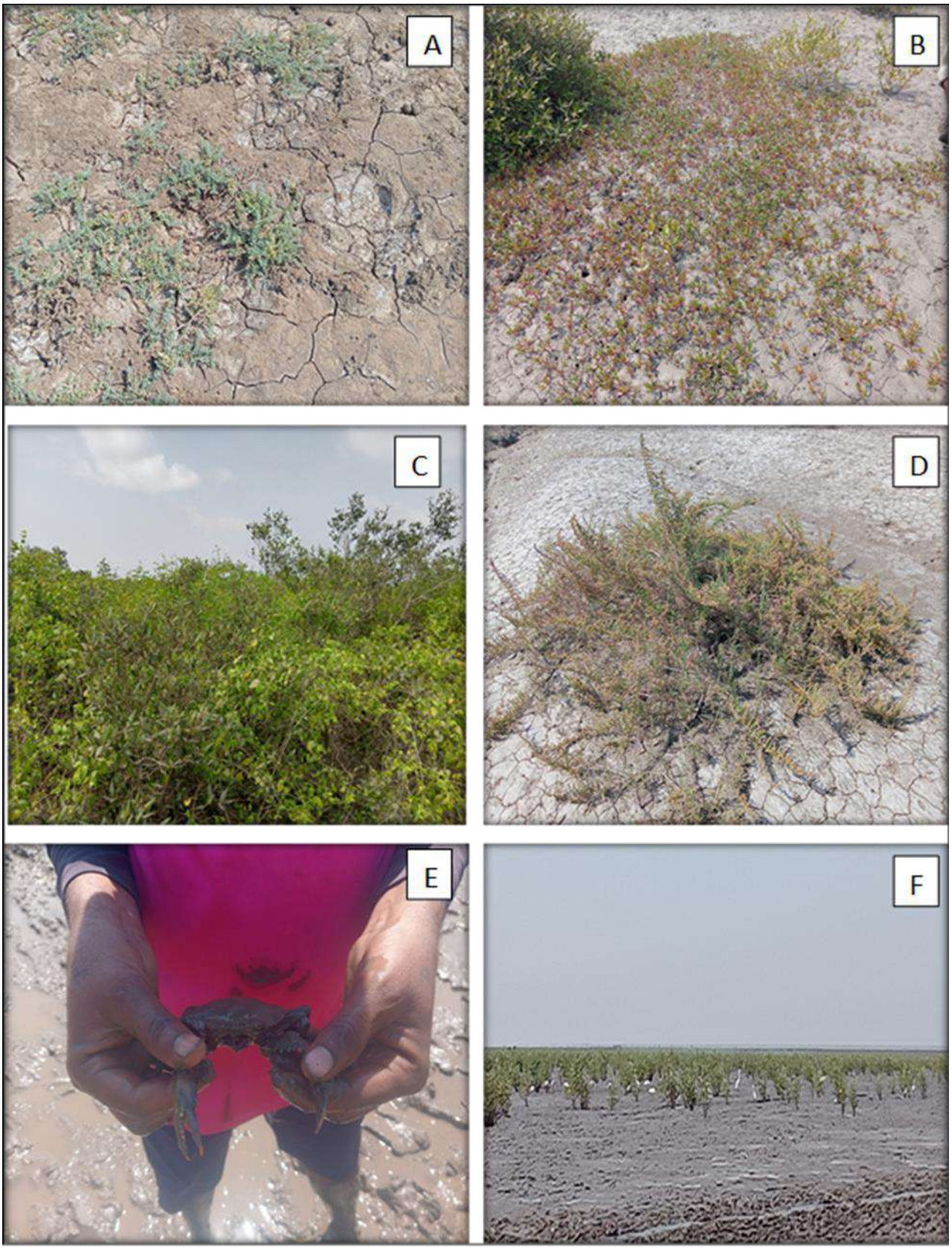

Plate 14. Mangrove associated Halophytes and fauna diversity in plantation site during a visit in 2025

[A-*Sueda* sp.; B- *Sesuvium* sp; C- *Salvadora* sp; D- *Salicornia* sp; E- Crab; F-Birds]

11. Field observation of threats for Mangroves

Plate 15 captures a coastal mudflat environment where the existing threats stress on the mangrove is most clear during the filed trip in 2025. The aforementioned plant's aerial roots suggests that this more or less eroded and unstable mangrove was subjected to tidal forces or soil erosion. The second and third image depicts dry mangrove vegetation which is indicative of an either experiencing salinity stress coupled with water logging or some unpleasant conditions that inhibit the development of a mangrove. The fourth image shows a grazing camel in what can be described as an all around difficult area of observing and holding sustained environmental control, capturing the extra attention on the stress mangroves experience in this region. Cumulatively, these evidences unveils the relative intense environmental load on mangroves like erosion, alternating human and animal interaction, salinity levels above normal and scarcity of water which deepens their fragility and lowered resilience in this habitat.

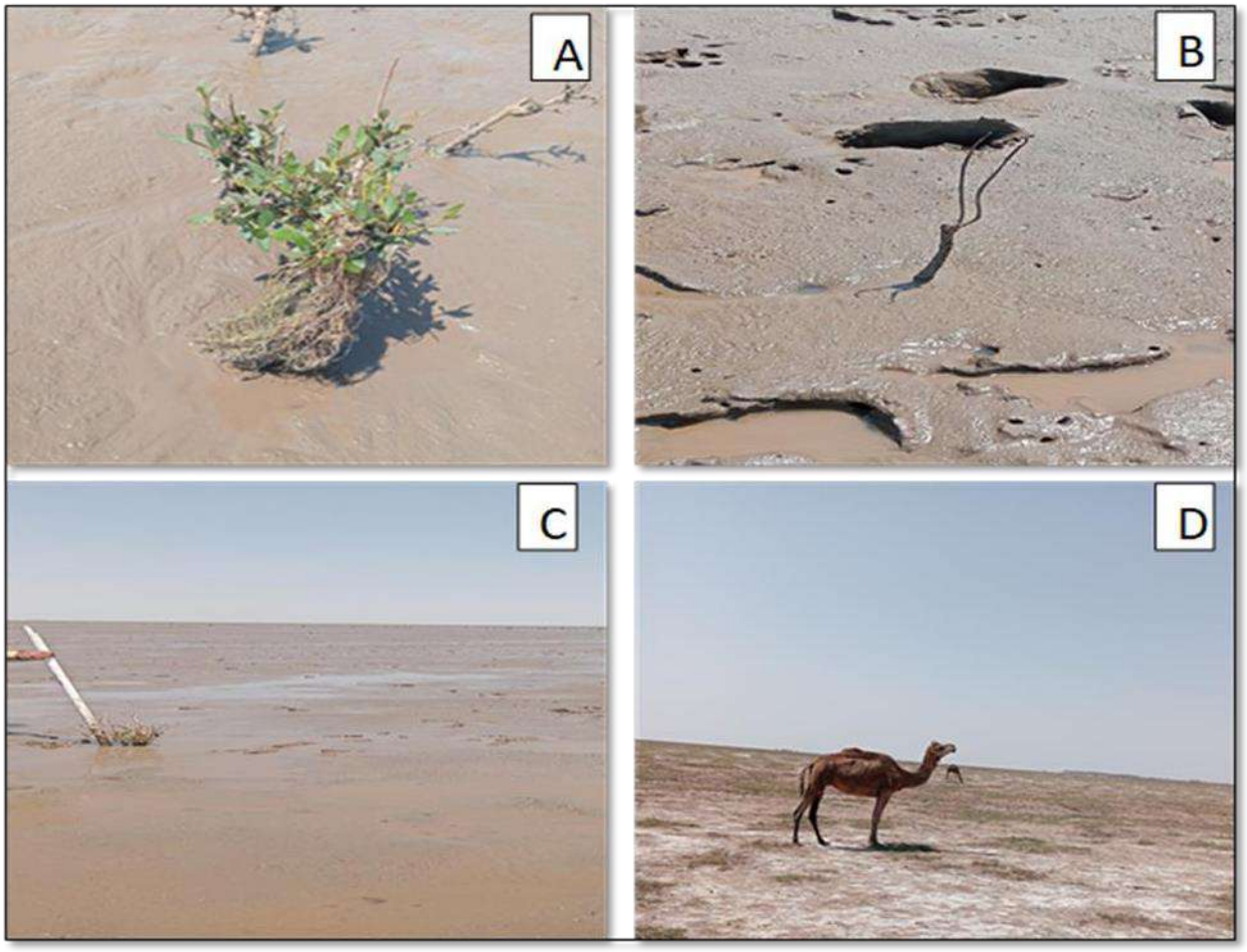

Plate 15. Mangrove Stress factors observed in plantation site during a visit in 2025.

[A-Fishing net; B- Animal foot; C- Sediment deposit; D-Camel grazing]

12. Summary and Discussion

The mangrove monitoring was conducted at sites located in Sat Saida Bet and Nakti Creek (near to Tuna village) in Kandla district as well sites located nearby Kantiyajal, Bharuch district. The sampling occurred at six plantation blocks in Sat Saida Bet, two in Nakti Creek, and five in Kantiyajal for monitoring the mangrove plantations developed over an area of total 1600 ha from 2005 to 2021. The primary objectives of this study included determination of the density and abundance of planted mangroves to estimate the carbon sequestration potential, understanding ecological concerns about the success of the plantation, and recommending appropriate conservation strategies. The sampling points are selected only where the mangroves are present inside the plantation blocks. Extensive field studies performed from February to May of 2025 revealed marked differences in the density and height growth of mangroves over the various sites. Most remarkably, carbon sequestration was the highest at Sat Saida Bet (up to 4043 Mg C ha^{-1}) while Nakti Creek exhibited the greatest concentration of carbon stock in topsoil, averaging 62.81% carbon stock. The monitoring show significant variation in mangrove density and tree height among the sites. At Sat Saida Bet, mangrove density was between 100 to 4000 individuals per hectare and the tree height was between 70 to 240 cm. Nakti Creek reported densities of 400–1,600 individuals per hectare and tree heights of 100–170 cm, while Kantiyajal showed densities of 500–1,600 individuals per hectare and tree heights of 70–140 cm. However, it should be noted that major area of Kantiyajal is empty and under various stresses on mangroves such as grazing pressure by camel, cattle etc. Soil analysis revealed average carbon stock values (0-30 cm depth) between 39.87% and 62.81%, with Nakti Creek recording the highest percentage. However, Sat Saida Bet demonstrated the highest carbon values overall ranging from 1,920.93 to 4,043.5 Mg C ha^{-1} and also led in CO_2 equivalent values at 31.65, compared to 27.66 at Nakti Creek and 24.97 at Kantiyajal. This study looked at the importance of mangrove ecosystems as blue carbon sinks which absorb carbon dioxide more effectively. Their multifunctional roles provide coastal protection, serve as habitats for various species, sustain fisheries and tourism, aid in climate change mitigation all at the same time. They demonstrate the impact of unsustainable practices as well as habitat destruction. In turn, this creates a need for ongoing restoration and conservation efforts. This report recommends targeted multi-species planting and natural regeneration to improve sparse patches while active

long-term management strengthens resilience to ensure sustainability for these ecosystems.

Globally, mangrove rehabilitation and restoration is regarded as one of the most effective management strategies for lost or damaged mangrove forests. Many biotic and abiotic factors such as predation, seed recruitment, soil quality, colonization rates, salinity, and temperature can hamper the overall plantation during various stages of planting. Rather, mangrove restoration projects tend to set specific criteria for success.

In the port development of DPA, we notice an effort that integrates port activity with environmental protection. The monitoring results offered invaluable information with regard to the restoration of mangroves and their relation to climate change, biodiversity as well as human health. The project illustrates the necessity of strategic investment in the conservation of mangroves which aids climate change and coast protective efforts, thereby setting an ecological benchmark in port management. As a source of blue carbon, defenders of coasts and regions abundant in biodiversity, the project highlighted the ecological and economic value of mangroves. Despite the ecological and economic value, the mangroves are still facing threats of habitat loss and unregulated resource extraction, particularly in Kantiyajal site, where the main stress factor on mangrove plantation is camel grazing which is observed. In order to enhance the resilience and sustainability of the critical ecosystems within the port limits, the report recommends of sparse patches with natural regeneration and gap filling as well as constant maintenance. With this, the site selection for mangrove plantation should be done after a scientific and social study of the location.

13. Recommendations in terms of future prospects

On the basis of this study, following recommendations are suggested for current and future plantation activities. This study clearly identified that a few blocks of plantations within Sat-Saida Bet was more promising than other locations for further mangrove plantation efforts. These areas have demonstrated the suitability for expansion of mangroves. Moreover, the availability of space allows for gap-filling, which can further enhance the overall mangrove coverage. To ensure the development of the planted mangroves into a mature and thriving ecosystem, several conservation measures are recommended.

- Appropriate site selection: Identifying suitable locations for mangrove plantations is essential for their survival and growth. Factors such as soil composition, tidal

influence, and existing ecological conditions must be thoroughly assessed before selecting a site.

- Monitoring to prevent camel grazing: Continuous monitoring of existing mangrove plantations is necessary to mitigate human activities that may disrupt growth. Grazing by camel is one of main stress in the plantation area at Kantiyajal, which can cause severe damage to young mangrove plants. Implementing protective barriers, enforcing regulations, and engaging local communities in conservation efforts may help safeguard these ecosystems. Or it will better to find different area for further plantations.
- Field observation and high-resolution mapping: The use of both ground-based surveys and advanced mapping techniques is necessary for effective mangrove monitoring, conservation, and management. Field observations provide real-time insights into plant health, while high-resolution mapping helps track vegetation changes over time and detect areas requiring intervention.
- Site-specific plantation techniques: Different mangrove species thrive in varying environmental conditions. Therefore, plantation techniques must be carefully adapted to match the specific hydrogeological features of each site. This includes selecting appropriate planting depths, spacing, and protective measures to prevent high mortality rates among mangrove seedlings.
- Ensuring tidal flushing and inundation: Mangroves rely on a dynamic water exchange system for nutrients and sediment deposition. Regular tidal flushing and controlled inundation must be maintained to sustain optimal soil salinity levels, support biodiversity, and promote natural regeneration. Proper hydrological management will further strengthen the mangrove ecosystem over time.
- Utilizing local seed sources for mangrove plantation: Selecting seed sources from the nearest available areas ensures genetic compatibility with the local environment. This approach accelerates adaptation to site-specific conditions, and strengthens the resilience of the mangrove species.
- Prioritizing restoration over new plantation sites: Instead of creating entirely new plantation sites, efforts should focus on restoring existing mangrove areas that have suffered degradation.
- Preserving natural tidal hydrology and seed dispersal: Mangroves rely on tidal movements for oxygen exchange, sediment deposition, and nutrient supply.

Maintaining the natural water-borne dispersal of seeds helps facilitate regeneration and promotes species diversity.

- Awareness and outreach programs for DPA staff: Strengthening conservation efforts requires active participation from local authorities, environmental organizations, and the general public. Awareness campaigns, training workshops, and stakeholder engagement activities will help develop a collective understanding of mangrove protection. Educating DPA staff and involving communities will encourage responsible stewardship.
- Promoting multispecies plantation for greater ecological benefits: Planting multiple mangrove species fosters biodiversity and enhances ecosystem resilience. A multispecies approach improves the adaptability of the plantation, ensuring long-term sustainability and ecological balance.
- Identification of stress factors: It is important that in any conservation efforts, stressors acting on the mangroves are to be identified and removed in order to maintain the ecosystem balance.
- Community-based management: Engaging local communities, particularly fishermen can significantly enhance mangrove plantations. Fishermen can be key participants in community-based restoration and conservation.

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Gujarat Institute
Of Desert Ecology

Annexure -D

Annual Environmental Monitoring Report

prepared under

"Preparing and monitoring of environmental monitoring and management plan for Deendayal Port Authority at Kandla and Vadinar for a period of 3 years"

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About this Document

Gujarat Environment Management Institute (GEMI) has been assigned with the work of "Preparing and monitoring of Environmental monitoring and Management plan for Deendayal Port Authority (DPA) at Kandla and Vadinar for a period of 3 years" by DPA, Kandla. Under the said project the report titled *"Environment Monitoring Annual Report (Monitoring Period: April 2024 - March 2025)"* is prepared.

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List of Abbreviations

A	Acceptable Limits as per IS: 10500:2012
AAQ	Ambient Air Quality
AWS	Automatic Weather monitoring stations
BIS	Bureau of Indian Standards
BOD	Biochemical Oxygen Demand
BQL	Below Quantification Limit
CCA	Consolidated Consent & Authorization
CO	Carbon Monoxide
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
DO	Dissolved Oxygen
DPA	Deendayal Port Authority
EC	Electrical Conductivity
EMMP	Environmental monitoring and Management Plan
EMP	Environment Management Plan
FPS	Fine Particulate Sampler
FY	Financial Year
GEMI	Gujarat Environment Management Institute
IFFCO	Indian Farmers Fertiliser Cooperative Limited
IMD	India Meteorological Department
IOCL	Indian Oil Corporation Limited
LNG	Liquefied Natural Gas
MGO	Marine Gas Oil
MMTPA	Million Metric Tonnes Per Annum
MoEF	Ministry of Environment & Forests
MoEF&CC	Ministry of Environment, Forest and Climate Change
NAAQS	National Ambient Air Quality Standards
NO_x	Nitrogen oxides
NTU	Nephelometric Turbidity Unit
OOT	Off Shore Oil Terminal
OSR	Oil Spill Response
P	Permissible Limits as per IS: 10500:2012
PAH	Poly Aromatic Hydrocarbons
PM	Particulate Matter
PTFE	Polytetrafluoroethylene
RCC	Reinforced Concrete Cement
RDS	Respirable Dust Sampler
SAR	Sodium Adsorption Ratio
SBM	Single Bouy Mooring
SO_x	Sulfur oxides
STP	Sewage Treatment Plant
TC	Total Coliforms
TDS	Total Dissolved Solids
TOC	Total organic Carbon
TSS	Total Suspended Solids
VOC	Volatile Organic Compounds

CHAPTER 1: INTRODUCTION

1.1 Introduction

Kandla Port, also known as the Deendayal Port is a seaport in Kachchh District near the city of Gandhidham in Gujarat state in western India. Located on the Gulf of Kachchh, it is one of major ports on the western coast, and is located at 256 nautical miles southeast of the Port of Karachi in Pakistan and over 430 nautical miles north-northwest of the Port of Mumbai (Bombay). It is the largest port of India by volume of cargo handled. Deendayal Port's journey began in 1931 with the construction of RCC Jetty by Maharao Khengarji. Kandla was constructed in the 1950s as the chief seaport serving western India, after the independence of India. On 31st March 2016, Deendayal Port created history by handling 100 MMT cargo in a year and became the first Major Port to achieve this milestone. Deendayal Port Authority (DPA), India's busiest major port in recent years, is gearing up to add substantial cargo handling capacity with private sector participation. DPA has created new record by handling 137 MMTPA (at Kandla and Vadinar) during the financial year 2022-23. The DPA had commissioned the Off-shore Oil Terminal facilities at Vadinar in the year 1978, for which M/s. Indian Oil Corporation Limited (IOCL) provided Single Bouy Mooring (SBM) system, with a capacity of 54 MMTPA. Further, significant Quantum of infrastructural upgradation has been carried out & excellent maritime infrastructure has been created at Vadinar for the 32 MMTPA Essar Oil Refinery in Jamnagar District.

1.2 Green Ports Initiative

DPA is committed to sustainable development and adequate measures are being taken to maintain the Environmental well-being of the Port and its surrounding environs. Weighing in the environmental perspective for sustained growth, the Ministry of Shipping had started, Project Green Ports" which will help in making the Major Ports across India cleaner and greener. "Project Green Ports" will have two verticals - one is "Green Ports Initiatives" related to environmental issues and second is "Swachh Bharat Abhiyaan".

The Green Port Initiatives include twelve initiatives such as preparation and monitoring plan, acquiring equipment required for monitoring environmental pollution, acquiring dust suppression system, setting up of sewage/waste water treatment plants/ garbage disposal plant, setting up Green Cover area, projects for energy generation from renewable energy sources, completion of shortfalls of Oil Spill Response (OSR) facilities (Tier-I), prohibition of disposal of almost all kind of garbage at sea, improving the quality of harbour wastes etc.

DPA had also appointed GEMI as an Advisor for "Making Deendayal Port a Green Port-Intended Sustainable Development under the Green Port Initiatives. DPA has also signed MoU with Gujarat Forest Department in August 2019 for Green Belt Development in an area of 31.942 Ha of land owned by DPA. The plantation is being carried out by the Social Forestry division of Kachchh.

1.3 Importance of Environmental monitoring and management plan (EMMP)

Port activities can cause deterioration of air and marine water quality in the surrounding areas due to multifarious activities. The pollution problems usually caused by port and harbour activities can be categorized as follows:

1. Air pollutant emissions due to ship emissions, loading and unloading activities, construction emission and emissions due to vehicular movement.

2. Coastal habitats may be destroyed and navigational channels silted due to causeway construction and land reclamation.
3. Deterioration of surface water quality may occur during both the construction and operation phases.
4. Harbour operations may produce sewage, bilge wastes, solid waste and leakage of harmful materials both from shore and ships.
5. Human and fish health may be affected by contamination of coastal water due to urban effluent discharge.
6. Oil pollution is one of the major environmental hazards resulting from port/harbour and shipping operations. This includes bilge oil released from commercial ships handling non-oil cargo as well as the more common threat from oil tankers.
7. Unregulated mariculture activities in the port and harbour areas may threaten navigation safety.

Hence, for the determination of levels of pollution, identification of pollution sources, control and disposal of waste from various point and non-point sources and for prediction of pollution levels for future, regular monitoring and assessment are required during the entire construction and operation phase of a major port. As per the Ministry of Environment, Forest and Climate Change **(MoEF&CC)**, The Environmental Management Plan (EMP) is required to ensure sustainable development in the area surrounding the project. Hence, it needs to be an all encompasses plan consist of all mitigation measures for each item wise activity to be undertaken during the construction, operation and the entire life cycle to minimize adverse environmental impacts resulting from the activities of the project. for formulation, implementation and monitoring of environmental protection measures during and after commissioning of projects. The plan should indicate the details of various measures are taken and proposed to be taken for appropriate management of the environment of Deendayal Port Authority.

It identifies the principles, approach, procedures and methods that will be used to control and minimize the environmental and social impacts of operational activities associated with the port. An EMP is a required part of environmental impact assessment of a new port project but could also be evolved for existing ports. It is useful not only during the construction and operational phases of the new port but also for operation of existing ports to ensure the effectiveness of the mitigation measures implemented and to further provide guidance as to the most appropriate way of dealing with any unforeseen impacts.

It is extremely essential that port and harbour projects should have an Environmental Monitoring and Management Plan (EMMP), which incorporates monitoring of Ambient Air, Drinking Water, Noise, Soil, Marine (water, sediment, ecology) quality along with the collection of online meteorological data throughout the duration of the project.

To ensure the effective implementation of the EMP and weigh the efficiency of the mitigation measures, it is essential to undertake environmental monitoring both during construction and operation period. In view of the above, Gujarat Environment Management Institute (GEMI) has been awarded with the work "**Preparing and Monitoring of Environmental Monitoring and Management Plan for Deendayal Port Authority at Kandla and Vadinar for a period of 3 years**" vide letter No. EG/WK/EMC/1023/2011/III/239 dated: 15/02/2023 by DPA.

This document presents the Environmental Monitoring Report (EMR) for Kandla and Vadinar for the environmental monitoring done during the period from April 2024-March 2025.

1.4 Objectives and scope of the Study

In line with the work order, the key objective of the study is to carry out the Environmental Monitoring and preparation the Management Plan for Kandla and Vadinar for a period of 3 years". Under the project, Environmental monitoring refers to systematic monthly monitoring and assessment of ambient air, water (drinking and surface), soil, sediment, noise and ecology in order to monitor the performance and implementation of a project in compliance with Environmental quality standards and/or applicable Statutory norms.

The scope of work includes not limited to following:

1. To review the locations/stations of Ambient Air, Ambient Noise, drinking water, and Marine Water, Soil and Sediments monitoring within the impacted region in-and-around DPA establishment, in view of the developmental projects.
2. To assess the Ambient Air quality, quality at 6 stations at Kandla and 2 at Vadinar in terms of gases and particulate matter.
3. To assess the DG stack emissions (gases and particulate matter).
4. To assess Drinking water quality at twenty locations (18 at Kandla and 2 at Vadinar) in terms of Physical, Chemical and Biological parameters viz., Color, Odor, turbidity, conductivity, pH, Total Dissolved Solids, chlorides, Hardness, total iron, sulphate, NH_4, PO_4, and bacterial count on a monthly basis.
5. To assess the Marine water quality in terms of aquatic Flora and Fauna and Sediment quality in terms of benthic flora and fauna.
6. To assess Marine Water Quality and sediment in term of physical and chemical parameter.
7. To assess the trends of water quality in terms of Marine ecology by comparing the data collected over a specified time period.
8. Weekly sample collection and analysis of inlet & Outlet points of the Sewage Treatment Plant (STP) to check the water quality being discharged by DPA as per the CC&A.
9. Carrying out monthly Noise monitoring; twice a day at the representative stations for a period of 24 hours.
10. Meteorological parameters are very important from air pollution point of view; hence precise and continuous data collection is of utmost importance. Meteorological data on wind speed, wind direction, temperature, relative humidity, solar radiation and rainfall shall be collected from one permanent station at DPA, Kandla and one permanent station at Vadinar.
11. To suggest mitigation measures, based on the findings of this study and also check compliance with Environmental quality standards, Green Port Initiatives, MIV 2030, and any applicable Statutory Compliance.
12. To recommend Environment Management Plans based on Monitoring programme and findings of the study.

CHAPTER 2: METHODOLOGY

2.1 Study Area

Under the study, the locations specified by Deendayal Port Authority for the areas of Kandla and Vadinar would be monitored. The details of the study area as follows:

a. Kandla

Deendayal Port (Erstwhile Kandla Port) is one of the twelve major ports in India and is located on the West Coast of India, in the Gulf of Kutch at 23001'N and 70013'E in Gujarat. The Major Port Authorities Act 2021 is the governing statute for Administration of Major Ports, under which, Deendayal Port Trust (DPT) has become Deendayal Port Authority (DPA). At Kandla, DPA has sixteen (16) cargo berths for handling various types of Dry Bulk Cargo viz, fertilizer, food grains, Coal, sulphur, etc.

- **Climatic conditions of Kandla**

Kandla has a semi-desert climate. Temperature varies from 25°C to 44°C during summer and 10°C to 25°C during winter. The average annual temperature is 24.8 °C. The average rainfall is 410 mm, most of which occurs during the monsoon from the months of June-to-September.

b. Vadinar

Vadinar is a small coastal town located in Devbhumi Dwarka district of the Gujarat state in India located at coordinates 22° 27' 16.20" N - 069° 40' 30.01". DPA had commissioned the Off Shore Oil Terminal (OOT) facilities at Vadinar in the year 1978, for which M/s. Indian Oil Corporation Limited (IOCL) provided Single Bouy Mooring (SBM) system, with a capacity of 54 MMTPA. The OOT of the DPA contributes in a large way to the total earnings of this port. Vadinar is now notable due to the presence of two refineries-one promoted by Reliance Industries and Essar Oil Ltd.

DPA also handled 43.30 MMT at Vadinar (which includes transhipment), the containerized cargo crossed 4.50 lakh TEU, grossing a total of 100 MMT overall. Major commodities handled by the Deendayal Port are Crude Oil, Petroleum product, Coal, Salt, Edible Oil, Fertilizer, etc.

- **Climatic conditions of Vadinar**

Vadinar has a hot semi-arid climate. The summer season lasts from March-to-May and is extremely hot, humid, but dry. The climatic conditions in Vadinar are quite similar to that recorded in its district head quarter i.e., Jamnagar. The annual mean temperature is 26.7 °C. Rainy season with extremely erratic monsoonal rainfall that averages around 630 millimetres. The winter season is from October-to-February remains hot during the day but has negligible rainfall, low humidity and cool nights.

The Kandla and Vadinar port have been depicted in the **Map 1 & 2** as follows:

SS

Map 1: Locations of Kandla and Vadinar Port

Map 2: Locations of Kandla Port

Map 3: Locations of Vadinar Port

2.2 Environmental Monitoring at Kandla and Vadinar

Regular monitoring of environmental parameters is of immense importance to assess the status of environment during project operation. With the knowledge of baseline conditions, the monitoring programme will serve as an indicator for identifying any deterioration in environmental conditions, thereby assist in recommending suitable mitigatory steps in time to safeguard the environment. Monitoring is as important as that of control of pollution since the efficiency of control measures can only be determined by a well-defined monitoring program. Environmental Monitoring is vital for monitoring the environmental status of the port for sustainable development. The list of main elements for which Environmental monitoring is to be carried out have been mentioned below:

- Meteorology
- Ambient Air
- DG Stack
- Noise
- Soil
- Drinking Water
- Sewage Treatment Plant
- Marine (Surface) water
- Marine Sediments
- Marine Ecology

GEMI has been entrusted by DPA to carry out the monitoring of the various aforementioned environmental aspects at the port, so as to verify effectiveness of prevailing Environment Management plan, if it confirms to the statutory and/or legal compliance; and identify any unexpected changes. Standard methods and procedures have been strictly adhered to in the course of this study. QA/QC procedures were strictly followed which covers all aspects of the study, and includes sample collection, handling, laboratory analyses, data coding, statistical analyses, interpretation and communication of results. The analysis was carried out in GEMI's NABL/MoEF accredited/recognized laboratory.

Methodology adopted for the study

Methodology is a strictly defined combination of practices, methods and processes to plan, develop and control a project along the continuous process of its implementation and successful completion. The aim of the project management methodology is to allow the control of whole process of management through effective decision-making and problem solving. The methodology adopted for the present study is shown in **Figure 1** as given below:

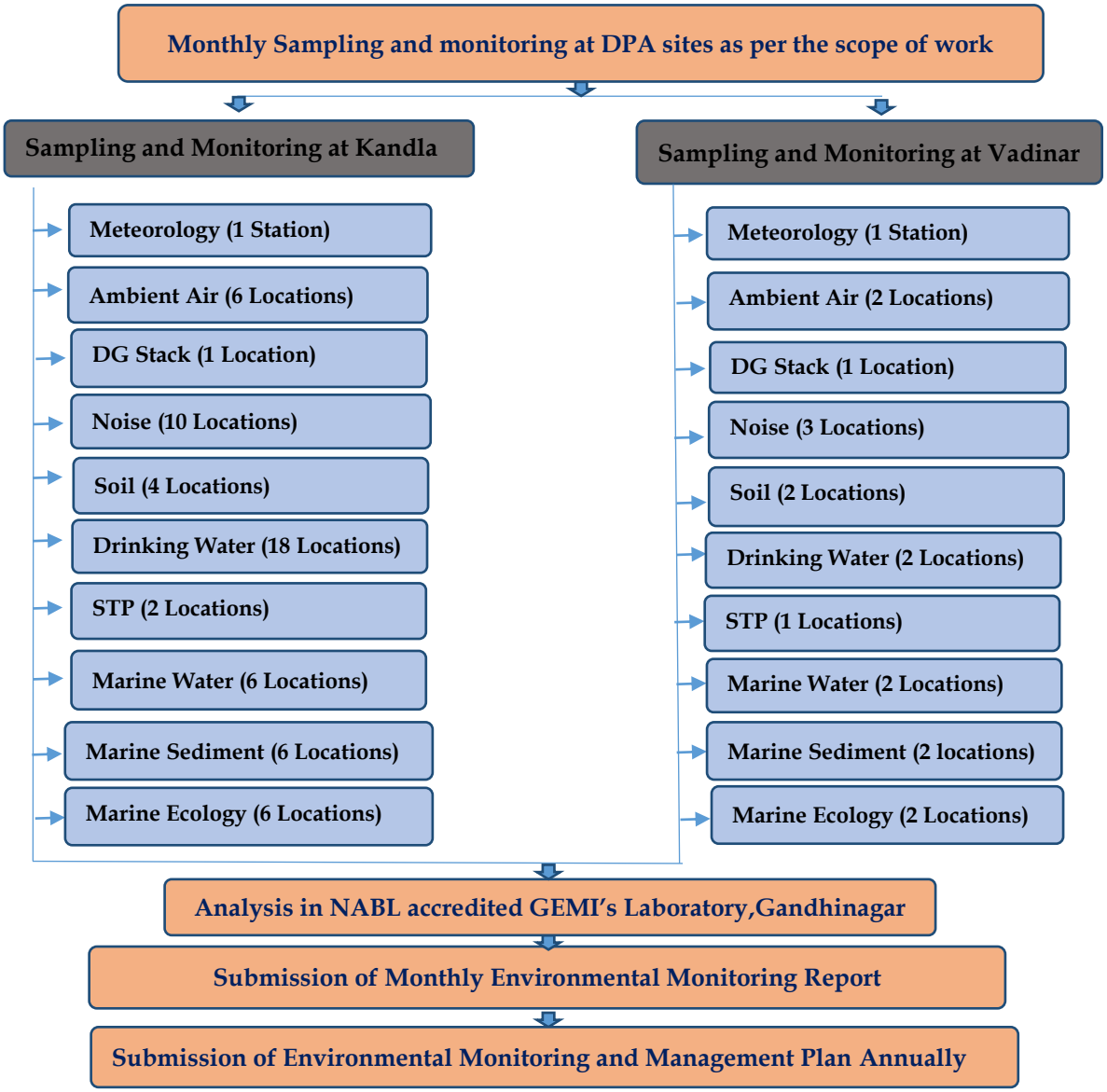


Figure 1: Methodology flow chart

The details of various sectors of Environment monitoring are described in subsequent chapters.

CHAPTER 3: METEOROLOGY MONITORING

3.1 Meteorology Monitoring

Meteorological conditions play a crucial role in dispersion of air pollutants as well as in environmental pollution studies particularly in pollutant transport irrespective of their entry into the environment. The wind speed and direction play a major role in dispersion of environment pollutants. In order to determine the prevailing micro-meteorological conditions at the project site an Automatic Weather Monitoring Stations (AWS) of Envirotech make (Model: WM280) were installed at both the sites of Kandla and Vadinar at 10 m above the ground. The details of the AWS installed have been mentioned in **Table 1** as follows:

Table 1: Details of Automatic Weather Station

Sr. No.	Site	Location Code	Location Name	Latitude Longitude
1.	Kandla	AWS-1	Environment Laboratory (DPA)	23.00996N 70.22175E
2.	Vadinar	AWS-2	Canteen Area	22.39994N 69.716608E

Methodology:

During the study, a continuous automatic weather monitoring station was installed at both the sites to record climatological parameters such as Wind speed, Wind Direction, Relative Humidity, Solar Radiation, Rainfall and Temperature to establish general meteorological regime of the study area. The methodology adopted for monitoring meteorological data shall be as per the standard norms laid down by Bureau of Indian Standards (BIS) and the India Meteorological Department (IMD). The details of Automatic Weather Monitoring Station have been mentioned in **Table 2**.

Table 2: Automatic Weather Monitoring Station details

Sr. No.	Details of Meteorological Data	Unit of Measurement	Instrument	Frequency
1.	Wind Direction	degree	Automatic Weather Monitoring Station (Envirotech WM280)	Hourly Average
2.	Wind Speed	Km/hr		
3.	Rainfall	mm/hr		
4.	Relative Humidity	% RH		
5.	Temperature	^{o}C		
6.	Solar Radiation	W/m^2		

Monitoring Frequency:

The Meteorological parameters were recorded at an interval of 1 hour in a day for the period of **April 2024 to March 2025** and the average value for all the Meteorological parameters were summarized for the sampling period of at both the observatory site.

Figure 2: Photographs of Automatic Weather Monitoring Station at Kandla and Vadinar

3.2 Results and discussion

The summary of hourly climatological observations recorded at Kandla and Vadinar during the monitoring period of April 2024 to March 2025, with respect to significant parameters has been mentioned in **Table 3** as follows:

Table 3: Meteorological data for Kandla and Vadinar

Details of Micro-meteorological data at Kandla Observatory												
Monitoring Month	**Wind Speed (Km/h)**			**Temperature (°C)**			**Relative humidity (%)**			**Solar Radiation (W/m²)**	**Wind Direction (°)**	**Total Rainfall (mm/hr)**
	Avg.	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**			
April 24	6.87	67.3	0.02	32.25	43.4	24.6	56.61	83.9	19.3	96.2	W-S-W	0.2
May 24	8.01	82.7	0.025	33.75	45.6	28.8	62.42	81.3	25.7	97.16	W-S-W	0.02
June 24	12.73	81.3	0.6	30.67	36.7	26.2	71.91	87.8	45.8	113.19	W-S-W	0.01
July 24	0.49	89.3	0.015	30.42	40.2	26.7	77.64	90	48.1	53.88	W-S-W	3.21
Aug 24	0.39	58	0.017	30.11	36.5	25.3	75.6	92.6	51.7	70.01	W-S-W	2.94
Sep 24	4.26	79.3	0.21	31.12	40.3	23.5	67.95	89.2	33.3	69.39	W-E	2.07
Oct 24	3.06	66	1.05	30.39	40.8	22.3	56.01	84.4	28.3	64.46	N	0.04
Nov 24	6.34	82.7	1.77	29.44	38.1	22.3	66.85	91.4	31.5	83.34	N-N-E	0
Dec 24	7.25	48	3.12	20.27	34.1	13.5	52.38	78	27.8	57.19	S	0
Jan 25	5.86	53.3	2.16	23.42	35.1	15.4	50.81	88.6	22.6	67.43	N	0
Feb 25	18.4	47.3	1.3	27.82	44	19.2	52.67	88.2	21	70.13	N	0
Mar 25	3.38	42.6	0.66	30.53	43	21.9	42.22	85	18.7	92.27	N	0

Details of Micro-meteorological data at Vadinar Observatory												
Monitoring Period	**Wind Speed (Km/h)**			**Temperature (°C)**			**Relative humidity (%)**			**Solar Radiation (W/m²)**	**Wind Direction (°)**	**Rainfall (mm/hr)**
	Avg.	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**			
April 24	10.48	61.3	0.1	28.58	35.4	24.9	71.73	92.5	23.4	114.6	E-N-E	0
May 24	12.73	81.3	0.6	30.67	36.7	26.2	71.91	87.8	45.8	113.19	S-S-W	0
June 24	9.69	139	3.98	30.13	36	24.4	77.43	91.5	55.3	71.63	S-W	0.09
July 24	7.33	139	1.33	28.24	32.9	21.7	80.58	90.8	62.1	51.19	S-W	0.72
Aug 24	6.37	164	1.33	28.14	33.6	23.5	79.31	94.3	55.8	73.99	S	1.13
Sep 24	7.76	110	1.68	29.07	38.6	23.8	75.1	90.2	36.8	77.77	N-W	0.03
Oct 24	6.34	82.7	1.77	29.44	38.1	22.3	66.85	91.4	31.5	83.34	N-E	0.03
Nov 24	5.48	66	2.31	24.53	32.3	15.1	55.49	83.7	26.9	76.03	NE & NNE	0
Dec 24	7.91	74.7	2.96	20.9	27.3	14.1	60.62	104.1	29.4	69.28	S-W	0
Jan 25	7.62	58.9	2.07	22.11	32.6	16	66.54	104.2	25.4	79.37	NNE & WSW	0
Feb 25	8.01	82.7	1.3	25.32	37.3	19.1	71.36	104.3	18.9	89.36	WNW	0
Mar 25	12.18	57.3	3.32	27.56	38.3	21.8	68.26	97.6	19.9	110.3	WNW	0

3.3 Data Interpretation and Conclusion

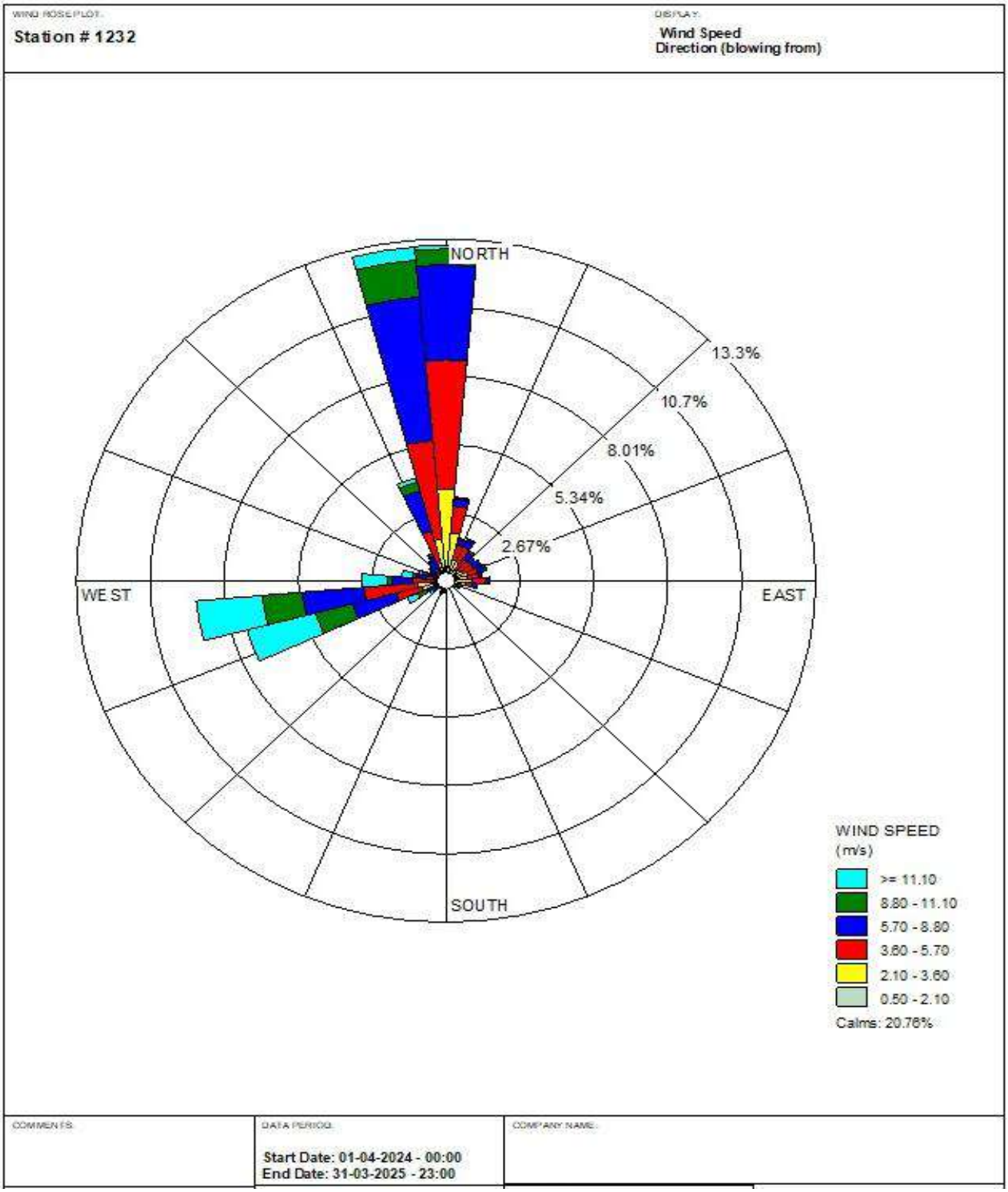
1) Kandla:

a. The ambient temperature for the summer season varies in the range of **21.9** to **45.6** °C; in the monsoon season, the temperature varies between **22.3** and **40.8** °C; and in the winter season, the temperature varies between **13.5** and **44** °C. The yearly average temperature at Kandla is observed to be around **29.18** °C, with a standard deviation of **3.77**.
b. The relative humidity for the summer season was recorded in the range of **18.7** % to **87.8** %; in the monsoon season, relative humidity was recorded in the range of **28.3** % to **92.6** %; and in the winter season, relative humidity was recorded in the range of **21** to **91.4** %; the yearly average humidity at Kandla was **61.08** % with a standard deviation of **11.03**.
c. The maximum rainfall at Kandla was observed at **3.21** mm/hr for the monitoring period of July to August 2024; the yearly average rainfall was found to be **1.21** mm/hr.
d. Wind speed and direction play a significant role in transporting pollutants and thus determining the air quality. In the summer season, wind blew from the West-South-West and North directions; in the monsoon season, wind blew from the West South West; and in the winter season, wind blew from the North and North-East direction.
e. The wind speed recorded ranges from **0.02** to **82.7** km/h in the summer season; in the monsoon season, the wind speed recorded ranges from **0.015** to **89.3** km/h; and in the winter season, the wind speed recorded ranges from **1.3** to **82.7** km/h. The yearly average wind speed at Kandla is **6.42** km/h, with a standard deviation of 5.07.
f. The maximum solar radiation at Kandla was observed at **113.19** W/m^2 during the monitoring period June to July 2024; the minimum solar radiation at Kandla was observed at **53.88** W/m^2 for the monitoring period July to August 2024; and the yearly average solar radiation was found to be **77.89** W/m2 with a standard deviation of **18.28**.

Wind rose diagram:

The wind-rose diagram for the monitoring period has been drawn on the basis of hourly wind speed and direction data.

This Wind Rose Diagram reveals that at Kandla during the monitoring period, the prevailing winds predominantly blow from the North direction at Kandla, whereas, high speed winds were also observed to blow from West West South direction.


WIND ROSE PLOT:
Station # 1232
DISPLAY:
Wind Speed
Direction (blowing from)
NORTH
EAST
SOUTH
WEST
13.3%
10.7%
8.01%
5.34%
2.67%
WIND SPEED
(m/s)
>= 11.10
8.80 - 11.10
5.70 - 8.80
3.60 - 5.70
2.10 - 3.60
0.50 - 2.10
Calms: 20.76%
COMMENTS:
DATA PERIOD:
Start Date: 01-04-2024 - 00:00
End Date: 31-03-2025 - 23:00
COMPANY NAME:

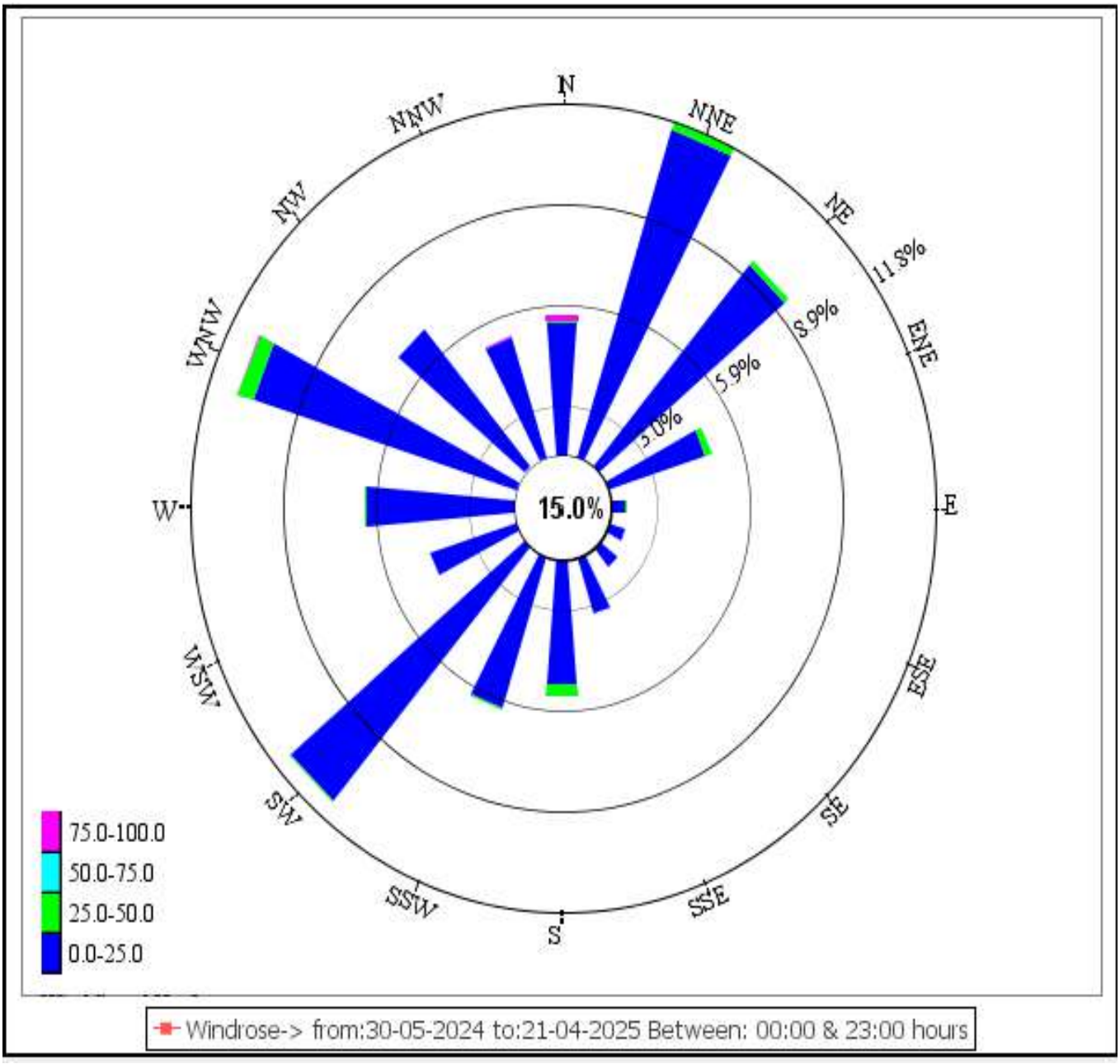
2) Vadinar:

a. The ambient temperature for the summer season varies between **21.8** and **38.3** °C; in the monsoon season, it varies between **21.7** and **38.6** °C; and in the winter season, it varies between **14.1** and **37.3** °C. The yearly average temperature at Vadinar is **27.06** °C with standard deviation of **2.4**.
b. The relative humidity for the summer season was recorded in the range of **19.9** % to **97.6** %; in the monsoon season, relative humidity was recorded in the range of **31.5** % to **94.3** %; and in the winter season, relative humidity was recorded in the range of **18.9** % to **104.3** %; the yearly average humidity at Vadinar was **70.43** % with a standard deviation of 6.38.
c. The **maximum** rainfall at Vadinar was observed at **1.13 mm** for the monitoring period from **August to September 2024**; the yearly **average** rainfall was found to be **0.4** mm.
d. In Summer Season wind blew from South West South Direction, in Monsoon season wind blew from South West South and North Direction and in Winter Season wind blew from North and South direction. The recorded wind speed ranges from **0.1** to **139.4** km/hr in the summer season, **1.33** to **164** km/hr, and in the monsoon season, the recorded wind speed ranges from **1.3** to **82.7** km/hr. The yearly average wind speed at Vadinar is **8.49** km/h with a standard deviation of **4.49**.
e. The maximum solar radiation at Vadinar was observed at **114.6** W/m2 for the monitoring period April to May 2024; the minimum solar radiation at Vadinar was observed at **51.19** W/m2 for the monitoring period July to August 2024; and the yearly average solar radiation was found to be **84.17** W/m2.

Wind rose diagram:

The wind-rose diagram for the monitoring period has been drawn on the basis of hourly wind speed and direction data.

At Vadinar, the winds were observed to blow from North-North-Easts, West-North-West and South-West direction.


N
NNE
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ENE
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ESE
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SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
11.8%
5.9%
5.9%
5.0%
15.0%
75.0-100.0
50.0-75.0
25.0-50.0
0.0-25.0
Windrose-> from:30-05-2024 to:21-04-2025 Between: 00:00 & 23:00 hours

CHAPTER 4: AMBIENT AIR QUALITY MONITORING

4.1 Ambient Air Quality

It is necessary to monitor the ambient air quality of the study area, in order to determine the impact of the shipping activities and port operations on the ambient air quality. The prime objective of ambient air quality monitoring is to assess the present air quality and its conformity to National Ambient Air Quality Standards i.e. NAAQS, 2009(1).

Methodology

The study area represents the area occupied by DPA and its associated Port area. The sources of air pollution in the region are mainly vehicular traffic, fuel burning, loading & unloading of dry cargo, fugitive emissions from storage area and dust arising from unpaved village roads. Considering the below factors, under the study, as per the scope specified by DPA eight locations wherein, 6 stations at Kandla and 2 at Vadinar have been finalized within the study area

- Meteorological conditions;
- Topography of the study area;
- Direction of wind;
- Representation of the region for establishing current air quality status
- Representation with respect to likely impact areas.

The description of various air quality stations monitored at Kandla and Vadinar have been specified in **Table 4**.

Table 4: Details of Ambient Air monitoring locations

Sr. No.	Location Code		Location Name	Latitude Longitude	Significance
1.	Kandla	A-1	Oil Jetty No. 1	23.029361N 70.22003E	Liquid containers and emission from ship
2.		A-2	Oil Jetty No. 7	23.043538N 70.218617E	
3.		A-3	Kandla Port Colony	23.019797N 70.213536E	Vehicular activity and dust emission
4.		A-4	Marine Bhavan	23.007653N 70.222197E	Construction and vehicular activity, road dust emission,
5.		A-5	Coal Storage Area	23.000190N 70.219757E	Coal Dust, Vehicular activity
6.		A-6	Gopalpuri Hospital	23.081506N 70.135258E	Residential area, dust emission, vehicular activity
7.	Vadinar	A-7	Admin Building	22.441806N 69.677056E	Vehicular activity
8.		A-8	Vadinar Colony	22.401939N 69.716306E	Residential Area, burning waste, vehicular activity

The monitoring locations at Kandla and Vadinar have been depicted in map in **Map 4 and 5** respectively.

Ambient Air monitoring photos

Kandla

A-1: Oil Jetty No. 1

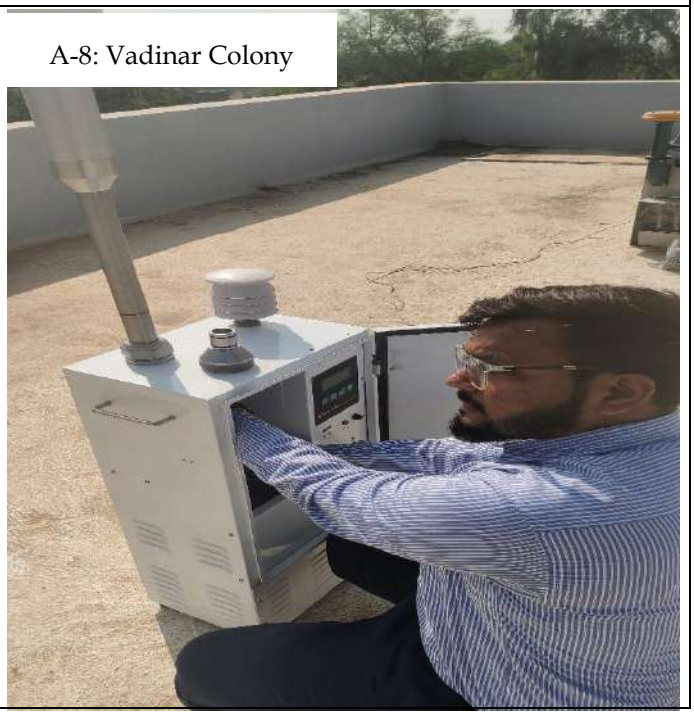
A-2: Oil Jetty No. 7

A-3: Kandla Port Colony

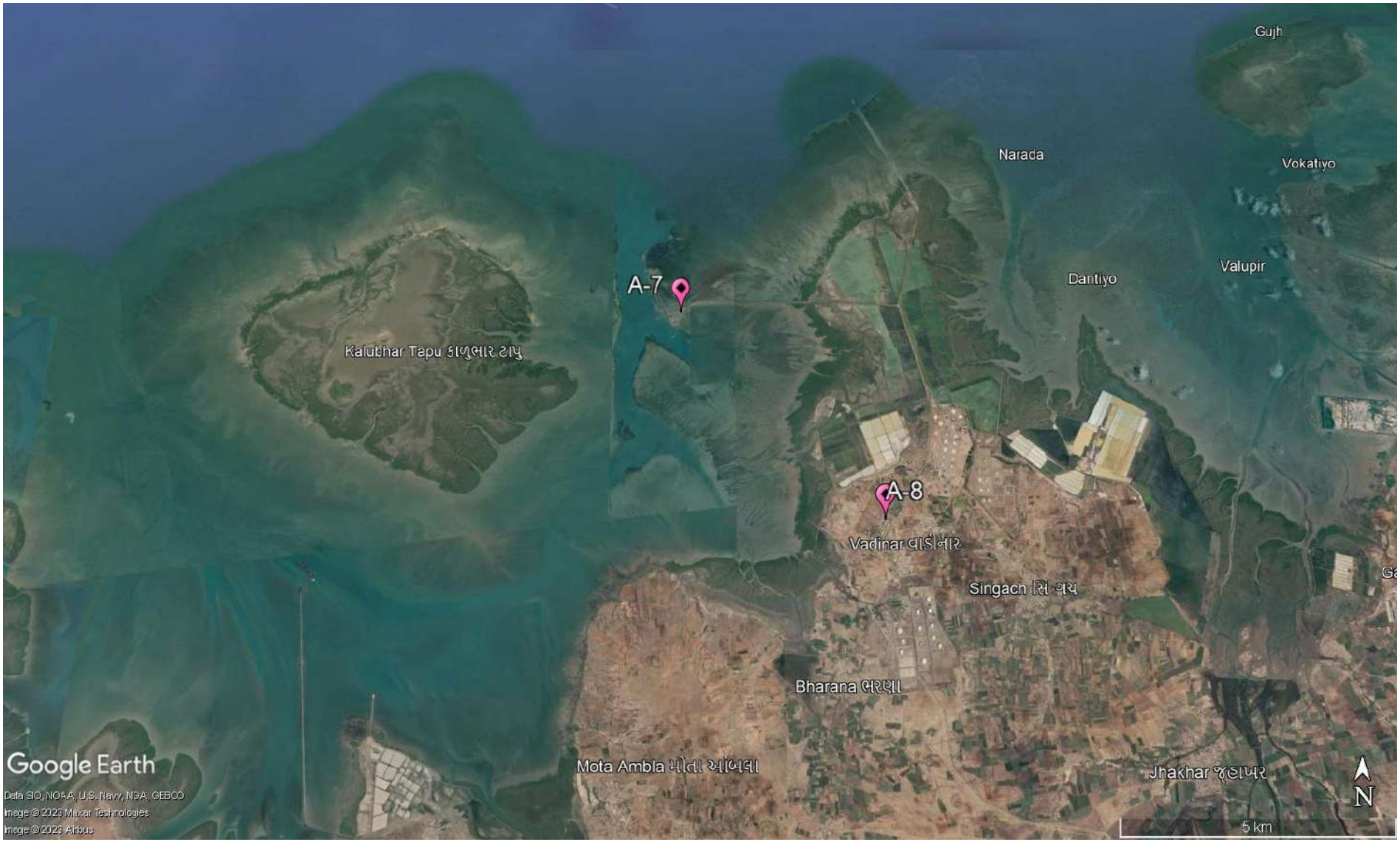
A-4: Marine Bhavan

A-5: Coal Storage Area

A-6: Gopalpuri Hospital

Vadinar	
A-7: Admin Building	A-8: Vadinar Colony 

Map 4: Ambient Air Monitoring locations at Kandla



Map 5: Ambient Air Monitoring locations at Vadinar

Monitoring Frequency

The sampling for Particulate matter, i.e., PM_{10} and $PM_{2.5}$, and gaseous components like SO_x, NO_x, and CO, as well as the total VOCs, was monitored twice a week for a period of 24 hours a day. Whereas, the sampling for the components of PAH, benzene, and non-methane VOCs was conducted on a monthly basis. The monitoring period for this study is from March 16, 2024, to April 17, 2025. During this period, 97 air samples were taken from six locations in Kandla, and two locations in Vadinar.

Sampling and Analysis

The Sampling of the Ambient Air Quality parameters and analysis is conducted as per the CPCB guidelines of National Ambient Air Quality Monitoring. The sampling was performed at a height of 3.5 m (approximately) from the ground level. For the sampling of PM_{10}, calibrated 'Respirable Dust Samplers' were used, where Whatman GF/A microfiber filter paper of size 8"x 10" were utilized, where the Gaseous attachment of the make Envirotech instrument was attached with Respirable Dust Sampler for the measurement of SO_x and NO_x. The Fine Particulate Sampler for collection of $PM_{2.5}$ was utilized for the particulate matter of size <2.5 microns. A known volume of ambient air is passed through the cyclone to the initially pre-processed filter paper. The centrifugal force in cyclone acts on particulate matter to separate them into two parts and collected as following:

- Particles <10 µ size (Respirable): GF/A Filter Paper
- Particles <2.5 µ size (Respirable): Polytetrafluoroethylene (PTFE)

Sampling and analysis of ambient SO_2 was performed by adopting the 'Improved West and Gaeke Method'. The ambient air, drawn through the draft created by the RDS, is passed through an impinger, containing a known volume of absorbing solution of Sodium tetrachloromercurate, at a pre-determined measured flow rate of 1 liter/minute (L/min). Similarly, NO_x was performed by adopting the 'Jacob Hochheister Modified' (Na arsenite) method. The impinger contains known volume of absorbing solution of Sodium Arsenite and Sodium Hydroxide.

Data has been compiled for PM_{10}, $PM_{2.5}$, SO_x and NO_x samples of 24-hour carried out twice a week. In case of CO, one hourly sample were taken on selected monitoring days using the sensor-based CO Meter. For the parameters Benzene, Methane & Non-methane and Volatile Organic Carbons (VOCs), the Low Volume Sampler is used, where the charcoal tubes are used as sampling media. The sampling in the Low Volume Sampler (LVS) is carried out as per IS 5182 (Part 11): 2006 RA: 2017, where the ambient air flow rate is maintained at 200 cc/min, the volume of air that passes through the LVS during two hours monitoring is approx. 24 L.

The sampling of PAHs is carried out as per IS: 5182 (Part 12): 2004. Where, the EPM 2000 Filter papers are utilized in the Respirable Dust Sampler (RDS). For the parameters, Benzene, PAH & Non-methane VOC's, monthly monitoring is carried out. The details of the parameters with their frequency monitored are mentioned in **Table 5:**

Table 5: Parameters for Ambient Air Quality Monitoring

Sr. No.	Parameters	Units	Reference method	Instrument	Frequency
1.	PM_{10}	µg/m³	IS 5182 (Part 23): 2006	Respirable Dust Sampler (RDS) conforming to IS:5182 (Part-23): 2006	Twice in a week
2.	$PM_{2.5}$	µg/m³	IS:5182 (Part:24):2019	Fine Particulate Sampler (FPS) conforming to IS:5182 (Part-24): 2019	
3.	Sulphur Dioxide (SO_x)	µg/m³	IS 5182 (Part:2): 2001	Gaseous Attachment conforming to IS:5182 Part-2	
4.	Oxides of Nitrogen (NO_x)	µg/m³	IS:5182 (Part-6): 2006	Gaseous Attachment conforming to IS:5182 Part-6	
5.	Carbon Monoxide (CO)	mg/m³	GEMI/SOP/AAQM/11; Issue no 01, Date 17.01.2019: 2019	Sensor based Instrument	
6.	VOC	µg/m³	IS 5182 (Part 17): 2004	Low Flow Air Sampler	
8.	PAH	µg/m³	IS: 5182 (Part 12): 2004	Respirable Dust Sampler (RDS) conforming to IS:5182 (Part-12): 2004	Monthly
7.	Benzene	µg/m³	IS 5182 (Part 11): 2006 RA: 2017	Low Flow Air Sampler	
9.	Non-methane VOC	µg/m³	IS 5182 (Part 11): 2006	Low Volume Sampler	

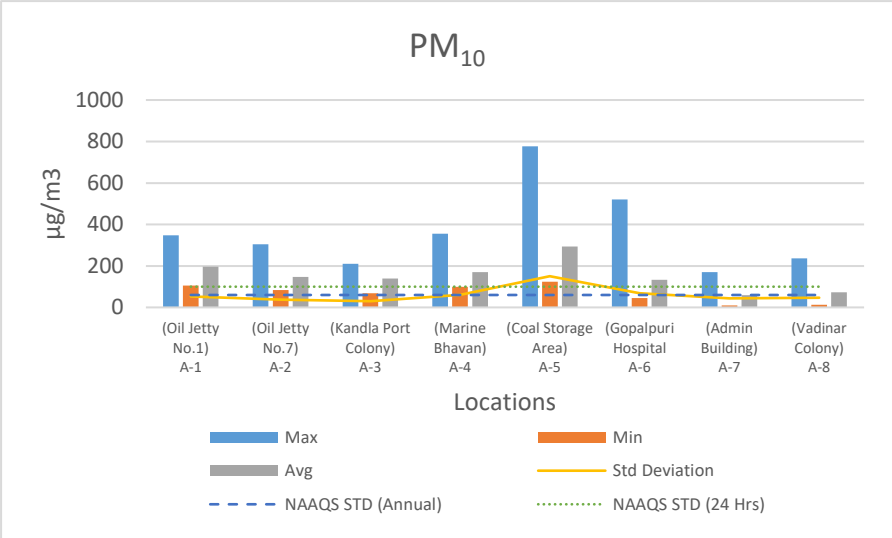
4.2 Result and Discussion

The summarized results of ambient air quality monitoring for the study period are presented in **Table-6 to 9** along with the graphical representation from **Graph 1 to Graph 6.** Various parameters monitored during the study have been presented by their maximum, minimum, average and Standard deviation**.**

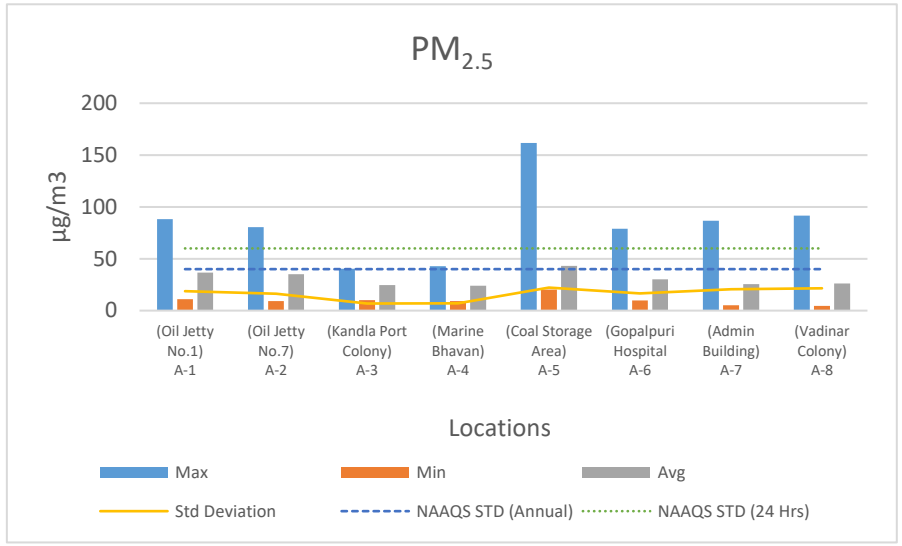
Table 6: Summarized results of PM_{10}, $PM_{2.5}$, SO_2, NO_x, VOC and CO for Ambient Air quality monitoring

Parameters / Locations	NAAQS by CPCB		(Oil Jetty No.1) A-1	(Oil Jetty No.7) A-2	(Kandla Port Colony) A-3	(Marine Bhavan) A-4	(Coal Storage Area) A-5	(Gopalpuri Hospital A-6	(Admin Building) A-7	(Vadinar Colony) A-8
PM_{10} (µg/m3)	24 Hours -100 Annual -60	Max	348.3	304	210.65	355.33	777.32	520.27	169.87	235.99
		Min	105.77	84.43	67.72	98.91	123.43	45.26	10.42	12.4
		Avg	196.94	146.66	140.05	170.08	293.30	132.36	59.56	73.63
		Std Deviation	53.08	37.12	29.92	60.82	150.49	68.24	43.15	47.02
$PM_{2.5}$ (µg/m3)	24 Hours -60 Annual -40	Max	88.35	80.64	40.22	42.95	161.69	79.04	86.70	91.70
		Min	11.12	9.31	9.99	9.23	20.15	9.65	5.12	4.49
		Avg	36.66	35.14	24.74	24.03	43.11	30.11	25.44	26.20
		Std Deviation	18.76	16.42	6.83	7.13	22.19	16.52	20.72	21.46
SO_2 (µg/m3)	24 Hours -80 Annual -50	Max	53.31	66.31	38.02	33.69	75.04	58.79	45.56	135.36
		Min	4.31	4.30	3.80	3.90	4.34	4.32	3.11	2.89
		Avg	16.78	20.23	15.63	16.83	25.32	16.74	11.22	12.86
		Std Deviation	10.85	13.12	8.06	7.70	13.52	11.15	8.10	15.31
NO_X (µg/m3)	24 Hours -80 Annual -40	Max	36.64	32.53	36.96	35.58	65.62	36.54	31.70	26.97
		Min	5.63	5.36	5.74	5.72	6.76	5.62	4.19	4.12
		Avg	17.03	15.80	18.23	15.69	25.51	15.68	8.71	8.13
		Std Deviation	7.17	6.67	7.33	7.25	13.72	7.55	5.11	4.06
VOC (µg/m3)	-	Max	1.90	1.94	1.67	1.44	1.74	1.17	0.79	0.99
		Min	0.00	0.01	0.01	0.00	0.05	0.00	0.00	0.00
		Avg	0.21	0.20	0.25	0.23	0.24	0.23	0.16	0.19
		Std Deviation	0.31	0.29	0.28	0.29	0.30	0.26	0.14	0.15
CO (mg/m3)	8 Hours -2 1 Hour -4	Max	1.04	1.02	0.87	0.95	1.06	0.89	0.85	1.03
		Min	0.58	0.61	0.64	0.64	0.63	0.29	0.56	0.52
		Avg	0.80	0.80	0.80	0.82	0.93	0.69	0.66	0.67
		Std Deviation	0.08	0.07	0.06	0.06	0.09	0.09	0.06	0.10

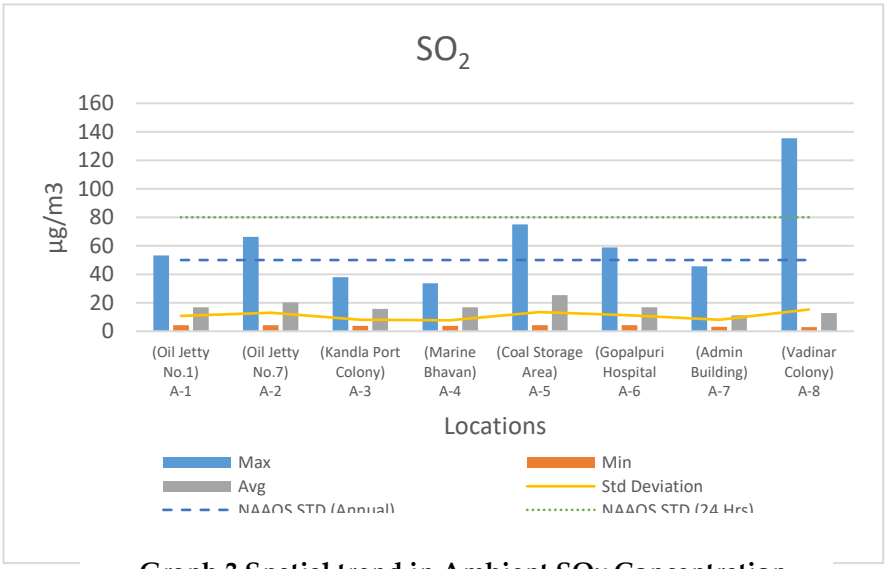
Graphs 1-6 shows spatial trend of ambient air parameter at all the eight-monitoring location (six at Kandla and 2 at Vadinar)



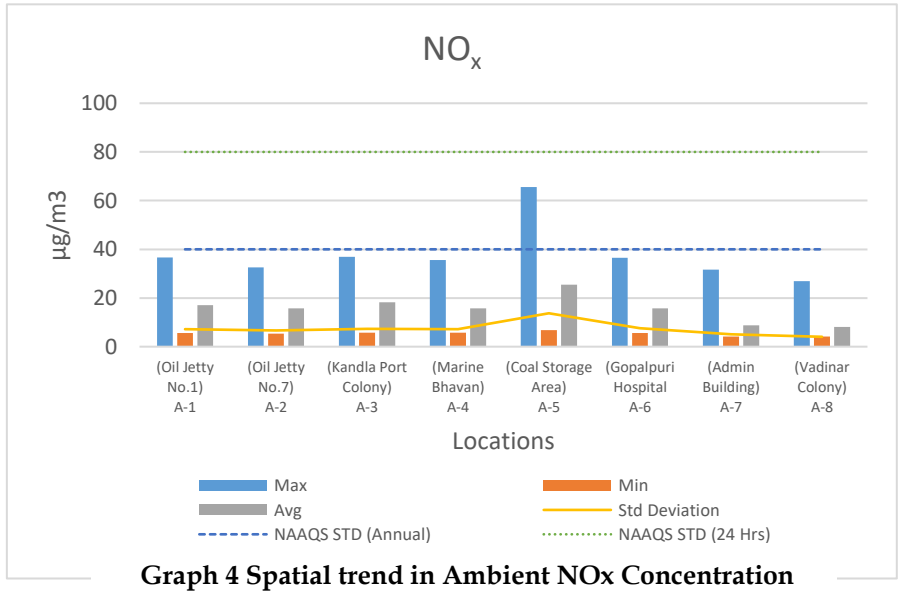
Graph 2 Spatial trend in Ambient PM_{10} Concentration



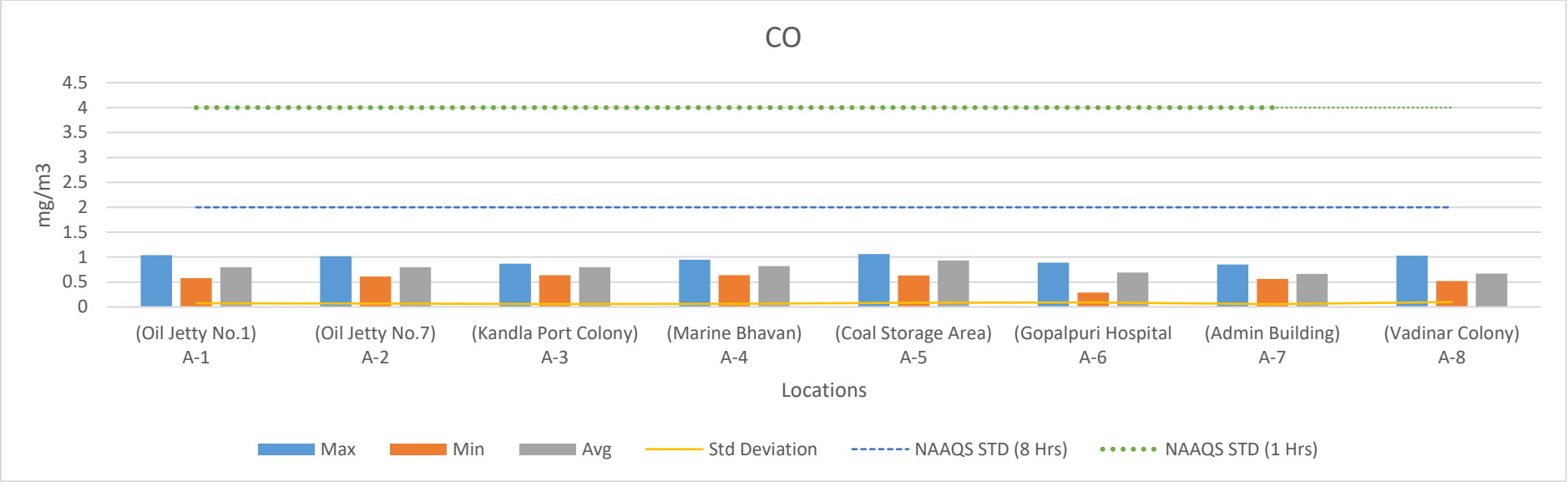
Graph 1 Spatial trend in Ambient $PM_{2.5}$ Concentration



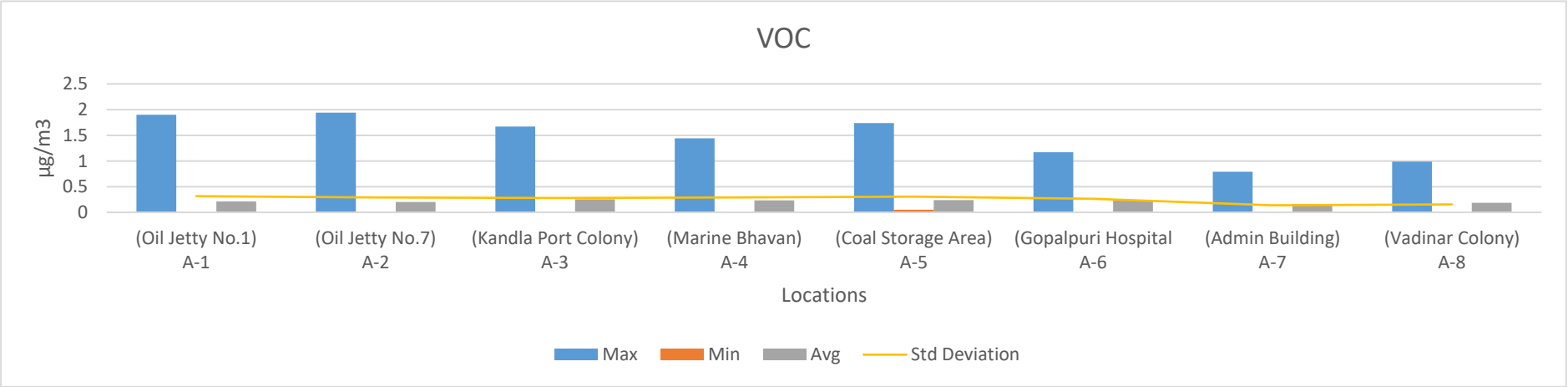
Graph 3 Spatial trend in Ambient SOx Concentration



Graph 4 Spatial trend in Ambient NOx Concentration



Graph 5 Spatial trend in Ambient CO Concentration



Graph 6 Spatial trend in Ambient Total VOCs

Table 7: Summarized results of Benzene for Ambient Air quality monitoring

Parameters / Locations	NAAQS by CPCB		(Oil Jetty No.1) A-1	(Oil Jetty No.7) A-2	(Kandla Port Colony) A-3	(Marine Bhavan) A-4	(Coal Storage Area) A-5	(Gopalpuri Hospital A-6	(Admin Building) A-7	(Vadinar Colony) A-8
Benzene (µg/m3)	Annual - 5	Max	0.050	0.060	0.040	0.020	0.090	0.010	0.000	0.000
		Min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		Avg	0.009	0.012	0.008	0.005	0.023	0.001	0.000	0.000

Table 8: Summarized results of Polycyclic Aromatic Hydrocarbons

Parameters / Locations		(Oil Jetty No.1) A-1	(Oil Jetty No.7) A-2	(Kandla Port Colony) A-3	(Marine Bhavan) A-4	(Coal Storage Area) A-5	(Gopalpuri Hospital A-6	(Admin Building) A-7	(Vadinar Colony) A-8
Napthalene (µg/m3)	Max	1.18	1.52	0.48	1.55	7.50	0.49	0.46	0.41
	Min	0.01	0.28	0.00	0.16	0.00	0.00	0.00	0.00
	Avg	0.46	0.70	0.18	0.79	1.18	0.13	0.13	0.15
Acenaphthylene (µg/m3)	Max	0.88	0.72	0.08	0.87	0.36	0.08	0.03	0.03
	Min	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	0.20	0.20	0.05	0.36	0.15	0.03	0.01	0.01
Fluorene (µg/m3)	Max	0.28	0.58	0.25	0.74	0.75	0.68	0.22	0.16
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	0.08	0.15	0.08	0.30	0.44	0.21	0.03	0.06
Anthracene (µg/m3)	Max	0.39	0.43	0.35	0.55	2.84	0.69	0.22	0.31
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	0.11	0.11	0.16	0.31	0.86	0.21	0.08	0.08
Phenanthrene (µg/m3)	Max	0.08	0.06	0.36	0.18	0.56	0.20	0.02	0.14
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	0.02	0.02	0.11	0.05	0.16	0.07	0.00	0.02
Fluoranthene (µg/m3)	Max	0.76	0.78	0.55	0.58	1.47	0.77	0.49	0.54
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	0.19	0.31	0.17	0.26	0.27	0.26	0.12	0.09
Pyrene (µg/m3)	Max	0.77	0.74	0.58	0.60	1.01	0.69	0.47	0.46
	Min	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	Avg	0.23	0.34	0.39	0.36	0.57	0.21	0.11	0.09
Chrycene (µg/m3)	Max	1.22	1.30	0.78	0.67	1.78	1.65	1.05	1.34

	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	0.43	0.41	0.37	0.43	0.58	0.53	0.10	0.13
Banz(a)anthracene (µg/m3)	Max	1.15	1.45	0.55	0.86	3.85	1.46	0.92	1.23
	Min	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
	Avg	0.33	0.43	0.23	0.34	0.87	0.21	0.09	0.14
Benzo[k]fluoranthene (µg/m3)	Max	3.70	2.05	5.30	2.70	4.51	1.68	0.15	0.04
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	1.18	0.22	1.22	0.39	1.15	0.45	0.02	0.02
Benzo[b]fluoranthene (µg/m3)	Max	3.86	0.09	0.10	0.23	5.87	0.18	0.10	0.16
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	0.65	0.03	0.04	0.06	0.97	0.05	0.01	0.03
Benzopyrene (µg/m3)	Max	3.32	4.99	3.59	2.95	8.99	6.53	2.84	4.26
	Min	0.02	0.01	0.00	0.00	0.19	0.01	0.00	0.00
	Avg	1.17	1.37	1.47	0.37	2.16	0.71	0.28	0.43
Indeno [1,2,3-cd] fluoranthene (µg/m3)	Max	0.52	0.75	0.74	0.57	0.98	1.76	3.28	2.35
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	0.24	0.32	0.26	0.28	0.39	0.68	0.36	0.36
Dibenz(ah)anthracene (µg/m3)	Max	1.74	0.71	0.27	0.32	7.74	0.09	0.20	0.47
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	0.29	0.21	0.17	0.12	1.38	0.05	0.04	0.09
Benzo[ghi]perylene (µg/m3)	Max	15.20	8.90	29.50	14.50	10.20	12.80	0.45	0.24
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	1.60	2.40	9.14	4.34	3.27	3.03	0.06	0.06
Acenaphthene (µg/m3)	Max	0.88	0.72	0.08	0.87	0.36	0.08	0.03	0.03
	Min	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	0.20	0.20	0.05	0.36	0.15	0.03	0.01	0.01

Table 9: Summarized results of Non-methane VOC

Parameters \ Locations		(Oil Jetty No.1) A-1	(Oil Jetty No.7) A-2	(Kandla Port Colony) A-3	(Marine Bhavan) A-4	(Coal Storage Area) A-5	(Gopalpuri Hospital A-6	(Admin Building) A-7	(Vadinar Colony) A-8
Non- Methane VOC (µg/m3)	Max	1.18	1.15	1.87	1.29	1.76	1.69	1.58	1.28
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Avg	0.66	0.68	0.89	0.70	1.15	0.75	0.63	0.50

4.3 Data Interpretation and Conclusion

The results were compared with the National Ambient Air Quality Standards (NAAQS), 2009 of Central Pollution Control Board (CPCB).

1) Kandla:

Particulate matter:

- The concentration of PM_{10} varies very widely and is reported in the range of **45.26** to **777.32** µg/m3, with a yearly average value of **179.90** with standard deviation **43.52** µg/m^3. As shown in Graph 1, the highest concentration (value) of PM_{10} is reported at location A-5 (coal storage area) during the winter. It can be seen that PM_{10} exceeds the NAAQS annual limit, i.e., 60 µg/m^3, in all locations. It can be seen that location A-5 (coal storage area) had the maximum percentage exceedance, and location A-6 (Gopalpuri Hospital) had the minimum percentage exceedance while comparing with the NAAQS 24-hour limit, i.e., 100 µg/m^3.
- The concentration of $PM_{2.5}$ varies in the range of **9.23** to **161.69** µg/m^3, with a yearly average value of **32.30** with standard deviation **6.30** µg/m^3. As shown in Graph 2, the highest concentration of $PM_{2.5}$ is at location A-5 (the coal storage area) in winter. It can be seen that $PM_{2.5}$ exceeds the NAAQS annual limit, i.e., 40 µg/m3, on five locations, and location A-3, i.e., Kandla Port Colony, falls within the NAAQS annual limit. It can be seen that location A-5 (coal storage area) had the maximum percentage exceedance, and location A-3 (Kandla Port Colony) had the minimum percentage exceedance while comparing with the NAAQS 24-hour limit, i.e., 60 µg/m^3.
- The elevated Particulate matter concentration at location A-5, the Coal Storage Area, can be attributed to several factors. Heavy vehicular traffic in upwind areas significantly contributes to the dispersion of particulate matter into the ambient air. The process of unloading coal directly onto trucks using grabs leads to the emission of coal dust into the air and its subsequent settling on the ground. This settled dust is re-entrained into the atmosphere as trucks travel through the area. Additionally, coal-loaded trucks are often not adequately covered with tarpaulin sheets, which exacerbates the suspension of coal particles during transit from vessels to the storage yard or site. These factors collectively contribute to increased Particulate matter levels in and around the Coal Storage Area and Marine Bhavan.

Gaseous Pollutants:

- The concentration of SOx varies from **3.80** to **75.04** µg/m^3, with a yearly average concentration of **18.59** with standard deviation **2.45** µg/m^3. As shown in Graph 3, the highest concentration of SOx is at location **A-5 (the coal storage area)** in winter. It can be seen that at all locations, SOx are within the NAAQS annual limit, i.e., 50 µg/m^3. Additionally, it can be seen that all six locations comply with the standards (compliance more than 98% times) while comparing with the NAAQS 24-hour limit, i.e., 80 µg/m^3. The concentration of NOx varies from **5.36** to **65.62** µg/m3, with a yearly average concentration of **17.99** with standard deviation **2.68** µg/m3. As shown in Graph 4, the highest concentration of NOx is at location A-5 (the coal storage area) in winter. It can be seen that on all

locations's NOx within the NAAQS annual limit, i.e., 40 µg/m^3, and all locations comply with the standards (complied more than 98% times) while comparing with the NAAQS 24-hour limit, i.e., 80 µg/m^3.

- CO concentrations range from **0.29** to **1.06** mg/m^3, with an average of **0.81** mg/m3 per year and a standard deviation of **0.01** mg/m3. Graph 5 illustrates that during the winter, position A-5 (the coal storage area) has the highest CO concentration. When compared to the NAAQS 8-hour limit, which is 2 mg/m3, it is evident that all locations are more than 98% compliant with the NAAQS 1-hour limit, which is 4 mg/m3.

- The concentration of total VOC levels was recorded in the range of **0.00** to **1.94** µg/m3, with a yearly average value of **0.23** with standard deviation **0.02** µg/m3 at Kandla. As shown in graph 6, the highest concentration of VOCs is at location A-2, (Oil Jetty No. 7); this is the only spike observed in the whole monitoring period for VOCs at this location. The main source of VOCs in the ambient air may be attributed to the burning of gasoline and natural gas in vehicle exhaust, burning fossil fuels, and garbage that releases VOCs into the atmosphere. During the monitoring period, the wind flows in the south direction at Kandla, and hence the wind direction and speed also contribute to increased dispersion of pollutants from the upward areas towards the downward areas.

  Polycyclic Aromatic Hydrocarbons (PAHs): are ubiquitous pollutants in urban atmospheres. Anthropogenic sources of total PAHs in ambient air emissions are greater than those that come from natural events. These locations are commercial areas where Vehicular activity and dust emission is common. PAHs are a class of chemicals that occur naturally in coal, crude oil, and gasoline. The higher concentration which results from burning coal, oil, gas, road dust, etc. Other outdoor sources of PAHs may be the industrial plants in-and-around the DPA premises.

- The concentration of Benzene levels was recorded in the range of **0.00** to **0.090** µg/m^3, with a yearly average value of **0.010** with standard deviation **0.011** µg/m^3. The highest concentration of Benzene is at location A-5, (Coal storage area) in Winter. It can be seen that at all locations, Benzene within the NAAQS annual limit, i.e., 5 µg/m3.

- The ambient air monitoring location of Kandla recorded the non-methane VOC (NM-VOC) concentration in the range of **0.00** to **1.87** µg/m3, with a yearly average value of **0.81** µg/m3 at Kandla. The highest concentration is at location A-3, (Kandla Port Colony) in Winter.

2) Vadinar:

Particulate matter: The concentration of PM_{10} at Vadinar varies in the range of **10.42** to **235.99** µg/m^3, with a yearly average value of **66.59** with a standard deviation of **2.74** µg/m^3. As shown in Graph 1, the highest concentration of PM_{10} is at location A-8 (Vadinar colony) in the winter. It can be seen that at location A-7 (Admin Building Vadinar), PM_{10} exceeds the NAAQS annual limit, i.e., 60 µg/m^3, and at location A-8 (Vadinar Colony), it falls within the annual standards. It can be seen that locations A-7 (Admin Building Vadinar) and A-8 (Vadinar Colony) had a 14.43% and 25.77% percentage exceedance while comparing with the NAAQS 24-hour limit, i.e., 100 µg/m^3.

- The concentration of $PM_{2.5}$ varies in the range of **4.49** to **91.70** µg/m³, with a yearly average value of **25.82** with a standard deviation of **0.52** µg/m³. As shown in Graph 2, the highest concentration of $PM_{2.5}$ is at location A-8 (Admin Building Vadinar) in winter. The data demonstrates that in both locations, $PM_{2.5}$ levels consistently surpass the NAAQS annual limit of 40 µg/m³. Additionally, it can be seen that locations A-7 (Admin Building Vadinar) and A-8 (Vadinar Colony) had an 8.24% and 10.30% percentage exceedance while comparing with the NAAQS 24-hour limit, i.e. 60 µg/m³.

Gaseous Pollutants:

- The concentration of SOx varies from **2.89** to **135.36** µg/m3, with a yearly average concentration of **12.04** with a standard deviation of **5.10** µg/m3. As shown in Graph 3, the highest concentration of SOx is at location A-8 (Vadinar Colony) in the winter. It can be seen that at both locations, SOx are within the NAAQS annual limit, i.e., 50 µg/m³. Additionally, it can be seen that both locations comply with the standards (compliance more than 98% times) while comparing with the NAAQS 24-hour limit, i.e., 80 µg/m³.
- The concentration of NOx varies from **4.12** to **31.70** µg/m³, with a yearly average concentration of **8.42** with a standard deviation of **0.74** µg/m³. As shown in Graph 4, the highest concentration of NOx is at location A-7 (Admin Building Vadinar) in the winter. The analysis indicates that nitrogen oxides (NOx) concentrations at all monitored sites complies with the National Ambient Air Quality Standards (NAAQS) annual limit of 40 µg/m³. Furthermore, in comparison to the NAAQS 24-hour limit of 80 µg/m³, both monitored sites comply with the established standards.
- The concentration of CO varies from **0.52** to **1.03** mg/m3, with a yearly average concentration of **0.67** with a standard deviation **0.03** mg/m³. As shown in Graph 5, the highest concentration of CO is at location A-8, (Vadinar colony) in winter. It is evident that at all locations, compliance with the NAAQS 1-hour limit of 4 mg/m³ has been achieved more than 98% of the time. In comparison, the NAAQS 8-hour limit is set at 2 mg/m³.
- The concentration of Total VOCs levels was recorded in a range of **0.00** to **0.99** µg/m³ with a yearly average value of **0.17** with a standard deviation of **0.01** µg/m³ at Vadinar. As shown in graph 6, the highest concentration of VOCs is at location A-8, (Vadinar Colony), this is the only spike observed in the whole monitoring period for VOCs at this location.

Polycyclic Aromatic Hydrocarbons (PAHs):

- Non-methane VOC (NM-VOC) concentration at Vadinar was observed in the range of **0.00** to **1.58** µg/m³ with a yearly average value of **0.56** with a standard deviation **0.113** µg/m³. the highest concentration is at A-7, (Admin building Vadinar) in Winter. While no Benzene concentration was observed during this monitoring period.

With reference to the Ambient Air Quality monitoring conducted under the study, it may be concluded that the particulate matter PM_{10}, were reported in higher concentration and apparently exceeds the NAAQS particularly at locations of Kandla., whereas $PM_{2.5}$ complies with the NAAQS at majority of the locations. For both the

ambient air monitoring parameters (PM_{10} and $PM_{2.5}$), the major exceedance was observed at location A-5 i.e. Coal Storage Area. The gaseous pollutants (NO_x, SO_x, CO, VOCs etc.) falls within the permissible limit. The probable reasons contributing to these emissions of pollutants into the atmosphere in-and-around the port area are summarized as follows: -

1. **Port Machinery:** Port activities involve the use of various machinery and equipment, including cranes, for lifts, tugboats, and cargo handling equipment. These machines often rely on diesel engines, which can emit pollutants such as NO_x, Particulate matter, and CO. Older or poorly maintained equipment tends to generate higher emissions.
2. **Port Vehicles:** Trucks and other vehicles operating within port and port area contributes to air pollution. Similar to port machinery, diesel-powered vehicles can emit NO_x, PM, CO, and other pollutants such as PAH, VOCs etc. Vehicle traffic and congestion in and around port areas can exacerbate the air quality issues.
3. **Coal Handling:** Resuspension of dust occurs due to the transportation of coal and the handling of coal.
4. **Construction Activities:** Construction and demolition activities majorly contribute to particulate matter pollution.

4.4 Remedial Measures:

Efficient mitigation strategies need to be implementation for substantial environmental and health co-benefits. To improve air quality, DPA has implemented a number of precautionary measures, such as maintaining Green zone, initiated Inter-Terminal Transfer of tractor-trailers, Centralized Parking Plaza, providing shore power supply to tugs and port crafts, the use of LED lights at DPA area helps in lower energy consumption and decreases the carbon foot prints in the environment, time to time cleaning of paved and unpaved roads, use of tarpaulin sheets to cover dumpers at project sites etc. are helping to achieve the cleaner and green future at port. To address air pollution from port shipping activities, various measures that can be implemented are as follows:

- Practice should be initiated for using mask as preventative measure, to avoid Inhalation of dust particle-Mask advised in sensitive areas. Covering vehicles with tarpaulin during transportation will help to reduce the suspension of pollutants in air.
- Frequent water sprinkling on roads to reduce dust suspension due to vehicular movement, this can be use during transporting coal to avoid suspension of coal dust.
- Ensuring maintenance of engines and machinery to comply with emission standards.
- Use of proper transport methods, such as a conveyor belt, for excavated material and screens around the construction site.
- Temporary pavement of roads in construction site could considerably reduce dust emission. Prohibition of use of heavy diesel oil as fuel could be possibly reduce pollutants. Encouraging use of low-sulphur fuels (viz. Marine Gas Oil (MGO)/Liquefied Natural Gas (LNG), can significantly reduce sulphur and PM emissions from ships.

- Investing in infrastructure for cold ironing allows ships to connect to the electrical grid while docked, reducing the need for auxiliary engines and associated emissions.
- Implementing efficient cargo-handling processes, optimizing logistics to reduce congestion and idling times, and encouraging use of cleaner port machinery and vehicles can all contribute to reducing air pollution in port areas.
- Shrouding shall be carried out in the work site enclosing the dock/proposed facility area. This will act as dust curtain as well achieving zero dust discharge from the site. These curtain or shroud will be immensely effective in restricting disturbance from wind in affecting the dry dock operations, preventing waste dispersion, improving working conditions through provision of shade for the workers.
- Dust collectors shall be deployed in all areas where blasting (surface cleaning) and painting operations are to be carried out, supplemented by stacks for effective dispersion.
- Periodic vacuum-sweeping mechanisms shall be adopted.

CHAPTER 5: DG STACK MONITORING

5.1 DG Stack Monitoring

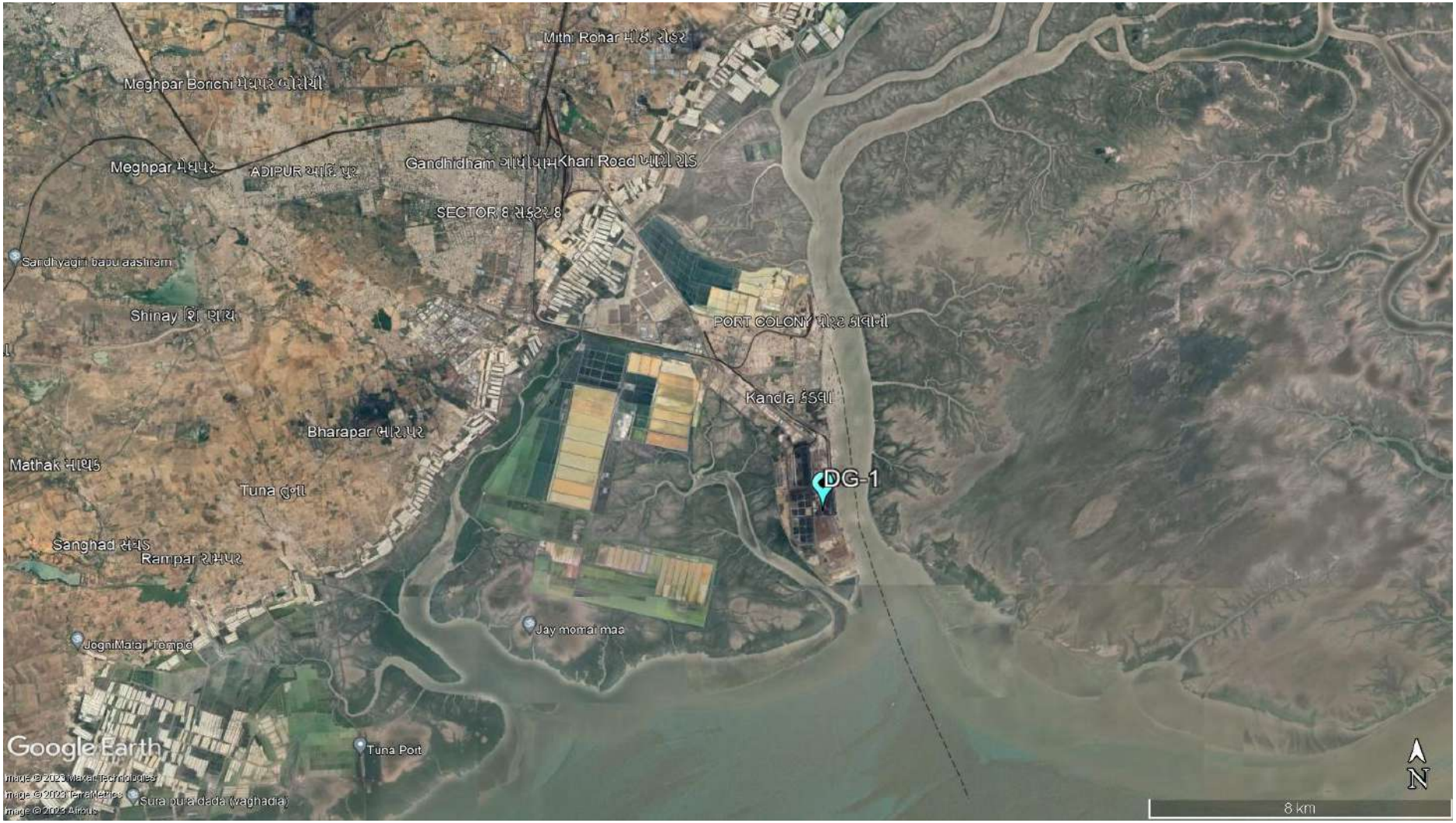
A diesel generator is a mechanical-electrical machine that produces electrical energy (electricity) from diesel fuel. They are used by the residential, commercial, charitable and governmental sectors to provide power in the event of interruption to the main power, or as the main power source. Diesel generating (DG) sets are generally used in places without connection to a power grid, or as an emergency power supply if the grid fails. These DG sets utilize diesel as fuel and generate and emit the air pollutants such as Suspended Particulate Matter, SO_2, NO_x, CO, etc. from the stack during its functioning. The purpose of stack sampling is to determine emission levels from plant processes to ensure they are in compliance with any emission limits set by regulatory authorities to prevent macro environmental pollution. The stack is nothing but chimney which is used to disperse the hot air at a great height, emissions & particulate matters that are emitted. Hence, monitoring of these stacks attached to DG Sets is necessary in order to quantify the emissions generated from it.

As defined in scope by DPA, the monitoring of DG Stack shall be carried out at two locations, one at Kandla and one at Vadinar. The details of the DG Sets at Kandla and Vadinar have been mentioned in Table 10 as follows:

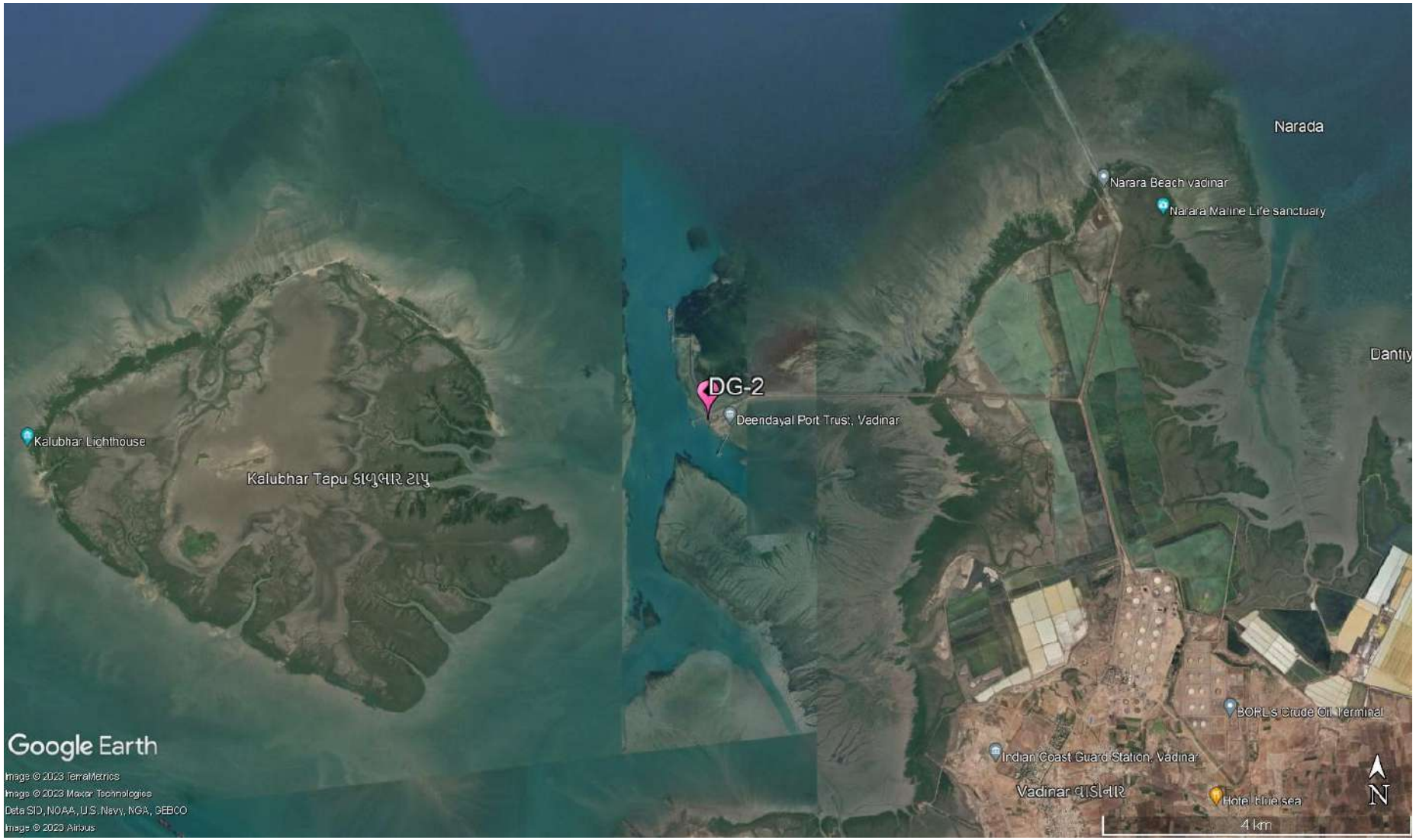
Table 10: Details of DG Stack monitoring locations

Sr. No.	Location Code	Location Name	Latitude/ Longitude
1.	DG-1	Kandla	22.98916N 70.22083E
2.	DG-2	Vadinar	22.44155N 69.67419E

The map depicting the locations of DG Stack Monitoring to be monitored in Kandla and Vadinar have been mentioned in **Map 6 and 7** as follows:



Map 6: DG Stack monitoring Locations at Kandla



Map 7: DG Stack monitoring Locations at Vadinar

Methodology:

Under the study, the list of parameters to be monitored under the projects for DG Stack Monitoring has been mentioned in **Table 11** as follows:

Table 11: DG stack parameters

Sr. No.	Parameter	Unit	Instrument
1.	Suspended Particulate Matter	**mg/Nm³**	**Stack Monitoring Kit**
2.	Sulphur Dioxide (SO_2)	PPM	**Sensor based Flue Gas Analyzer (Make: TESTO, Model 350)**
3.	Oxides of Nitrogen (NO_x)	PPM	
4.	Carbon Monoxide	%	
5.	Carbon Dioxide	%	

The methodology for monitoring of DG Stack has been mentioned as follows:

The monitoring of DG Stack is carried out as per the IS:11255 and USEPA Method. The Stack monitoring kit is used for collecting representative samples from the stack to determine the total amount of pollutants emitted into the atmosphere in a given time. Source sampling is carried out from ventilation stack to determine the emission rates/or characteristics of pollutants. Sample collected must be such that it truly represents the conditions prevailing inside the stack. Whereas the parameters Sulphur Dioxide, Oxides of Nitrogen (NO_x), Carbon Monoxide and Carbon Dioxide, the monitoring is carried out by using the sensor-based Flue Gas Analyzer.

Monitoring Frequency

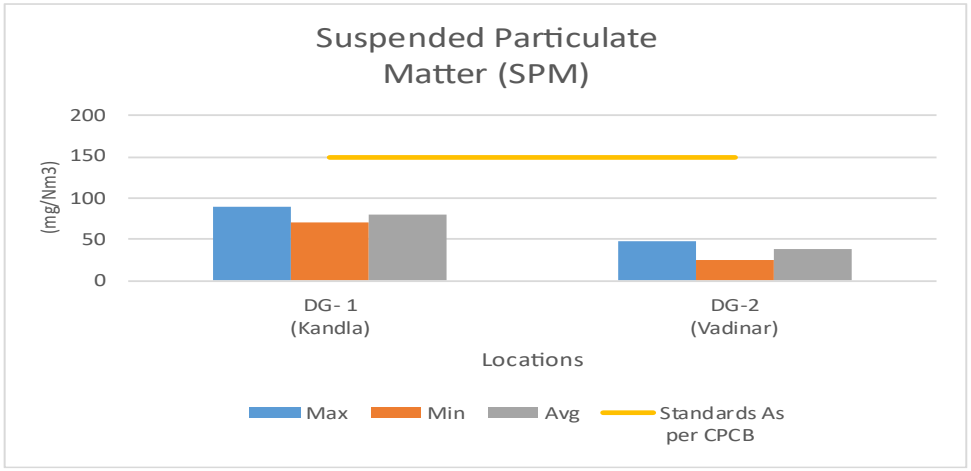
Monitoring is required to be carried out once a month for both the locations of Kandla and Vadinar for a period of April 2024 to March 2025.

5.2 Result and Discussion

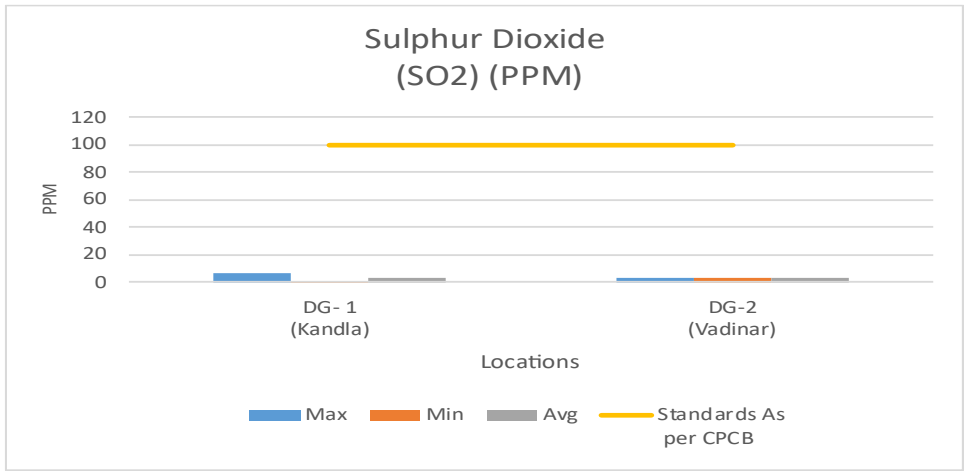
The sampling and monitoring of DG stack emission was carried out for monitoring period at Kandla and Vadinar and its comparison with CPCB or Indian standards for Industrial Stack Monitoring the flue gas emission from DG set has given in **Table 12.**

Table 12: DG monitoring data

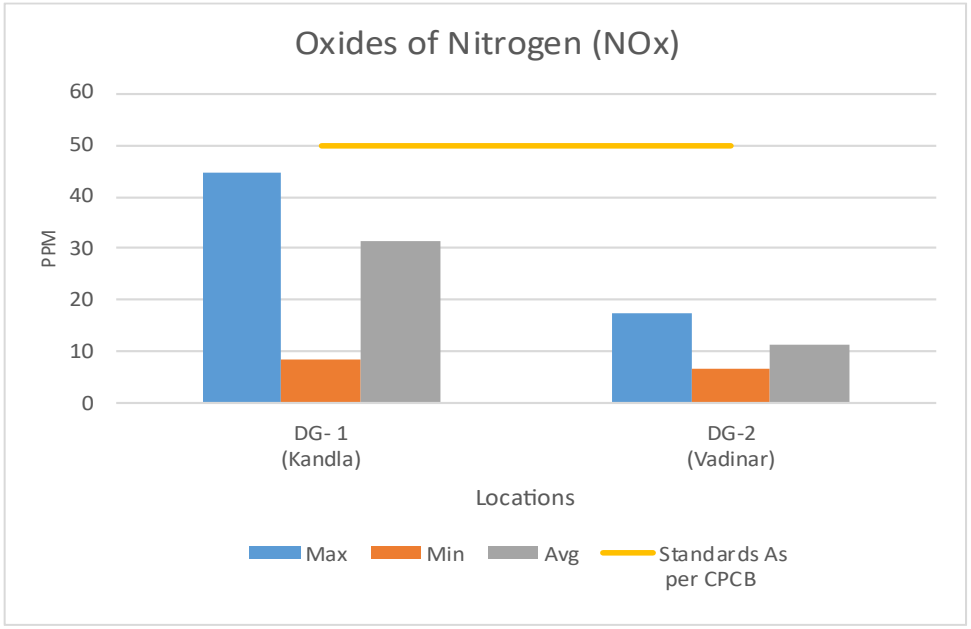
Sr. No.	Stack Monitoring Parameters for DG Sets		DG- 1 (Kandla)	DG-2 (Vadinar)	Stack Monitoring Limits /Standards As per CPCB
1.	**Suspended Particulate Matter (SPM) (mg/Nm³)**	**Max**	89.5	48.7	**150**
		Min	71.45	25.04	
		Avg.	79.32	39.27	
2.	**Sulphur Dioxide (SO2) (PPM)**	**Max**	6.31	3.14	**100**
		Min	1.12	3.14	
		Avg.	3.46	3.14	
3.	**Oxides of Nitrogen (NO_x) (PPM)**	**Max**	44.58	17.32	**50**
		Min	8.6	6.88	
		Avg.	31.46	11.34	
4.	**Carbon Monoxide (CO) (%)**	**Max**	0.41	0.16	**1**
		Min	0.15	0.011	
		Avg.	0.26	0.06	
5.	**Carbon Dioxide (CO_2) (%)**	**Max**	3.18	2.12	**-**
		Min	1.03	1	
		Avg.	1.79	1.38	



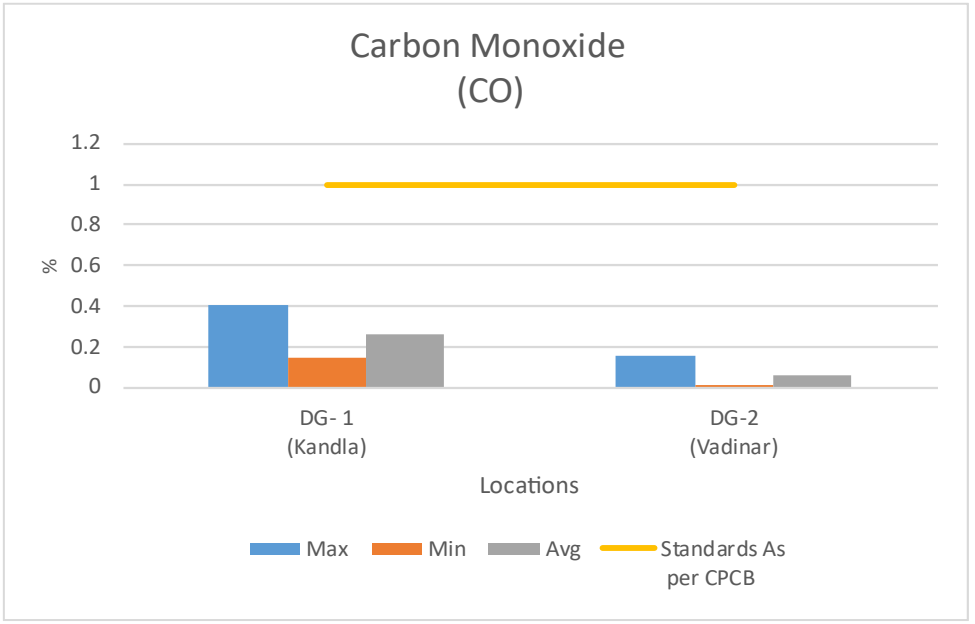
Graph 7 Spatial trend in SPM Concentration



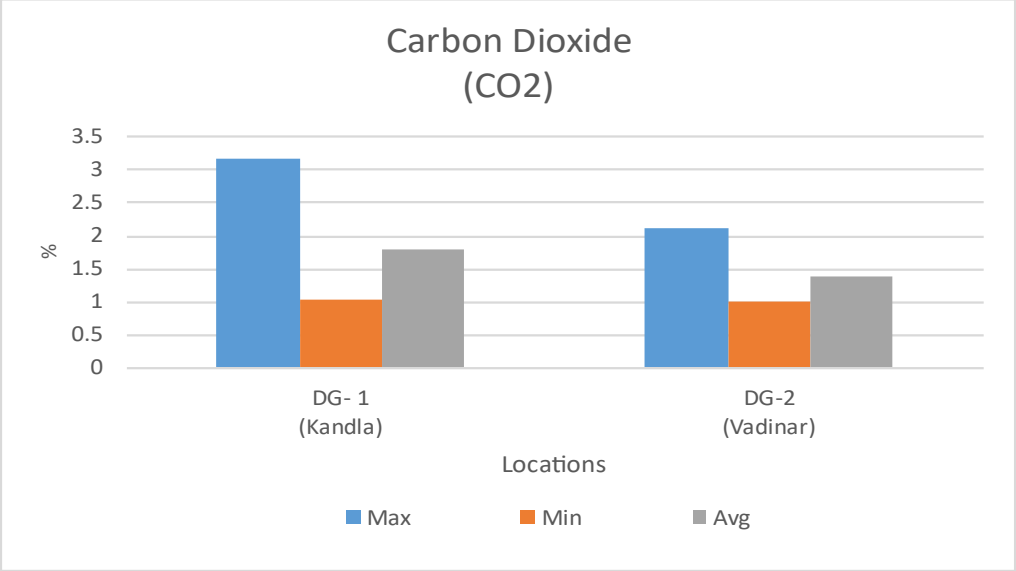
Graph 8 Spatial trend in SO_x Concentration



Graph 9 Spatial trend in NOx Concentration



Graph 10 Spatial trend in CO Concentration



Graph 11 Spatial trend in CO_2 Concentration

5.3 Data Interpretation and Conclusion

1) Kandla:

The Suspended Particulate Matter (SPM) varies in the range of **71.45** to **89.5** mg/m^3. The yearly average SPM of D.G stack-1 is **79.32** mg/m^3. The maximum concentration for SPM was observed in the monitoring period of April to May 2024. The Sulphur dioxide (SO_x) varies in the range of **1.12** to **6.31** PPM. The yearly average SO_x of D.G stack-1 is **3.47** PPM.

The NO_x varies in the range of **8.60 to 44.58** PPM. The yearly average of NO_x of D.G stack-1 at Kandla is **31.47** PPM. The maximum concentration of NO_x observed in the monitoring period of **April to May 2024**.

The CO at Kandla varies in the range of **0.15 to 0.41** %. The yearly average of CO of D.G stack-1 at Kandla is **0.26** % The maximum concentration of CO observed in the monitoring period of **April to May 2024**.

The CO_2 at Kandla varies in the range of **1.03 to 3.18** %. The yearly average of CO_2 of D.G stack-1 at Kandla is **1.79** % The maximum concentration of CO_2 observed in the monitoring period of **July to August 2024**.

The results of all the above parameters of DG stack-1 at Kandla emission are compared with the permissible limits mentioned in the consent issued by GPCB, and have been found within the prescribed limit for all the monitored parameters.

2) Vadinar:

The Suspended Particulate Matter (SPM) in the range of **25.04 to 48.70** mg/m^3. The yearly average SPM of D.G stack-2 at Vadinar is **39.27** mg/m^3. The maximum concentration of SPM was observed in the monitoring period of **April to May 2024**. Sulphur dioxide (SOx) concentration was found to be below the detection limit during this monitoring period, except in **August–September 2024** at Vadinar.

The NO_x at Vadinar varies in the range of **6.88 to 17.32** PPM. The yearly average of NO_x of D.G stack-2 at Vadinar is **11.34** PPM. The maximum concentration of NO_x observed in the monitoring period of **April to May 2024.**

The CO at Vadinar varies in the range of **0.01 to 0.16** %. The yearly average of CO of D.G stack-2 at Vadinar is **0.06** % The maximum concentration of CO observed in the monitoring period of **July to August 2024**.

The CO_2 at Vadinar varies in the range of **1.00 to 2.12** %. The yearly average in CO_2 of D.G stack-2 at Vadinar is **1.38** % The maximum concentration of CO_2 observed in the monitoring period of **July to August 2024**.

The results of all the above parameters of DG stack-2 at Vadinar emission are compared with the permissible limits mentioned in the consent issued by GPCB, and have been found within the prescribed limit for all the monitored parameters.

CHAPTER 6: NOISE MONITORING

6.1 Noise Monitoring

Noise can be defined as an unwanted sound, and it is therefore, necessary to measure both the quality as well as the quantity of environmental noise in and around the study area. Noise produced during operation stage and the subsequent activities may affect surrounding environment impacting the fauna and as well as the human population. Under the scope, the noise monitoring is required to be carried out at 10 locations in Kandla and 3 locations in Vadinar. The sampling locations for noise are not only confined to commercial areas of DPA but also the residential areas of DPA.

The details of the noise monitoring stations are mentioned in **Table 13** and locations have been depicted in the **Map 8 and 9** as follow:

Table 13: Details of noise monitoring locations

Sr. No.	Location Code		Location Name	Latitude/ Longitude
1.	Kandla	N-1	Oil Jetty 7	23.043527N 70.218456E
2.		N-2	West Gate No.1	23.006771N 70.217340E
3.		N-3	Canteen Area	23.003707N 70.221331E
4.		N-4	Main Gate	23.007980N 70.222525E
5.		N-5	Main Road	23.005194N 70.219944E
6.		N-6	Marin Bhavan	23.007618N 70.222087E
7.		N-7	Port & Custom Building	23.009033N 70.222047E
8.		N-8	Nirman Building	23.009642N 70.220623E
9.		N-9	ATM Building	23.009985N 70.221715E
10.		N-10	Wharf Area/ Jetty	22.997833N 70.223042E
11.	Vadinar	N-11	Near Main Gate	22.441544N 69.674495E
12.		N-12	Near Vadinar Jetty	22.441002N 69.673147E
13.		N-13	Port Colony Vadinar	22.399948N 69.716608E

Map 8: Locations for Noise Monitoring at Kandla

Map 9: Locations for Noise Monitoring at Vadinar

Methodology:

The intensity of sound energy in the environment is measured in a logarithmic scale and is expressed in a decibel (dB(A)) scale. The ordinary sound level meter measures the sound energy that reaches the microphone by converting it into electrical energy and then measures the magnitude in dB(A). Whereas, in a sophisticated type of sound level meter, an additional circuit (filters) is provided, which modifies the received signal in such a way that it replicates the sound signal as received by the human ear and the magnitude of sound level in this scale is denoted as dB(A). The sound levels are expressed in dB(A) scale for the purpose of comparison of noise levels, which is universally accepted. Noise levels were measured using an integrated sound level meter of the make Envirotech Sound Level Meter (Class-I) (model No. SLM-109). It has an indicating mode of Lp and Leq. Keeping the mode in Lp for few minutes and setting the corresponding range and the weighting network in "A" weighting set the sound level meter was run for one-hour time and Leq was measured at all locations.

Monitoring Frequency

Monitoring was carried out at each noise monitoring station for Leq. noise level (Day and Night), which was recorded for 24 hours continuously at a monthly frequency with the help of Sound/Noise Level Meter (Class-1). The details of the noise monitoring have been mentioned in **Table 14**.

Table 14: Details of the Noise Monitoring

Sr. No.	Parameters	Units	Reference Method	Instrument
1.	Leq (Day)	dB(A)	IS 9989: 2014	Noise Level Meter (Class-I) model No. SLM-109
2.	Leq (Night)	dB(A)		

Standard for Noise

Ministry of Environment & Forests (MoEF) has notified the noise standards vide the Gazette notification dated February 14, 2000 for different zones under the Environment Protection Act (1986). The day time noise levels have been monitored from 6.00 AM to 10.00 PM and night noise levels were measure from 10.00 PM to 6.00 AM at all the thirteen locations (10 at Kandla and 3 at Vadinar) monthly. The specified standards are as mentioned in **Table 15** as follows:

Table 15: Ambient Air Quality norms in respect of Noise(2)

Area Code	Category of Area	Noise dB(A) Leq	
		Daytime	Night time
A	Industrial Area	75	70
B	Commercial Area	65	55
C	Residential Area	55	45
D	Silence Zone	50	40

6.2 Result and Discussion

The details of the Noise monitoring conducted during the monitoring period April 2024 to March 2025 have been summarized in the **Table 16** as below:

Table 16: The Results of Ambient Noise Quality

Sr. No.	Station Code	Station Name	Category of Area	Standard	Day Time in dB(A)			Standard	Night Time in dB(A)		
					Max.	Min.	Avg.		Max.	Min.	Avg.
1	N-1	Oil Jetty 7	A	75	58.1	33.8	47.0	70	58.1	31.6	39.3
2	N-2	West Gate No.1	A	75	67.3	44.2	55.3	70	67.3	36.7	45.6
3	N-3	Canteen Area	B	65	64.8	38	51.9	55	64.8	31.2	40.9
4	N-4	Main Gate	A	75	71.9	37.1	53.3	70	71.9	33.7	43.2
5	N-5	Main Road	A	75	70.5	36.2	52.3	70	70.5	33.6	42.9
6	N-6	Marin Bhavan	B	65	62.6	34.4	51.2	55	62.6	32.6	42.1
7	N-7	Port & Custom Building	B	65	67.3	34.9	50.0	55	67.3	33.5	41.9
8	N-8	Nirman Building	B	65	66.2	34.8	49.6	55	66.2	32.7	41.8
9	N-9	ATM Building	B	65	77.4	35.9	52.3	55	77.4	32.1	43.7
10	N-10	Wharf Area/ Jetty	A	75	69.2	38.8	54.2	70	69.2	35.4	42.9
11	N-11	Near Main Gate	A	75	71.1	53.1	59.4	70	71.1	44.7	53.5
12	N-12	Near Vadinar Jetty	A	75	73.4	57.2	59.2	70	73.4	49.2	55.2
13	N-13	Port Colony Vadinar	C	55	62.4	35.5	43.7	45	64.8	33.8	41.4

6.3 Data Interpretation and Conclusion

1) **Kandla:** The noise levels were compared with the standard limits set by the CPCB under the NAAQS. During the daytime, average noise levels at all 10 locations in Kandla ranged from **33.8 dB(A) to 77.4 dB(A)**. At night, the noise levels ranged from **31.2 dB(A) to 77.4 dB(A)**. Out of the 10 locations, seven had noise levels within the permissible limits during day time while only three locations noise levels within the permissible limits during night time for industrial, commercial, and residential areas.

   Other Four locations such as i.e., N-3 (Canteen Area), N-7 (Port & Custom Building), N-8 (Nirman Building) and N-9 (ATM building) which are Commercial areas, slightly exceed the standard limits prescribed by NAAQS by CPCB, in the monitoring period of **March to April 2025.**

2) **Vadinar:** The noise level was compared with the standard limits specified in NAAQS by CPCB. During the Day Time, the average noise level at all 3 locations at Vadinar ranged from **35.5 dB(A) to 73.4 dB(A)** while, during Night Time the average Noise Level ranged from **33.8 dB(A) to 73.4 dB(A)** at Vadinar, on location N-11 (Near main gate) noise level was within the permissible limits for the industrial zone for Day time and night time.

   On locations of Vadinar such as i.e., **N-12 (Near Vadinar jetty)**, which are considered as industrial area slightly exceed the standard limits prescribed by NAAQS by CPCB, in the monitoring period **of October to November 2024**. And on location **N-13 (Port Colony Vadinar)**, most frequently exceed the permissible limit during the day time as well as night time.

6.4 Remedial Measures

The noise levels detected at the locations of Kandla and Vadinar, are found within the prescribed norms. The noise can further be considerably reduced by adoption of low noise equipment or installation of sound insulation fences. Green belt of plants can be a good barrier. If noise exceeds the applicable norms, then the working hours may be altered as a possible means to mitigate the nuisances of construction activities.

CHAPTER 7: SOIL MONITORING

7.1 Soil Quality Monitoring:

The purpose of soil quality monitoring is to track changes in the features and characteristics of the soil, especially the chemical properties of soil occurring at specific time intervals under the influence of human activity. Soil quality assessment helps to determine the status of soil functions and environmental risks associated with various practices prevalent at the location.

As defined in scope by Deendayal Port Authority (DPA), Soil Quality Monitoring shall be carried out at Six locations, four at Kandla and two at Vadinar. The details of the soil monitoring locations within the Port area of DPA are mentioned in **Table 17:**

Table 17: Details of the Soil quality monitoring

Sr. No.	Location Code		Location Name	Latitude Longitude
1.	Kandla	S-1	Oil Jetty 7	23.043527N 70.218456E
2.		S-2	IFFCO Plant	23.040962N 70.216570E
3.		S-3	Khori Creek	22.970382N 70.223057E
4.		S-4	Nakti Creek	23.033476N 70.158461E
5.	Vadinar	S-5	Near SPM	22.400026N 69.714308E
6.		S-6	Near Vadinar Jetty	22.440759N 69.675210E

Methodology

As per the defined scope by Deendayal Port Authority (DPA), the sampling and analysis of Soil quality has been carried out on monthly basis.

The samples of soil collected from the locations of Kandla and Vadinar and analyzed for the various physico-chemical parameter. Collection and analysis of these samples was carried out as per established standard methods and procedures. The samples were analyzed for selected parameters to get the present soil quality status and environmental risks associated with various practices prevalent at the location. GEMI has framed its own guidelines for collection of soil samples titled as ***'Soil Sampling Manual'***. Soil samples were collected from 30 cm depth below the surface using scrapper, filled in polythene bags, labelled on-site with specific location code and name and sent to GEMI's laboratory, Gandhinagar for further detailed analysis. The samples collected from all locations are homogeneous representative of each location. The list of parameters to be monitored under the projects for the Soil Quality Monitoring been mentioned in **Table 18** as follows:

Monitoring Frequency

Monitoring is required to be carried out once a month for both the locations of Kandla and Vadinar. The monitoring was done from **April 2024, to March, 2025**.

Table 18: Soil parameters

Sr. No.	Parameters	Units	Reference method	Instruments
1.	TOC	%	Methods Manual Soil Testing in India January, 2011, 09. Volumetric method (Walkley and Black, 1934)	Titration Apparatus
2.	Organic Carbon	%		
3.	Inorganic Phosphate	Kg/Hectare	Practical Manual Chemical Analysis of Soil and Plant Samples, ICAR-Indian Institute of Pulses Research 2017 Determination of Available Phosphorus in Soil	UV-Visible Spectrophotometer
4.	Texture	-	Methods Manual Soil Testing in India January 2011,01	Hydrometer
5.	pH	-	IS 2720 (Part 26): 1987	pH Meter
6.	Conductivity	µS/cm	IS 14767: 2000	Conductivity Meter
7.	Particle size distribution & Silt content	-	Methods Manual Soil Testing in India January 2011	Sieves Apparatus
8.	SAR	meq/L	Procedures for Soil Analysis, International Soil Reference and Information Centre, 6th Edition 2002 13-5.5.3 Sodium Absorption Ratio (SAR), Soluble cations	Flame Photometer
9.	Water Holding Capacity	%	NCERT, Chapter 9, 2022-23 and Water Resources Department Laboratory Testing Procedure for Soil & Water Sample Analysis	Muffle Furnace
10.	Aluminium	mg/Kg	EPA Method 3051A	ICP-OES
11.	Chromium	mg/Kg		
12.	Nickel	mg/Kg		
13.	Copper	mg/Kg	Methods Manual Soil Testing in India January, 2011, 17a	
14.	Zinc	mg/Kg	Methods Manual Soil Testing in India January, 2011, 17a	
15.	Cadmium	mg/Kg	EPA Method 3051A	
16.	Lead	mg/Kg		
17.	Arsenic	mg/Kg		
18.	Mercury	mg/Kg		

The map depicting the locations of Soil Quality Monitoring to be monitored in Kandla and Vadinar have been mentioned in **Map 10 and 11** as follows:

Map 10: Soil Quality Monitoring Locations at Kandla

Map 11: Soil Quality Monitoring Locations at Vadinar

7.2 Result and Discussion

The analysis results of physical analysis of the soil samples collected during environmental monitoring period during **April 2024 to March 2025** mentioned in **Table 19** are shown below:

Table 19: Soil Quality for the Monitoring period

Sr. No	Parameters / Location		Kandla				Vadinar	
			S-1 (Oil Jetty 7)	S-2 IFFCO Plant)	S-3 (Khori Creek)	S-4 (Nakti Creek)	S-5 (Near SPM)	S-6 (Near Vadinar Jetty)
1	pH	Max	9.33	8.73	9.22	8.54	8.37	7.68
		Min	7.34	7.30	8.10	7.75	7.74	9.07
		Avg.	8.28	8.32	8.45	8.30	8.09	8.33
2	Conductivity (µS/cm)	Max	45300.00	27200.00	14120.00	38500.00	271.00	120.00
		Min	1063.00	1000.00	226.00	219.00	82.00	360.00
		Avg	16674.66	14282.50	5314.00	12100.33	141.91	214.31
3	Inorganic Phosphate (Kg/ha)	Max	2.06	8.52	5.49	4.64	1.91	0.02
		Min	0.49	0.42	0.33	0.54	0.26	1.67
		Avg	1.07	2.13	2.24	1.75	0.73	0.74
4	Organic Carbon (%)	Max	0.58	1.62	2.04	1.01	1.33	0.26
		Min	0.14	0.24	0.04	0.14	0.10	0.96
		Avg	0.38	0.56	0.57	0.56	0.45	0.55
5	Organic Matter (%)	Max	0.99	2.79	3.51	1.74	2.30	0.44
		Min	0.24	0.42	0.06	0.25	0.17	1.65
		Avg	0.65	0.97	0.98	0.98	0.77	0.94
6	SAR (meq/L)	Max	24.88	29.34	18.27	19.84	0.68	0.04
		Min	1.86	0.27	0.39	0.38	0.02	0.73
		Avg	14.05	11.80	4.68	9.19	0.17	0.21
7	Aluminium (mg/Kg)	Max	19449.51	23540.38	13547.03	16874.40	53066.52	820.23
		Min	4848.98	4977.45	2697.97	2385.83	854.99	44431.53
		Avg	12037.89	12373.29	8521.19	8423.31	20777.15	20940.08
8	Chromium (mg/Kg)	Max	85.69	85.51	106.37	90.14	847.00	55.38
		Min	43.81	46.48	35.55	31.13	47.81	106.83
		Avg	64.71	63.42	65.57	47.77	140.31	76.86
9	Nickel (mg/Kg)	Max	35.25	36.70	35.58	29.00	39.83	11.76
		Min	14.22	5.76	11.96	5.67	3.68	49.62
		Avg	22.86	22.79	22.85	17.62	28.00	30.91
10	Copper (mg/Kg)	Max	109.5	163.64	161.49	87.77	109.80	67.37
		Min	20.094	30.29	14.59	13.12	20.42	106.90
		Avg	66	73.64	78.97	24.43	80.87	86.33
11	Zinc (mg/Kg)	Max	146.081	230.12	283.81	105.23	82.44	15.95
		Min	36.78	43.34	32.38	17.20	33.47	72.68
		Avg	79.42	86.13	76.21	44.65	57.38	54.89
12	Cadmium (mg/Kg)	Max	BQL	BQL	BQL	BQL	BQL	BQL
		Min	BQL	BQL	BQL	BQL	BQL	BQL
		Avg	BQL	BQL	BQL	BQL	BQL	BQL
13	Lead (mg/Kg)	Max	15.314	18.40	61.28	12.35	6.57	0.37
		Min	1.57	2.58	2.29	1.59	4.29	0.37
		Avg	6.21	7.41	9.56	6.20	5.43	0.37

Sr. No	Parameters / Location		Kandla				Vadinar	
			S-1 (Oil Jetty 7)	S-2 IFFCO Plant)	S-3 (Khori Creek)	S-4 (Nakti Creek)	S-5 (Near SPM)	S-6 (Near Vadinar Jetty)
14	Arsenic (mg/Kg)	Max	8.09	6.10	11.36	4.64	3.49	0.16
		Min	0.198	0.04	0.60	0.80	0.20	0.72
		Avg	2.81	2.93	3.08	2.80	1.08	0.35
15	Mercury (mg/Kg)	Max	BQL	BQL	BQL	BQL	BQL	BQL
		Min	BQL	BQL	BQL	BQL	BQL	BQL
		Avg	BQL	BQL	BQL	BQL	BQL	BQL
16	Water Holding Capacity (%)	Max	66	61.90	55.96	65.98	70.00	39.97
		Min	37.98	43.96	33.97	39.97	32.00	72.00
		Avg	52.15	52.41	46.39	51.97	46.75	56.61
17	Sand (%)	Max	72.08	67.68	82.40	80.85	85.37	57.69
		Min	2.84	20.84	53.53	24.43	59.69	80.24
		Avg	49.3	51.34	66.69	60.97	71.85	72.07
18	Silt (%)	Max	75.57	74.84	39.27	60.84	35.44	14.00
		Min	20	18.16	11.43	9.98	13.59	31.98
		Avg	37.34	41.15	25.89	29.51	25.94	23.67
19	Clay (%)	Max	29.59	17.60	17.58	31.59	6.31	0.16
		Min	1.2	0.32	1.44	2.32	0.32	13.60
		Avg	13.35	7.52	7.50	9.52	2.21	4.26
20	Texture		Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Loamy Sand	Loamy Sand

7.3 Data Interpretation and Conclusion

Soil samples were collected from 6 locations (4 at Kandla and 2 at Vadinar) and further analysed for its physical & chemical characteristics. Each of the parameters have been given an interpretation based on the observations as follows:

1) Kandla:

- The value of pH ranges from **7.30 to 9.33**, with the highest at location **S-1 (Oil Jetty 7)** and the lowest at location **S-2 (IFFCO plant)**, while the average pH for Kandla was observed to be **8.34**. The pH in Kandla varies from Slightly alkaline to strongly alkaline
- At all monitoring locations, the value of Electrical Conductivity ranges from **219.00** to **45300** µs/cm, with the highest at location **S-1 (Oil Jetty 7)** and the lowest at **S-4 (Nakti Creek)**. The average Electrical Conductivity is **12092.88** µs/cm.
- The concentration of inorganic phosphate varied from **0.33 to 8.52** kg/ha, with an average of **1.82** kg/ha. The highest concentration of inorganic phosphate was found at **S-2 (IFFCO plant**) and the lowest concentration was found at **S-3 (Khori Creek).** The availability of phosphorus in the soil solution is influenced by several factors, such as organic matter, clay content, pH, temperature, and more.
- The concentration of Total Organic Carbon ranges from **0.04 % to 2.04** %, with an average TOC of **0.52** % detected. The highest concentration was found at location **S-3 (Khori Creek)**, and the minimum concentration was found at **S-3 (Khori Creek)**.

- The Sodium Adsorption Ratio ranges from **0.27 to 29.34** meq/L, with an average value of **9.93** meq/L at Kandla. The highest concentration of SAR is found at **S-1 (Oil Jetty 7)** and the lowest concentration at **S-2 (IFFCO plant).**
- The Water Holding Capacity (WHC) in the soil samples of Kandla varies from **33.97 % to 66.00** %, with an average of **50.73** %. The highest concentration of WHC was observed at **S-2 (IFFCO plant)** and the lowest concentration at **S-3 (Khori Creek).**
- The Soil Texture was observed as "**Sandy loam**" at all the monitoring locations in Kandla.

Heavy Metals

- During the sampling period, the concentration of Aluminium varied from **2385.83 to 23540.38** mg/kg. The average Aluminium concentration was observed to be **10338.92** mg/kg at the Kandla monitoring station. The highest concentration was observed at **S-2 (IFFCO Plant)**, and the lowest concentration was observed at **S-4 (Nakti Creek)**.
- The concentration of Chromium varied from **31.13 to 106.37** mg/kg, with an average value of **60.37** mg/kg observed at the Kandla monitoring station. The highest concentration was observed at **S-3 (Khori Creek)**, and the lowest concentration was observed at **S-4 (Nakti Creek)**.
- The concentration of Nickel varied from **5.67 to 36.70** mg/kg at Kandla, with an average value of **21.53** mg/kg at the Kandla monitoring station. The highest concentration was observed at **S-2 (IFFCO Plant)**, while the lowest concentration was also observed at **S-4 (Nakti Creek)**.
- The concentration of Zinc varied from **17.20 to 283.81** mg/kg at Kandla, with an average value of **71.60** mg/kg at the Kandla monitoring station. The highest concentration was observed at **S-3 (Khori Creek)**, which was the only spike observed during the entire monitoring period at Kandla. The lowest concentration was observed at **S-4 (Nakti Creek)**.
- The concentration of copper varied from **13.12 to 163.64** mg/kg, with an average value of **60.76** mg/kg observed at the Kandla monitoring station. The highest concentration was observed at **S-2 (IFFCO Plant)** and the lowest concentration was observed at **S-4 (Nakti Creek)**.
- The concentration of Lead varied from **1.57 to 61.28** mg/kg, with an average value of **7.34** mg/kg. The highest concentration was observed at **S-3 (Khori creek)**; this was the only spike observed during the entire monitoring period, while the lowest concentration was observed at **S-1 (Oil Jetty 7)**.
- The concentration of A**rsenic** varied from **0.04 to 11.36** mg/kg, with an average value of **2.91** mg/kg. The highest concentration was observed at **S-3 (Khori Creek)**, and the lowest concentration was observed at **S-2 (IFFCO Plant)**.
- During the monitoring period, it was observed that the concentration of Cadmium and Mercury was mostly found **Below the quantification limit (BQL)** at all locations.

2) Vadinar:

- The value of pH ranges from **7.74 to 8.37**, with the highest and lowest at location **S-5 (Near SPM)** but during different months. while the average pH for Vadinar was observed to be **8.21**. pH of Soil at Vadinar was found to be moderately alkaline.
- At all monitoring locations in Vadinar, the value of Electrical Conductivity ranges from **82 to 271** µs/cm, with the highest and the lowest at **S-5 (Near SPM)**. The average Electrical Conductivity is **178.11** µs/cm.
- The concentration of inorganic phosphate varied from **0.26 to 1.91** kg/ha, with an average of **0.74** kg/ha. The highest and lowest concentration of inorganic phosphate was found at **S-5 (Near SPM)**.
- The concentration of Total Organic Carbon ranges from **0.10 % to 1.33** %, with an average TOC of **0.50** % detected at Vadinar. The highest and lowest concentration was found at **S-5 (Near SPM)**.
- The Sodium Adsorption Ratio ranges from **0.02 to 0.68** meq/L, with an average value of **0.19** meq/L at Vadinar. The highest and lowest concentration of SAR is found at **S-5 (Near SPM)**.
- The Water Holding Capacity (WHC) in the soil samples of Vadinar varies from **32 % to 70** %, with an average of **51.68** %. The highest and lowest concentration of WHC was observed at **S-5 (Near SPM)**.
- The soil texture of Vadinar varies from "loamy Sand".

Heavy Metals

- During the sampling period, the concentration of Aluminium varied from **854.99 to 53066.52 mg/kg**. The average Aluminium concentration was observed to be **20858.62 mg/k**g at the Vadinar monitoring station. The highest and lowest concentration was observed at S-5 (Near SPM) but during different months.
- The concentration of Chromium varied from **47.81 to 847 mg/kg**, with an average value of **108.58 mg/kg** observed at the Vadinar monitoring station. The highest and lowest concentration was observed at S-5 (Near SPM).
- The concentration of Nickel varied from **3.68 to 39.83 mg/kg**, with an average value of **29.46 mg/kg** at the Vadinar monitoring station. The highest and the lowest concentration was observed at S-5 (Near SPM).
- The concentration of Zinc varied from **33.47 to 82.44 mg/kg**, with an average value of **56.14 mg/kg** at the Vadinar monitoring station. The highest concentration was observed at S-5 (Near SPM), and the lowest concentration was also observed at S-5 (Near SPM) but during different months.
- The concentration of copper varied from **20.42 to 109.80 mg/kg,** with an average value of **83.60 mg/kg** observed at the Vadinar monitoring station. The highest concentration was observed at S-5 (Near SPM) and the lowest concentration was observed at S-5 (Near SPM).
- The concentration of Lead varied from **0.37 to 6.57 mg/kg**, with an average value of **2.90 mg/kg.** The highest concentration was observed at S-5 (Near SPM); this was the only spike observed during the entire monitoring period at Kandla, while the lowest concentration was observed at S-6 (Near Vadinar jetty).

- The concentration of Arsenic varied from **0.20 to 3.49 mg/kg**, with an average value of **0.71 mg/kg**. The highest and the lowest concentration was observed at S-5 (Near SPM), during different monitoring periods.
- During the monitoring period, it was observed that the concentration of Mercury and Cadmium was mostly found **below the quantification limit (BQL)** at all locations.

CHAPTER 8: DRINKING WATER MONITORING

8.1 Drinking Water Monitoring

It is necessary to check with the drinking water sources regularly so as to know whether water quality conforms to the prescribed standards for drinking. Monitoring the drinking water quality is essential to protect human health and the environment. With reference to the scope specified by DPA, a total of 20 locations (18 at Kandla and 2 at Vadinar) were monitored to assess the Drinking Water quality.

The details of the drinking water sampling stations have been mentioned in **Table 20** and the locations have been depicted through Google map in **Map 12 and 13.**

Table 20: Details of Drinking Water Sampling Locations

Sr. No.	Location Code		Location Name	Latitude/ Longitude
1.	Kandla	DW-1	Oil Jetty 7	23.043527N 70.218456E
2.		DW-2	Port & Custom Building	23.009033N 70.222047E
3.		DW-3	North Gate	23.007938N 70.222411E
4.		DW-4	Workshop	23.009372N 70.222236E
5.		DW-5	Canteen Area	23.003707N 70.221331E
6.		DW-6	West Gate 1	23.006771N 70.217340E
7.		DW-7	Sewa Sadan -3	23.009779N 70.221838E
8.		DW-8	Nirman Building	23.009642N 70.220623E
9.		DW-9	Custom Building	23.018930N 70.214478E
10.		DW-10	Port Colony Kandla	23.019392N 70.212619E
11.		DW-11	Wharf Area/ Jetty	22.997833N 70.223042E
12.		DW-12	Hospital Kandla	23.018061N 70.212328E
13.		DW-13	A.O. Building	23.061914N 70.144861E
14.		DW-14	School Gopalpuri	23.083619N 70.132061E
15.		DW-15	Guest House	23.078830N 70.131008E
16.		DW-16	E- Type Quarter	23.083306N 70.132422E
17.		DW-17	F- Type Quarter	23.077347N 70.135731E
18.		DW-18	Hospital Gopalpuri	23.081850N 70.135347E
19.	Vadinar	DW-19	Near Vadinar Jetty	22.440759N 69.675210E
20.		DW-20	Near Port Colony	22.401619N 69.716822E

Map 12: Drinking Water Monitoring Locations at Kandla

Map 13: Drinking Water Monitoring Locations at Vadinar

Methodology

The water samples were collected from the finalized sampling locations and analyzed for physico-chemical and microbiological parameter, for which the analysis was carried out as per APHA, 23rd Edition and Indian Standard method in GEMI's NABL Accredited Laboratory, Gandhinagar. GEMI has followed the CPCB guideline as well as framed its own guidelines for the collection of water/wastewater samples, under the provision of Water (Preservation and Control of Pollution) Act 1974, titled as '**Sampling Protocol for Water & Wastewater'**; approved by the Government of Gujarat vide letter no. ENV-102013-299-E dated 24-04-2014. The samples under the study were collected and preserved as per the said Protocol. The parameters finalized to assess the drinking water quality have been mentioned in **Table 21** as follows:

Table 21: List of parameters for Drinking Water Quality monitoring[3]

Sr. No.	Parameters	Units	Reference method	Instrument
1.	pH	-	APHA, 23rd Edition (Section-4500-H^+B):2017	pH Meter
2.	Colour	Hazen	APHA, 23rd Edition, 2120 B:2017	Color Comparator
3.	EC	µS/cm	APHA, 23rd Edition (Section-2510 B):2017	Conductivity Meter
4.	Turbidity	NTU	APHA, 23rd Edition (Section -2130 B):2017	Nephlo Turbidity Meter
5.	TDS	mg/L	APHA, 23rd Edition (Section-2540 C):2017	Vaccum Pump with filtration assembly and Oven
6.	TSS	mg/L	APHA, 23rd Edition, 2540 D: 2017	
7.	Chloride	mg/L	APHA, 23rd Edition (Section-4500-Cl-B):2017	Titration Apparatus
8.	Total Hardness	mg/L	APHA, 23rd Edition (Section-2340 C):2017	
9.	Ca Hardness	mg/L	APHA, 23rd Edition (Section-3500-Ca B):2017	
10.	Mg Hardness	mg/L	APHA, 23rd Edition (Section-3500-Mg B):2017	
11.	Free Residual Chlorine	mg/L	APHA 23rd Edition, 4500	
12.	Fluoride	mg/L	APHA, 23rd Edition (Section-4500-F-D):2017	UV- Visible Spectrophotometer
13.	Sulphate	mg/L	APHA, 23rd Edition (Section 4500-SO4-2-E):2017	
14.	Sodium	mg/L	APHA, 23rd Edition (Section-3500-Na-B):2017	Flame Photometer
15.	Potassium	mg/L	APHA,23rd Edition, 3500 K-B: 2017	
16.	Salinity	mg/L	APHA, 23rd Edition (section 2520 B, E.C. Method)	Salinity /TDS Meter
17.	Nitrate	mg/L	APHA, 23rd Edition, 4500 NO3- B: 2017	UV- Visible Spectrophotometer
18.	Nitrite	mg/L	APHA, 23rd Edition, 4500 NO2-B: 2017	
19.	Hexavalent Chromium	mg/L	APHA, 23rd Edition, 3500 Cr B: 2017	
20.	Manganese	mg/L	APHA,23rd Edition, ICP Method 3120 B: 2017	ICP-OES

Sr. No.	Parameters	Units	Reference method	Instrument
21.	Mercury	mg/L	EPA 200.7	
22.	Lead	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
23.	Cadmium	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
24.	Iron	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
25.	Total Chromium	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
26.	Copper	mg/L	APHA,23rd Edition, ICP Method 3120 B: 2017	ICP-OES
27.	Zinc	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
28.	Arsenic	mg/L	APHA ICP 23rd Edition (Section-3120 B):2017	
29.	Total Coliforms	MPN/ 100ml	IS 15185: 2016	LAF/ Incubator

Monitoring Frequency

Monitoring is required to be carried out once a month for both the locations of Kandla and Vadinar. Sample Collected from this location during the monitoring period April 2024 to March 2025.

8.2 Result and Discussion

The drinking water quality of the locations at Kandla and Vadinar and its comparison with the to the stipulated standard (Drinking Water Specifications i.e., IS: 10500:2012) [4] have been summarized in **Table 22A, 22B, 22C** as follows:

Table 22A: Drinking Water Quality for the Monitoring period

Parameters	Standard values as per IS-		DW-1 (Oil Jetty 7)			DW-2 (Port & Custom Building)			DW-3 (North Gate)			DW-4 (Workshop)			DW-5 (Canteen Area)			DW-6 (West Gate 1)			DW-7 (Sewa Sadan -3)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
pH	6.5-8.5		8.4	6.1	7.32	8.31	4.36	6.89	7.73	6.56	7.29	8.78	6.45	7.44	8.48	6.98	7.52	8.40	7.01	7.75	8.48	6.73	7.62
Colour (Hazen)	5	15	5	1	1.33	1.00	1.00	1.00	5.00	1.00	1.33	1.00	1.00	1.00	1.00	1.00	1.00	5.00	1.00	2.00	5.00	1.00	1.33
EC (µS/ cm)			1751	15	415.2	279.00	34.10	137.46	677.00	13.46	94.95	48.70	20.60	33.39	1214.00	17.87	384.99	678.00	17.60	248.17	44.80	9.78	22.84
Salinity (PSU)			0.88	0.02	0.20	0.21	0.02	0.08	0.33	0.01	0.05	0.03	0.02	0.02	0.65	0.02	0.23	0.33	0.02	0.15	0.03	0.01	0.02
Turbidity (NTU)	1	5	0.72	0.52	0.604	0.64	0.64	0.64	0.68	0.52	0.59	0.71	0.71	0.71	0.82	0.64	0.68	0.73	0.61	0.65	0.65	0.65	0.65
Chloride (mg/L)	250	1000	342.39	4.96	92.18	60.12	5.50	28.43	119.11	4.50	19.76	13.80	4.93	10.21	271.36	3.94	79.50	112.63	2.96	63.49	11.00	3.70	6.99
Total Hardness (mg/L)	200	600	310	2	61.87	40.00	2.00	21.33	165.00	2.00	21.18	13.00	2.00	3.78	240.00	2.00	72.17	210.00	2.00	68.42	10.50	1.50	4.06
Ca Hardness (mg/L)			150	1	33.12	25.00	1.00	11.66	100.00	1.00	12.41	10.00	1.00	2.29	153.00	1.50	44.00	110.00	1.50	39.63	9.00	1.00	2.60
Mg Hardness (mg/L)			160	1	28.75	22.00	1.00	9.41	65.00	1.00	13.28	3.00	1.00	1.50	90.00	2.00	34.00	100.00	1.00	35.15	2.00	1.00	1.63
Free Residual Chlorine (mg/L)	0.2	1	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
TDS (mg/L)	500	2000	894	8	225.3	142.00	18.00	64.58	356.00	8.00	50.50	26.00	12.00	18.00	618.00	10.00	197.42	342.00	10.00	166.92	22.00	6.00	12.58
TSS (mg/L)			BQL	BQL	BQL	BQL	BQL	BQL	2.00	2.00	2.00	2.00	2.00	2.00	BQL	BQL	BQL	2.00	2.00	2.00	4.00	4.00	4.00
Fluoride (mg/L)	1	1.5	0.434	0.332	0.383	0.34	0.34	0.34	0.35	0.35	0.35	0.62	0.38	0.54	0.54	0.33	0.41	0.65	0.33	0.42	0.38	0.38	0.38
Sulphate (mg/L)	200	400	133.88	112.78	123.3	15.26	11.54	14.02	33.51	33.51	33.51	BQL	BQL	BQL	83.25	52.38	72.95	37.82	31.56	35.68	BQL	BQL	BQL

Parameters	Standard values as per IS-		DW-1 (Oil Jetty 7)			DW-2 (Port & Custom Building)			DW-3 (North Gate)			DW-4 (Workshop)			DW-5 (Canteen Area)			DW-6 (West Gate 1)			DW-7 (Sewa Sadan -3)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Nitrate (mg/L)	45		16.66	1.653	6.51	4.86	1.43	2.44	2.78	1.05	2.10	BQL	BQL	BQL	28.36	1.04	11.35	9.28	3.66	6.72	BQL	BQL	BQL
Nitrite (mg/L)			BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	0.41	0.31	0.34	0.23	0.03	0.08	BQL	BQL	BQL
Sodium (mg/L)			284.1	5.27	75.81	41.14	11.61	26.04	72.16	8.22	25.18	9.49	5.42	7.03	156.32	6.27	65.29	79.74	16.59	55.37	6.58	4.28	5.43
Potassium (mg/L)			18.2	16.02	17.11	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	9.47	7.22	7.84	BQL	BQL	BQL	BQL	BQL	BQL
Hexavalent Chromium (mg/L)			BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Odour (TON)	Agreeable		1	1	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Arsenic (mg/L)	0.01	0.05	BQL	BQL	BQL	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	BQL	BQL	BQL	9.79	0.01	4.43	0.01	0.01	0.01
Cadmium (mg/L)	0.003		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Copper (mg/L)	0.05	1.5	BQL	BQL	BQL	7.46	0.01	1.87	0.03	0.01	0.02	0.02	0.01	0.02	7.50	0.01	1.51	0.01	0.01	0.01	0.01	0.01	0.01
Iron (mg/L)	0.3		BQL	BQL	BQL	0.16	0.16	0.16	0.23	0.18	0.21	2.16	0.12	1.14	0.00	0.00	0.00	0.47	0.26	0.38	BQL	BQL	BQL
Lead (mg/L)	0.01		BQL	BQL	BQL	BQL	BQL	BQL	3.09	2.12	2.60	0.03	0.03	0.03	0.00	0.00	0.00	BQL	BQL	BQL	BQL	BQL	BQL
Manganese (mg/L)	0.1	0.3	BQL	BQL	BQL	102.60	102.60	102.60	BQL	BQL	BQL	0.12	0.12	0.12	BQL	BQL	BQL	0.07	0.06	0.07	BQL	BQL	BQL
Mercury (mg/L)	0.001		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Total Chromium (mg/L)	0.05		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	0.02	0.02	0.02	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Zinc (mg/L)	5	15	BQL	BQL	BQL	9.12	9.12	9.12	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Total Coliform* (MPN/ 100ml)	Shall not be detected		59,510	BQL	6839	390	BQL	116	3900	BQL	456	430	BQL	71	9250	BQL	1045	8150	BQL	712	485	BQL	143

Table 22B: Drinking Water Quality for the Monitoring period

Parameters	Standard values as per IS		DW-8 (Nirman Building)			DW-9 (Custom Building)			DW-10 (Port Colony Kandla)			DW-11 (Wharf Area/ Jetty)			DW-12 (Hospital Kandla)			DW-13 (A.O. Building)			DW-14 (School Gopalpuri)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
pH	6.5-8.5		8.50	6.88	7.52	7.79	6.51	7.14	8.15	6.67	7.22	7.99	6.77	7.69	7.88	6.82	7.26	7.94	6.77	7.37	8.10	6.70	7.23
Colour (Hazen)	5	15	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	5.00	1.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
EC (µS/ cm)			73.20	16.41	31.44	1689.00	25.10	398.24	756.00	105.30	228.57	1364.0	104.30	709.81	212.00	57.90	150.60	186.40	28.20	74.43	1746.0	107.90	349.63
Salinity (PSU)			0.04	0.02	0.02	0.86	0.02	0.20	0.37	0.05	0.11	0.62	0.05	0.30	0.10	0.03	0.07	0.09	0.02	0.04	0.88	0.06	0.17
Turbidity (NTU)	1	5	0.94	0.50	0.71	0.73	0.63	0.70	0.79	0.79	0.79	0.98	0.69	0.85	0.59	0.59	0.59	0.52	0.52	0.52	0.71	0.71	0.71
Chloride (mg/L)	250	1000	15.50	3.45	8.60	340.00	7.34	93.46	134.03	20.20	45.92	285.80	20.70	147.04	47.64	14.39	31.66	42.49	9.86	18.89	344.93	22.17	72.53
Total Hardness (mg/L)	200	600	12.00	1.50	3.64	230.00	3.00	48.25	170.00	11.00	38.83	245.00	18.00	138.58	36.00	4.00	25.33	25.00	2.00	7.00	230.00	19.00	53.25
Ca Hardness (mg/L)			6.00	1.00	2.50	110.00	3.00	24.29	90.00	5.00	20.83	174.00	10.00	87.08	18.00	3.00	14.17	12.50	1.00	3.38	100.00	11.00	27.00
Mg Hardness (mg/L)			6.00	1.00	2.25	120.00	1.50	26.14	80.00	5.00	18.00	95.00	7.00	54.08	20.00	1.00	11.17	12.50	1.00	5.07	130.00	8.00	26.25
Free Residual Chlorine (mg/L)	0.2	1	BQL	BQL	BQL	2.65	2.65	2.65	BQL	BQL	BQL	4.96	4.96	4.96	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
TDS (mg/L)	500	2000	38.00	6.00	16.00	970.00	14.00	216.50	398.00	60.00	119.50	672.00	58.00	375.50	110.00	30.00	79.00	98.00	14.00	39.67	994.00	56.00	190.50
TSS (mg/L)			BQL	BQL	BQL	4.00	4.00	4.00	2.00	2.00	2.00	3.00	2.00	2.33	BQL	BQL	BQL	2.00	2.00	2.00	BQL	BQL	BQL
Fluoride (mg/L)	1	1.5	0.43	0.36	0.40	1.54	0.54	1.04	0.80	0.33	0.56	0.47	0.26	0.35	0.44	0.44	0.44	0.33	0.32	0.33	1.48	0.38	0.76
Sulphate (mg/L)	200	400	BQL	BQL	BQL	134.11	12.56	52.23	39.51	10.38	17.18	96.75	12.62	54.54	13.08	10.59	11.41	BQL	BQL	BQL	133.90	10.73	38.72
Nitrate (mg/L)	45		0.00	0.00	0.00	13.25	1.69	5.63	8.39	1.06	2.11	30.93	1.04	10.50	1.94	1.04	1.46	5.32	1.29	3.11	12.67	1.07	3.95
Nitrite (mg/L)			BQL	BQL	BQL	0.49	0.13	0.31	BQL	BQL	BQL	1.64	0.24	0.61	BQL	BQL	BQL	BQL	BQL	BQL	0.48	0.48	0.48

Parameters	Standard values as per IS		DW-8 (Nirman Building)			DW-9 (Custom Building)			DW-10 (Port Colony Kandla)			DW-11 (Wharf Area/ Jetty)			DW-12 (Hospital Kandla)			DW-13 (A.O. Building)			DW-14 (School Gopalpuri)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Sodium (mg/L)			13.32	4.90	9.05	196.70	3.62	71.55	83.61	10.49	28.23	153.41	11.25	88.17	30.75	10.63	18.10	29.24	5.08	12.01	241.50	10.82	45.26
Potassium (mg/L)			BQL	BQL	BQL	7.00	6.60	6.80	BQL	BQL	BQL	7.91	5.86	7.27	BQL	BQL	BQL	BQL	BQL	BQL	7.30	7.30	7.30
Hexavalent Chromium (mg/L)			BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Odour (TON)	Agreeable		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Arsenic (mg/L)	0.01	0.05	BQL	BQL	BQL	0.02	0.02	0.02	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	0.01	0.01	0.01
Cadmium (mg/L)	0.003		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Copper (mg/L)	0.05	1.5	0.01	0.01	0.01	6.54	0.01	1.65	27.22	0.01	3.41	0.01	0.01	0.01	24.87	0.01	2.78	0.01	0.01	0.01	20.69	0.01	6.90
Iron (mg/L)	0.3		BQL	BQL	BQL	0.12	0.12	0.12	0.22	0.10	0.14	0.25	0.12	0.21	0.87	0.87	0.87	0.22	0.22	0.22	0.20	0.12	0.16
Lead (mg/L)	0.01		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Manganese (mg/L)	0.1	0.3	0.06	0.06	0.06	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	0.10	0.10	0.10
Mercury (mg/L)	0.001		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	0.00
Total Chromium (mg/L)	0.05		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	0.00
Zinc (mg/L)	5	15	BQL	BQL	BQL	1.50	1.50	1.50	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Total Coliform* (MPN/ 100ml)	Shall not be detected		1500	BQL	298	5900	BQL	675	3500	BQL	332	4250	BQL	675	2500	BQL	332	6300	BQL	1105	615	BQL	141

Table 22C: Drinking Water Quality for the Monitoring period

Parameters	Standard values as per IS		DW-15 (Guest House)			DW-16 (E- Type Quarter)			DW-17 (F- Type Quarter)			DW-18 (Hospital Gopalpuri)			DW-19 (Near Vadinar Jetty)			DW-20 (Near Port Colony)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
pH	6.5-8.5		8.44	6.88	7.48	8.48	7.01	7.42	8.39	6.52	7.31	8.08	6.60	7.14	8.19	6.90	7.59	8.32	6.79	7.46
Colour (Hazen)	5	15	1.00	1.00	1.00	1.00	1.00	1.00	5.00	1.00	1.33	5.00	1.00	1.33	1.00	1.00	1.00	1.00	1.00	1.00
EC (µS/ cm)			467.00	87.10	171.01	945.00	12.10	175.35	728.00	15.67	138.67	694.00	23.90	134.81	612.00	57.30	281.44	170.50	55.40	109.50
Salinity (PSU)			0.23	0.05	0.09	0.47	0.02	0.09	0.36	0.02	0.07	0.34	0.02	0.07	0.30	0.03	0.14	0.08	0.03	0.06
Turbidity (NTU)	1	5	0.00	0.00	0.00	2.15	2.15	2.15	0.63	0.63	0.63	1.38	0.83	1.01	0.74	0.68	0.71	0.65	0.65	0.65
Chloride (mg/L)	250	1000	84.77	19.22	38.03	188.23	5.17	37.76	133.01	6.90	29.93	126.96	6.90	31.52	79.41	7.88	34.71	21.84	8.87	15.02
Total Hardness (mg/L)	200	600	110.00	4.00	20.13	190.00	1.00	43.89	170.00	2.00	23.11	170.00	3.00	19.38	165.00	16.00	79.79	44.00	8.00	25.71
Ca Hardness (mg/L)			50.00	2.00	12.04	105.00	2.00	28.31	85.00	1.00	10.80	80.00	2.00	9.67	75.00	10.00	40.08	30.00	4.00	14.13
Mg Hardness (mg/L)			60.00	1.00	8.08	85.00	1.00	21.06	85.00	1.00	14.29	90.00	1.00	9.54	90.00	6.00	39.71	20.00	4.00	11.58
Free Residual Chlorine (mg/L)	0.2	1	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
TDS (mg/L)	500	2000	242.00	48.00	89.50	492.00	8.00	91.67	374.00	8.00	71.83	358.00	12.00	70.67	316.00	32.00	149.17	90.00	30.00	58.00
TSS (mg/L)			2.00	2.00	2.00	2.00	2.00	2.00	BQL	BQL	BQL	BQL	BQL	BQL	2.00	2.00	2.00	BQL	BQL	BQL
Fluoride (mg/L)	1	1.5	0.51	0.35	0.42	0.41	0.37	0.00	0.56	0.53	0.55	0.43	0.31	0.37	0.66	0.50	0.58	1.45	0.36	0.81
Sulphate (mg/L)	200	400	24.61	24.61	24.61	52.86	21.77	37.31	43.64	15.66	29.65	42.24	42.24	42.24	38.89	33.62	35.89	BQL	BQL	BQL
Nitrate (mg/L)	45		2.23	1.02	1.36	4.96	2.18	3.92	9.84	2.95	5.37	3.97	3.97	3.97	3.67	1.32	2.57	1.71	1.04	1.29
Nitrite (mg/L)			BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Sodium (mg/L)			48.60	10.07	23.21	112.62	6.54	35.47	73.07	6.66	33.65	68.18	5.25	16.34	61.83	5.95	23.18	18.29	5.06	11.20

Parameters	Standard values as per IS		DW-15 (Guest House)			DW-16 (E- Type Quarter)			DW-17 (F- Type Quarter)			DW-18 (Hospital Gopalpuri)			DW-19 (Near Vadinar Jetty)			DW-20 (Near Port Colony)		
	A	P	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Potassium (mg/L)			BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	1.49	1.49	1.49	BQL	BQL	BQL
Hexavalent Chromium (mg/L)			BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Odour (TON)	Agreeable		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Arsenic (mg/L)	0.01	0.05	BQL	BQL	BQL	0.02	0.02	0.02	0.01	0.01	0.01	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Cadmium (mg/L)	0.003		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Copper (mg/L)	0.05	1.5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	11.77	0.01	1.19
Iron (mg/L)	0.3		0.27	0.24	0.26	1.73	0.11	0.70	0.28	0.15	0.22	0.16	0.11	0.13	0.13	0.13	0.13	BQL	BQL	BQL
Lead (mg/L)	0.01		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	3.98	3.98	3.98	2.43	BQL	0.41	BQL	BQL	BQL
Manganese (mg/L)	0.1	0.3	0.07	0.07	0.07	0.00	0.00	0.00	0.05	0.05	0.05	40.12	40.12	40.12	BQL	BQL	BQL	BQL	BQL	BQL
Mercury (mg/L)	0.001		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Total Chromium (mg/L)	0.05		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Zinc (mg/L)	5	15	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Total Coliform* (MPN/ 100ml)	Shall not be detected		8250	BQL	1302	2300	BQL	283	6150	BQL	609	995	BQL	253	682	BQL	157	49000	BQL	4259

A: Acceptable, P:Permissible, BQL: Below Quantification limit Turbidity (QL=0.5 NTU), Free Residual Chlorine (QL=2 mg/L), Total Suspended Solids (QL=2 mg/L), Fluoride (QL=0.3 mg/L), Sulphate (QL=10 mg/L), Nitrate as NO_3 (QL=1 mg/L), Nitrite as NO_2 (QL=0.1mg/L), Sodium as Na (QL=5mg/L), Potassium as K (QL=5mg/L), Hexavalent Chromium (QL=0.01 mg/L), Arsenic (QL=0.005 mg/L), Cadmium (QL=0.002 mg/L), Copper (QL=0.005 mg/L), Iron (QL=0.1mg/L), Lead (QL=0.002 mg/L), Manganese (QL=0.04 mg/L), Mercury (QL=0.0005 mg/L), Total Chromium (QL=0.005 mg/L), Zinc (QL=0.5 mg/L), Total Coliforms (QL=1 MPN/ 100ml)

Note: For Total Coliform, one MPN is equivalent to one CFU. The use of either method; MPN or CFU for the detection of bacteria are considered valid measurements for bacteria limits.

8.3 Data Interpretation and Conclusion

Drinking water samples were taken from 20 locations (18 at Kandla and 2 at Vadinar), and their physical and chemical properties were analyzed. The analysis's results were compared with standard values as prescribed in IS 10500:2012 Drinking Water Specification.

Physico-Chemical Parameters:

- **pH:** The pH values of drinking water samples in Kandla were reported to be in the range of **4.36 to 8.78,** with an average pH of **7.37**. In Vadinar, its values ranged from **6.79 to 8.32**, with an average pH of **7.53**. Notably, the pH levels at both project sites fall within the acceptable range of **6.5 to 8.5**, as specified under IS:10500:2012.
- **Colour:** The colour varies from **1 to 5** at the monitoring locations in Kandla. Locations **DW-1, DW-3, DW-6, DW-7, DW-11, DW-17 & DW-18** showed the value of **5 Hazen** at Kandla. At Vadinar, the color was observed with the value of **1 Hazen** at both locations & falls within the acceptable range of 1 to 15, as specified under IS:10500:2012, within the monitoring period of **April to May 2024**.
- **Electrical Conductivity (EC):** It is a measure of the ability of a solution to conduct electric current, and it is often used as an indicator of the concentration of dissolved solids in water. During the monitoring period, the EC values for samples collected in Kandla were observed to range from **9.78 to 1751.0 µS/cm**, with an average value of **216.64 µS/cm**. In Vadinar, the EC values showed variation from **55.4 to 612.0 µS/cm**, with an average value of **195.47 µS/cm**. It's important to regularly monitor EC levels in drinking water as it can provide valuable information about water quality and presence of dissolved substances.
- **Salinity:** Salinity at Kandla varies from **0.01 to 0.88 PSU** with an average of **0.11 PSU**, while at Vadinar, salinity was observed within the range of **0.03 to 0.30 PSU**.
- **Turbidity**: The Turbidity values of drinking water samples in Kandla were reported to be in the range of **0.0 to 2.15 NTU**, with an average of **0.73**. In Vadinar, its values ranged from **0.65 to 0.74**, with an average **0.68**. Notably, the Turbidity levels at both project sites fall within the acceptable range of 1 to 5 NTU, as specified under IS:10500:2012.
- **Chlorides:** The chloride concentrations in Kandla varied from **2.96 to 344.93 mg/L**, with an average value of **47.55 mg/L.** At Vadinar the chloride concentration was observed within the range of **7.88 mg/L to 79.41 mg/L**, with an average value **of 24.87 mg/L.** Thus, the chloride levels at both project sites fall within the Permissible limit of 1000 mg/L, as specified under IS:10500:2012.
- **Total Hardness (TH):** The concentration of Total Hardness varies from **1.0 to 310 mg/L,** with an average concentration of **37.46 mg/L.** While at Vadinar, the observed values were within range of **8 to 165.00 mg/L**. at both study areas Total Hardness found to be within the Permissible limit norm of 600 mg/L as specified by IS:10500:2012 and is not harmful for local inhabitants.

- **Total Dissolved Solids (TDS):** Monitoring TDS is crucial because it provides an indication of overall quality of the water. During the monitoring period, the TDS concentrations in Kandla were observed to vary in a wide range i.e., between **6 to 994 mg/L,** with an average concentration of **116.42 mg/L.** which is within the permissible limit. while in Vadinar, it ranged from **30 to 316 mg/L**, with an average of **103.59 mg/L.** It is important to note that the TDS concentrations in both Kandla and Vadinar fall well within the Permissible limit of 2000 mg/L.
- **Fluoride:** The concentration Fluoride varies from **0.26 to 1.54 mg/L**, with an average concentration of **0.45 mg/L**. While at Vadinar Fluoride concentration was varies within range of **0.36 to 1.45 mg/L**, with an average concentration of **0.70 mg/L**. The Fluoride concentration was found to be BQL in majority of the monitoring location at Kandla and Vadinar. at both study areas Fluoride found to be within the Permissible limit norm of **1.5 mg/L** as specified by IS:10500:2012 except
- **Sulphate:** The concentration Sulphate varies from **10.59 to 134.11 mg/L**, with an average concentration of **32.63 mg/L**. While at Vadinar Sulphate concentration was **38.89 mg/L** at DW-19 while BQL Was Observed for DW-20. During monitoring period in Kandla and Vadinar, the sulphate concentrations were found to be within the acceptable limits i.e., 200 mg/L as per the specified norms.
- **Nitrate:** The concentration Nitrate varies from 1.**02 to 30.93 mg/L**, with an average concentration of **3.92 mg/L.** While at Vadinar Nitrate concentration was varies within range of **1.04 to 3.67 mg/L**, with an average concentration of **1.93 mg/L**. The Nitrate concentration was found to be BQL in majority of the monitoring location at Kandla and Vadinar. at both study areas Nitrate found to be within the Acceptable limit norm of 45 mg/L as specified by IS: 10500:2012.
- **Nitrite:** The concentration Nitrite varies from **0.03 to 1.64 mg/L**. While at Vadinar Nitrite concentration was found to be of **BQL** value at both locations. The Nitrite concentration was found to be **BQL** in majority of the monitoring location at Kandla and Vadinar.
- **Sodium:** During the monitoring period, at Kandla variation in the concentration of Sodium was observed to be in the range of **3.62 to 284.10 mg/L**, with the average concentration of **35.62 mg/L**. While at Vadinar, the concentration recorded between **5.06 to 61.83 mg/L,** with the average concentration of **17.19 mg/L.**
- **Odour:** Odour values recorded **1 TON** at all monitoring locations of Kandla and Vadinar.

Metals:

- **Arsenic:** The Arsenic concentrations in Kandla varied from **0.01 to 9.79 mg/L**. At Vadinar the Arsenic concentration was observed to be of **BQL**. Thus, the Arsenic levels at both project sites fall within the Permissible limit of 0.05 mg/L, as specified under IS:10500:2012, except on one location at Kandla DW-6 where Arsenic Concentration found 9.79 mg/L.
- **Copper:** The Copper concentrations in Kandla varied from **0.01 to 27.22 mg/L**. At Vadinar the Copper concentration was observed within the range of **0.01** mg/L to **11.77 mg/L**. Thus, the Copper levels at both project sites fall within the Permissible limit of 1.5 mg/L, as specified under IS:10500:2012, except for locations DW-20 of

Vadinar for some samples taken during whole monitoring period. The Copper concentrations were recorded BQL for majority of the locations in Kandla and Vadinar.

- **Iron:** The Iron concentrations in Kandla varied from **0.1 to 2.16 mg/L**, with an average concentration of **0.31 mg/L.** At Vadinar the Iron concentration was observed **0.13 mg/L** at DW-19 & **BQL** was observed at DW-20. Thus, the Iron levels at both project sites fall within the Acceptable limit of 0.3 mg/L, as specified under IS:10500:2012, except for locations DW-4, DW-6, DW-12 & DW-16 in Kandla The Iron concentrations were recorded by BQL for the majority of the locations in Kandla and Vadinar.
- **Lead:** The Lead concentrations in Kandla varied from 0.03 to 3.98 mg/L, with an average concentration of 1.10 mg/L. While at Vadinar the Lead concentration was observed **2.43 mg/L** at DW-19 & **BQL** was observed at DW-20. Thus, the Lead levels at both project sites fall within the Acceptable limit of 0.01 mg/L, as specified under IS:10500:2012, except for locations DW-3, DW-4 & DW-18 in Kandla and on Location DW-19 of Vadinar for some samples taken during the whole monitoring period. The Lead concentrations were recorded in BQL for the majority of the locations in Kandla and Vadinar.
- **Manganese:** The Manganese concentrations in Kandla varied from **0.05 to 102.60 mg/L,** with an average concentration of **13.02 mg/L**. While at Vadinar, the Manganese concentration was observed with the value of **BQL** at both Locations. Thus, the Manganese levels at both project sites fall within the Acceptable limit of 0.3 mg/L, as specified under IS:10500:2012, except for locations DW-2, and DW-18 in Kandla for some samples taken during the whole monitoring period. The Manganese concentrations were recorded BQL for the majority of the locations in Kandla and Vadinar.
- **Free Residual chlorine:** The Free Residual Chlorine concentrations in Kandla varied from **2.65 to 4.96 mg/L**, with an average concentration of **3.81 mg/L**. While at Vadinar, the Free Residual Chlorine concentration was observed with the value of **BQL** at both the locations. Thus, the Free Residual Chlorine levels at both project sites fall within the Acceptable limit of 0.2 mg/L, as specified under IS:10500:2012, except for locations DW-9 & DW-11 in Kandla for some samples taken during the whole monitoring period. The Manganese concentrations were recorded BQL for the majority of the locations in Kandla and Vadinar.
- **Total Suspended Solid:** The Total Suspended Solid concentrations in Kandla varied from 2.00 to 4.00 mg/L, with an average concentration of 2.43 mg/L. While at Vadinar, the Potassium concentration was observed **2.00 mg/L** at DW-19 & **BQL** was observed at DW-20.
- **Potassium:** The Potassium concentrations in Kandla varied from **5.86 to 18.20 mg/L**, with an average concentration of **9.26 mg/L.** While at Vadinar, the Potassium concentration was observed **1.49 mg/L** at DW-19 & **BQL** was Observed at DW-20.
- **Zinc:** The Zinc concentrations in Kandla varied from **1.50 to 9.12 mg/L**, with an average concentration of **5.31 mg/L**. While at Vadinar, the Zinc concentration was observed **BQL** at both the locations.

- The concentrations of parameters such Hexavalent Chromium and the metals (Cadmium, Mercury and Total Chromium) were observed to fall within the Permissible limit at both project sites. Observed "**Below the Quantification Limit (BQL)"** at majority of the locations during the monitoring period.
- Bacteriological Analysis of the drinking water reveals that **Total Coliforms (TC)** were detected in the range of **BQL** to **59,510** MPN/100ml, with the average of **855** MPN/100ml. The maximum concentration of Total Coliform was observed at location DW-1 during the April–May 2024 monitoring period. Except for this spike, the concentration of Total Coliform remained below quantification limits (BQL) or very low across most locations. However, noticeable spikes were also observed at DW-3, DW-5, DW-6, DW-8, DW-9, DW-10, DW-11, DW-15, and DW-17. At these locations, one or two peaks were recorded, which may be considered outliers. Inclusion of these outlier values has skewed the overall average of the Coliform data, making it appear higher than typical.
- While at Vadinar the observed within the range of **BQL** to **49,000 MPN/100ml,** with the average concentration of **2,208 MPN/100ml.** The maximum concentration of Total Coliform was observed at location DW-20 during the October-November 2024 monitoring period. Except for this spike, the concentration of Total Coliform remained below quantification limits (BQL) or very low across most locations. At both locations, one or two peaks were recorded, which may be considered outliers. Inclusion of these outlier values has skewed the overall average of the Coliform data, making it appear higher than typical. Reporting such concentration of Coliforms indicates certain external influx may contaminate the source. Hence, it should be checked at every distribution point. The higher concentration of total coliforms was observed at all locations in Kandla and Both location of Vadinar.

8.4 Remedial Measures

Appropriate water treatment processes should be administered to eradicate coliform bacteria. The methods of disinfection such as **chlorination, ultraviolet (UV), or ozone** etc, apart from that, filtration systems can also be implemented to remove bacteria (Total coliforms), sediment, and other impurities.

The following steps can be implemented to ensure that the water being supplied is safe for consumption:

- Regular monitoring should be carried out to assess the quality of drinking water at various stages, including the source, purification plants, distribution network, and consumer endpoints would help in early detection of coliform bacteria or other contaminants in the drinking water.
- It is necessary to carry out a system assessment to determine whether the drinking-water supply chain (up to the point of consumption) as a whole can deliver water of a quality that meets identified targets. This also includes the assessment of design criteria of the treatment systems employed.
- Identifying control measures in a drinking-water system that will collectively control identified risks and ensure that the health-based targets are met. For each control measure identified, an appropriate means of operational monitoring should be

defined that will ensure that any deviation from required performance (water quality) is rapidly detected in a timely manner.

- Management and communication plan should be formulated describing actions to be taken during normal operation as well as during incident conditions (such as drinking water contamination) and documenting the same.

CHAPTER 9: SEWAGE TREATMENT PLANT MONITORING

9.1 Sewage Treatment Plant (STP) Monitoring:

The principal objective of STP is to remove contaminants from sewage to produce an effluent that is suitable to discharge to the surrounding environment or an intended reuse application, thereby preventing water pollution from raw sewage discharges. As defined in the scope by Deendayal Port Authority (DPA), Kandla, the STP Monitoring is to be carried out weekly at three locations, one at Kandla, one at Gopalpuri and one STP at Vadinar. The samples from the inlet and outlet of the STP have been collected weekly. The details of the locations of STP to be monitored for Kandla and Vadinar have been mentioned in **Table 23A** as follows:

Frequency of monitoring: weekly

Table 23A: Details of the monitoring locations of STP

Sr. No.	Location Code		Location Name	Latitude Longitude
1.	Kandla	STP-1	STP Kandla	23.021017N 70.215594E
2.		STP-2	STP Gopalpuri	23.077783N 70.136759E
3.	Vadinar	STP-3	STP at Vadinar	22.406289N 69.714689E

The Consolidated Consent and Authorization (CC&A) issued by the GPCB were referred for the details of the STP for Kandla and Gopalpuri. The CC&A of Kandla and Gopalpuri entails that the treated domestic sewage should conform to the norms specified in **Table 23B**. The treated effluent conforming to the norms shall be discharged on the land within the premises strictly for the gardening and plantation purpose. Whereas, no sewage shall be disposed outside the premises in any manner.

Table 22B: Discharge norms (as per CC&A of Kandla STP)

Sr. No.	Parameters	Prescribed limits
1.	pH	6.5-8.5
2.	BOD (3 days at 27°C)	30 mg/L
3.	Suspended Solids	100 mg/L
4.	Fecal Coliform	< 1000 MPN/100 ml

The detailed process flow diagram of the Kandla and Gopalpuri STP have been mentioned in **Figure 3 and 4** as follows:

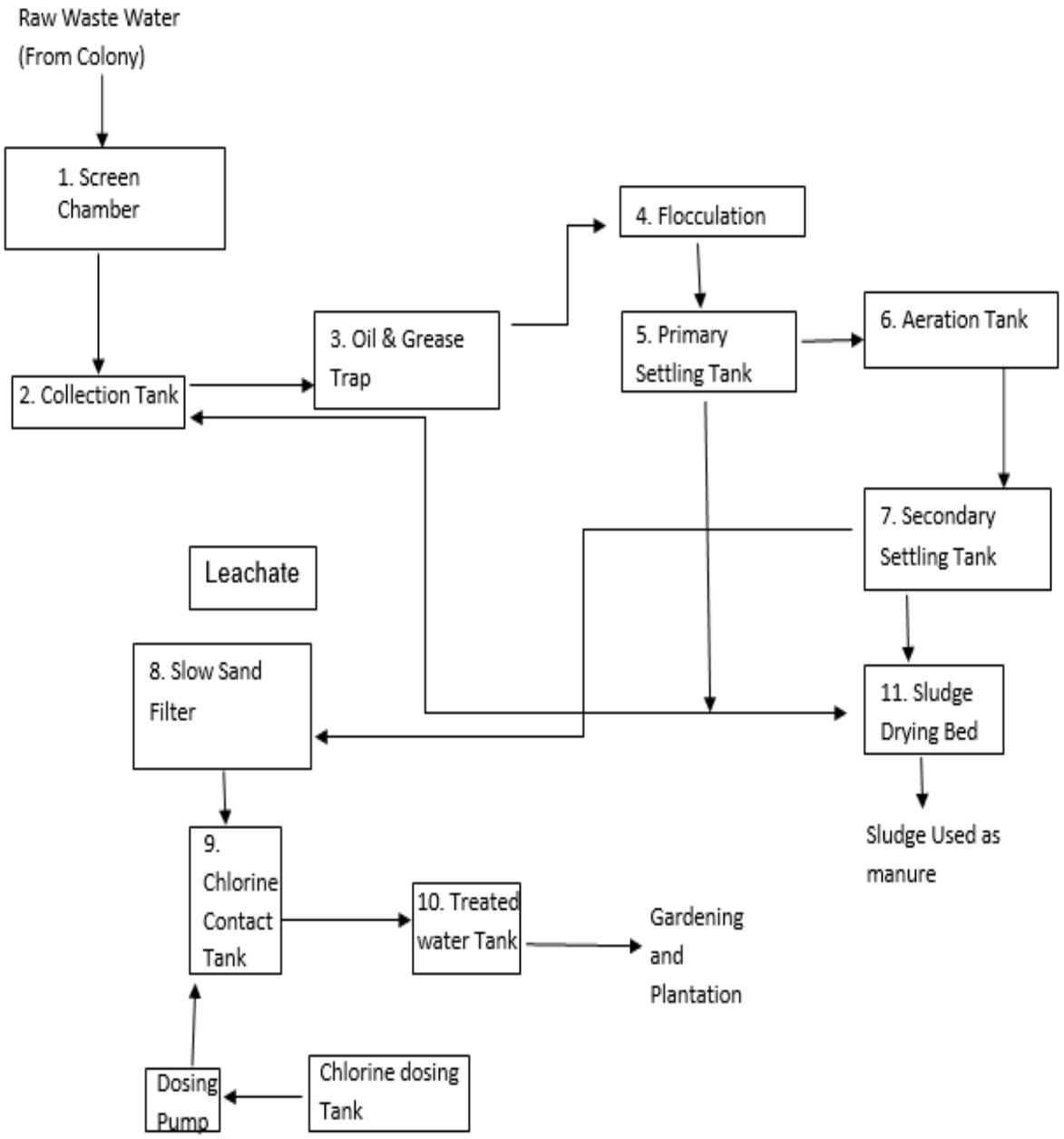


Figure 3: Process flow diagram of STP at Kandla

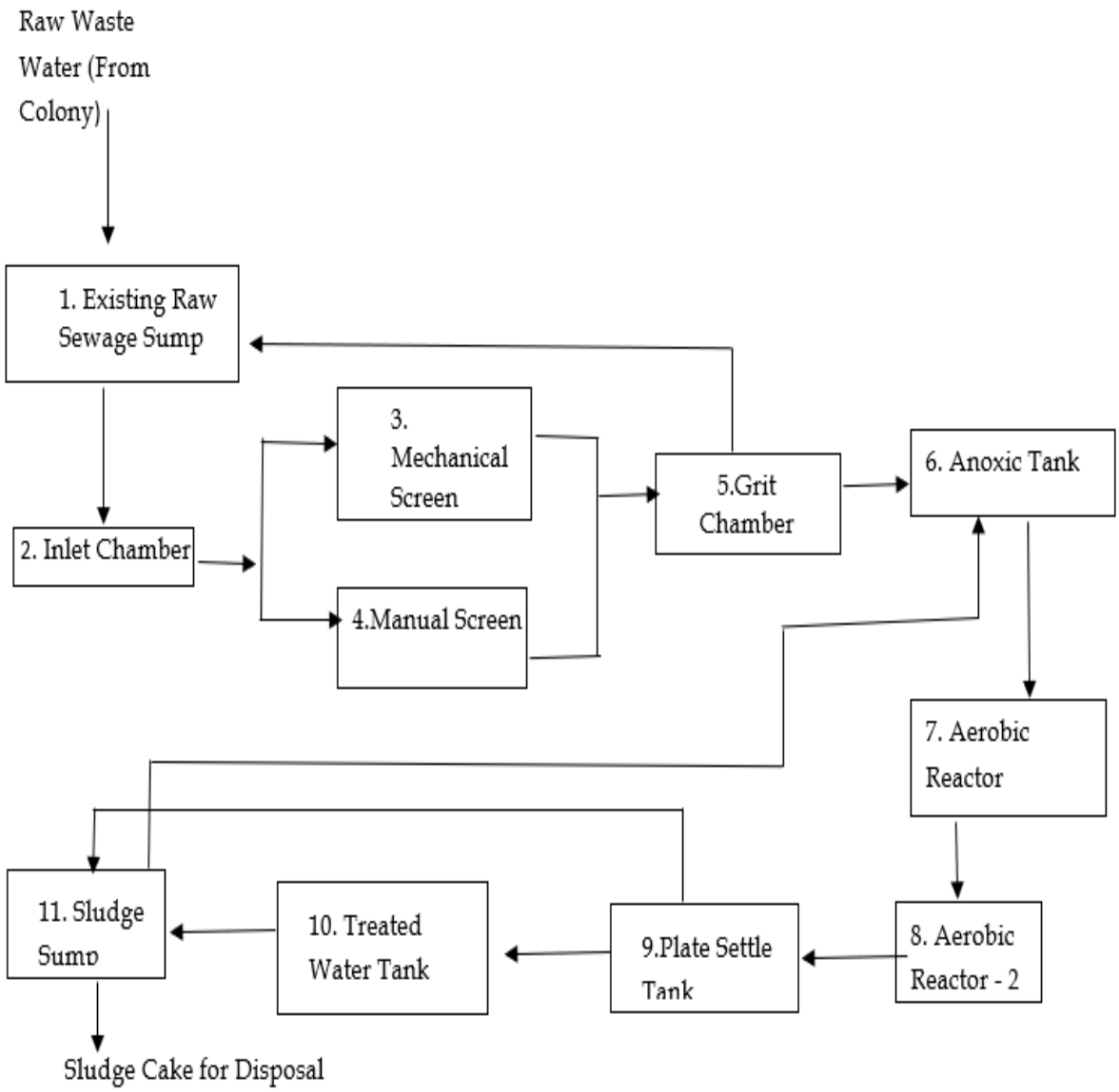


Figure 4: Process flow diagram of STP at Gopalpuri, Kandla

STP at Vadinar

The STP at Vadinar has been built with a treatment capacity of 450 KLD/day. The Consolidated Consent and Authorization (CC&A) issued by the GPCB has been referred for the details of the said STP. The CC&A of the Vadinar STP suggests that the domestic effluent generated shall be treated as per the norms specified in **Table 24**. The treated effluent conforming to the norms shall be discharged on the land within the premises strictly for the gardening and plantation purpose. Whereas, no sewage shall be disposed outside the premises in any manner.

Table 23: Norms of treated effluent as per CC&A of Vadinar STP

Sr. No.	Parameters	Prescribed limits
1.	pH	5.5-9
2.	BOD (3 days at 27°C)	10 mg/L
3.	Suspended Solids	20 mg/L
4.	Fecal Coliform	Desirable 100 MPN/100 ml Permissible 230 MPN/100 ml

Sr. No.	Parameters	Prescribed limits
5.	COD	50 mg/L

The detailed process flow diagram of the Vadinar STP have been mentioned in **Figure 5** as follows:

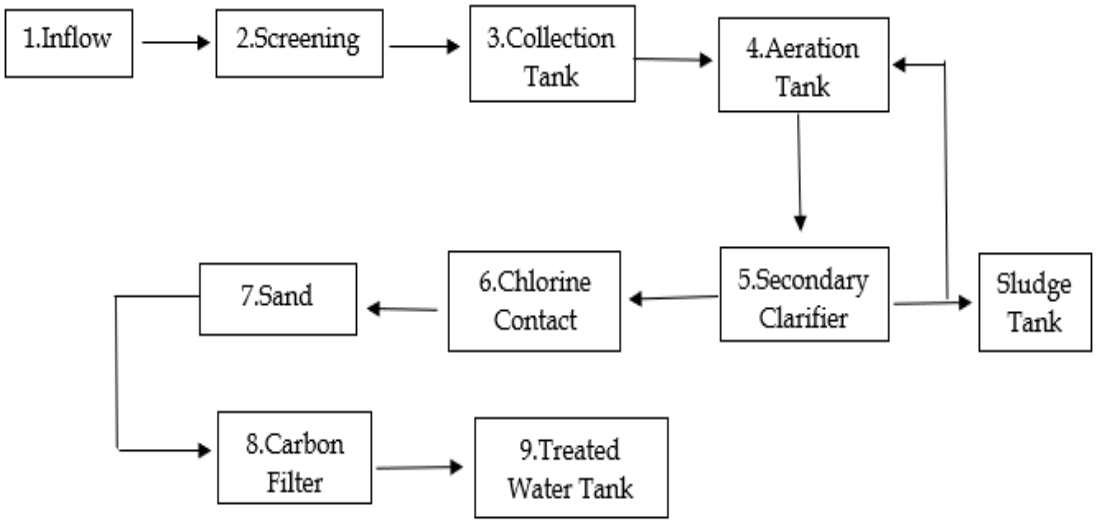
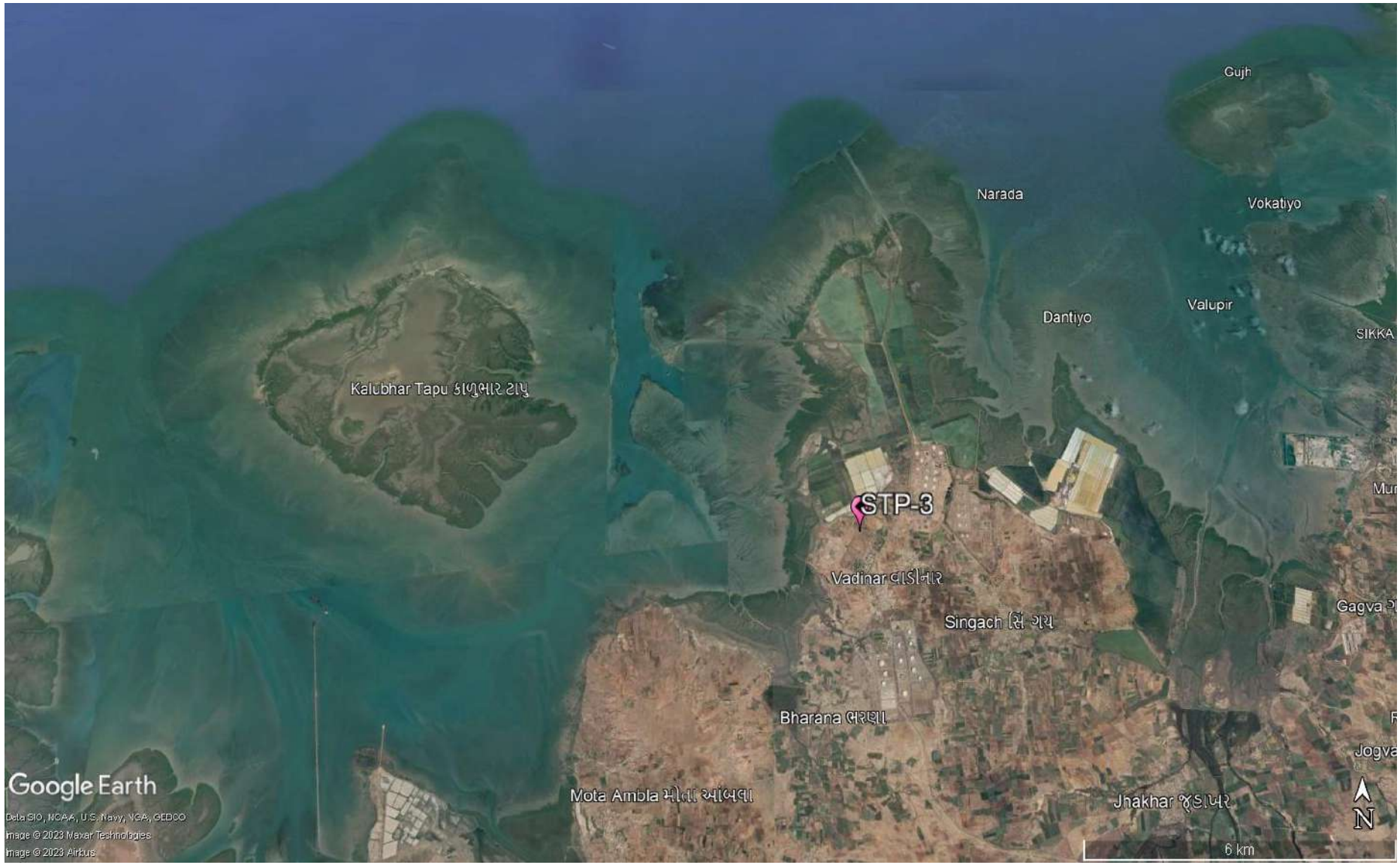


Figure 5: Process flowchart for the STP at Vadinar

The map depicting the locations of STP to be monitored in Kandla and Vadinar have been shown in **Map 14 and 15** as follows:

Map 14: STP Monitoring Locations at Kandla



Map 15: STP Monitoring Locations at Vadinar

Methodology

As per the defined scope by DPA, the sampling and analysis of water samples from the inlet and outlet of the STP's of Kandla and Vadinar are carried out once a week, i.e., four times a month.

The water samples were collected from inlet and the outlet of the STP's and analyzed for physico-chemical and microbiological parameter. Collection and analysis of these samples was carried out as per established standard methods and procedures for the examination of water. The samples were analyzed for selected parameters to establish the existing water quality of the inlet and outlet points of the STP. GEMI has framed its own guidelines for collection of water/wastewater samples titled as 'Sampling Protocol for Water & Wastewater'; which has been approved by the Government of Gujarat vide letter no. ENV-102013-299-E dated 24-04-2014 under the provision of Water (Preservation and Control of Pollution) Act 1974. The sample collection and preservation are done as per the said Protocol. Under the project, the list of parameters to be monitored for the STP have been mentioned in **Table 26** as follows:

Monitoring Frequency

Monitoring is required to be carried out once a week for monitoring location of Kandla and Vadinar i.e., two STP station at Kandla and one STP station at Vadinar. Sample Collected from this location during the monitoring period April 2024 to March 2025.

Table 24: List of parameters monitored for STP's at Kandla and Vadinar

Sr. No.	Parameters	Units	Reference method	Instruments
1.	pH	-	APHA, 23rd edition, 4500- H^+ B, 2017	pH Meter
2.	TDS	mg/L	APHA, 23rd Edition, 2540 C: 2017	Vacuum Pump with filtration assembly and Oven
3.	TSS	mg/L		
4.	DO	mg/L	APHA, 23rd Edition, 4500 C: 2017	Titration Apparatus
5.	COD	mg/L	APHA, 23rd Edition, 5220 B: 2017	Titration Apparatus plus Digester
6.	BOD	mg/L	IS-3025, Part 44, 1993	BOD Incubator plus Titration Apparatus
7.	SAR	meq/L	IS 11624: 2019	Flame Photometer
8.	Total Coliforms	MPN/100ml	IS 1622: 2019	LAF/ Incubator

9.2 Result and Discussion

Analytical results of the STP samples collected from the inlet and the outlet of the STP's of Kandla and Vadinar have been summarized in **Table 26**. Further it was compared with the standard norms specified in the CC&A of the respective STPs.

Table 25: Water Quality of inlet and outlet of STP of Kandla

Sr No.	Parameter	Units	Kandla					Vadinar		
			GPCB Norms (Kandla)	STP-1		STP-2		GPCB Norms (Vadinar)	STP-3	
				Inlet	Outlet	Inlet	Outlet		Inlet	Outlet
				Avg	Avg	Avg	Avg		Avg	Avg
1.	pH	-	**6.5-8.5**	7.15	7.27	7.09	7.38	**5.5-9**	7.22	7.42
2.	TDS	mg/L	-	2388.59	1819.10	1306.73	1246.20	-	435.31	384.33
3.	TSS	mg/L	**100**	63.18	14.04	118.37	14.27	**20**	22.83	4.85
4.	COD	mg/L	-	203.86	80.16	277.22	54.32	**50**	142.19	29.10
5.	DO	mg/L	-	BQL	3.65	BQL	3.80	-	2.67	6.54
6.	BOD	mg/L	**30**	59.18	11.88	84.50	7.52	**10**	41.71	5.09
7.	SAR	meq/L	-	11.80	8.94	6.45	5.89	-	2.31	2.17
8.	Total Coliforms	MPN/ 100ml	**<1000**	1600.00	947.69	1600.00	1261.63	**100-230**	1563.27	1149.39

BQL: Below Quantification limit; Total Suspended Solids (QL=2), Dissolved Oxygen (QL=0.5), Biochemical Oxygen Demand (QL=3 mg/L)

9.3 Data Interpretation and Conclusion

For physicochemical analysis, the treated sewage water was gathered from the Kandla STP, Gopalpuri STP, and Vadinar STP and the analytical results were compared with the standards mentioned in the Consolidated Consent and Authorization (CC&A) by GPCB.

- The average pH at the inlet of STP-1, STP-2, and STP-3 is, respectively, **7.15, 7.09**, and **7.22**. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had an average pH of **7.27, 7.38**, and **7.42**, respectively. Which conform to their respective stipulated norms of 6.5–8.5 at Kandla and 5.5–9 at Vadinar, respectively.
- The average TDS concentrations at the inlet of STP-1, STP-2, and STP-3 are, respectively**, 2388.59, 1306.73**, and **435.31** mg/L. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had an average TDS concentration of **1819.10, 1246.20**, and **384.33** mg/L, respectively.
- The average TSS at the inlet of STP-1, STP-2, and STP-3 is respectively **63.18, 118.37**, and **22.83** mg/L. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had an average TSS of **14.04, 14.27**, and **4.85** mg/L, respectively. Which conform to their respective stipulated norms of 100 mg/L at Kandla and 20 mg/L at Vadinar, respectively, as mentioned in their respective CCA, except in STP-2 at Kandla, which exceeds norms in the Week 2 of April of 2024.
- The average COD at the inlet of STP-1, STP-2, and STP-3 is respectively **203.86, 277.22**, and **142.19** mg/L. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had an average COD concentration of **80.16, 54.32**, and **29.10** mg/L, respectively.
- The average DO concentrations at the inlet of STP-1, STP-2, and STP-3 are, respectively, **BQL, BQL**, and **2.67** mg/L. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had an average DO concentration of **3.65, 3.80**, and **6.54**, mg/L respectively.
- The average BOD at the inlet of STP-1, STP-2, and STP-3 is respectively **59.18, 84.50**, and **41.71** mg/L. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) had an average BOD of **11.88, 7.52**, and **5.09** mg/L, respectively. Which conform to their respective stipulated norms of 30 mg/L at Kandla and 10 mg/L at Vadinar, respectively, as mentioned in their respective CCA.
- The average SAR concentrations at the inlet of STP-1, STP-2 and STP-3 are respectively **11.80, 6.45** and **2.31** meq/L. After treatment, the treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) having Average SAR concentration **8.94, 5.89** and **2.17** meq/L respectively.
- The Total Coliforms was observed to exceed the norms at the locations of the STP-1 & STP-2 for the treated effluent at Kandla and STP-3 at Vadinar.

During the monitoring period, only Total Coliforms were observed to be exceeding the limits at STPs of Kandla and Vadinar while rest of the treated sewage parameters for STP outlet were within norms as specified under the CCA at both the monitoring sites.

Regular monitoring of the STP performance should be conducted on regular basis to ensure adequate treatment as per the norms.

9.4 Remedial Measures:

- The quantum of raw sewage (influent) entering the STP should be monitored by installation of the flow meter. If the quantity of the sewage exceeds the treatment capacity of the treatment plant, then provision of additional capacity of collection sump should be provided.
- The adequacy and efficacy of the stages of Sewage treatment units shall be conducted.
- The results show the presence of total coliforms; hence the method of disinfection (Chlorination) sodium or calcium Hypochlorite can be used.
- Effectiveness of any technology depends on factors such as the specific pollutants in the wastewater, plant size, local regulations, and available resources. There are several processes that may be implemented such as - Advanced oxidation process involve using strong oxidants to break down complex organic compounds. Methods like Fenton's reagent (hydrogen peroxide and iron catalyst) and UV/H_2O_2 treatment can help in reducing COD through oxidation.
- Electrochemical processes like Electrocoagulation (EC) and Electrooxidation (EO) that involve the application of an electric current to facilitate the removal of pollutants through coagulation, flocculation, and oxidation. These methods can be useful for treating sewage containing various pollutants.

CHAPTER 10: MARINE WATER QUALITY MONITORING

10.1 Marine Water

Deendayal Port is one of the largest ports of the country and thus, is engaged in wide variety of activities such as movement of large vessels, oil tankers and its allied small and medium vessels and handling of dry cargo several such activities whose waste if spills in water, can cause harmful effects to marine water quality.

Major water quality concerns at ports include wastewater and leakage of toxic substances from ships, stormwater runoff, etc. This discharge of wastewater, combined with other ship wastes which includes sewage and wastewater from other on-board uses, is a serious threat to the water quality as well as to the marine life. As defined in the scope by DPA, the Marine Water sampling and analysis has to be carried out at a total of eight locations, six at Kandla and two at Vadinar. The marine water sampling has been carried out with the help of Niskin Sampler with a capacity of 5L. The Niskin Sampler is a device used to take water samples at a desired depth without the danger of mixing with water from other depths. Details of the locations to be monitored have been mentioned in **Table 27:**

Table 26: Details of the sampling locations for Marine water

Sr. No.	Location Code		Location Name	Latitude Longitude
1.	Kandla	MW-1	Near Passenger Jetty One	23.017729N 70.224306E
2.		MW-2	Kandla Creek (nr KPT Colony)	23.001313N 70.226263E
3.		MW-3	Near Coal Berth	22.987752N70.227923E
4.		MW-4	Khori Creek	22.977544N 70.207831E
5.		MW-5	Nakti Creek (nr Tuna Port)	22.962588N 70.116863E
6.		MW-6	Nakti Creek (nr NH-8A)	23.033113N 70.158528E
7.	Vadinar	MW-7	Near SPM	22.500391N 69.688089E
8.		MW-8	Near Vadinar Jetty	22.440538N 69.667941E

The map depicting the locations of Marine Water to be sampled and analysed for Kandla and Vadinar have been mentioned in **Map 16 and 17** as follows:

Map 16: Marine Water Monitoring Locations at Kandla

Map 17: Marine Water Monitoring Locations at Vadinar

Methodology

The methodology adopted for the sampling and monitoring of Marine Water was carried out as per the '**Sampling Protocol for Water & Wastewater'** developed by GEMI. The water samples collected through the Niskin Sampler are collected in a clean bucket to reduce the heterogeneity. The list of parameters to be monitored under the project for the Marine Water quality have been mentioned in **Table 28** along with the analysis method and instrument.

Monitoring Frequency

As defined in the scope by DPA, the sampling and analysis of Marine Water has to be carried out once in a month at the eight locations (i.e., six at Kandla and two at Vadinar). For the period April 2024 to March 2025.

Table 27: List of parameters monitored for Marine Water

Sr. No	Parameters	Units	Reference method	Instrument
1.	Electrical Conductivity	µS/cm	APHA, 23rd Edition (Section-2510 B):2017	Conductivity Meter
2.	Dissolved Oxygen (DO)	mg/L	APHA, 23rd Edition, 4500 O C, 2017	Titration Apparatus
3.	pH	-	APHA, 23rd Edition (Section-4500-H+B):2017	pH meter
4.	Color	Hazen	APHA, 23rd Edition, 2120 B: 2017	Color comparator
5.	Odour	-	IS 3025 Part 5: 2018	Heating mantle & odour bottle
6.	Turbidity	NTU	IS 3025 Part 10: 1984	Nephlo Turbidity Meter
7.	Total Dissolved Solids (TDS)	mg/L	APHA, 23rd Edition (Section-2540 C):2017	Vaccum Pump with Filtration Assembly and Oven
8.	Total Suspended Solids (TSS)	mg/L	APHA, 23rd Edition, 2540 D: 2017	
9.	Particulate Organic Carbon	mg/L	APHA, 23rd Edition, 2540 D and E	TOC analyser
10.	Chemical Oxygen Demand (COD)	mg/L	IS-3025, Part- 58: 2006	Titration Apparatus plus Digester
11.	Biochemical Oxygen Demand (BOD)	mg/L	IS-3025, Part 44,1993,	BOD Incubator plus Titration apparatus
12.	Silica	mg/L	APHA, 23rd Edition, 4500 C, 2017	UV- Visible Spectrophotometer
13.	Phosphate	mg/L	APHA, 23rd Edition, 4500 P-D: 2017	
14.	Sulphate	mg/L	APHA, 23rd Edition, 4500 SO4-2 E: 2017	
15.	Nitrate	mg/L	APHA, 23rd Edition, 4500 NO3-B: 2017	
16.	Nitrite	mg/L	APHA, 23rd Edition, 4500 NO2- B: 2017	
17.	Sodium	mg/L	APHA, 23rd Edition, 3500 Na-B: 2017	Flame photometer

Sr. No	Parameters	Units	Reference method	Instrument
18.	Potassium	mg/L	APHA, 23rd Edition, 3500 K-B: 2017	
19.	Manganese	µg/L	APHA, 23rd Edition, ICP Method 3120 B: 2017	ICP-OES
20.	Iron	mg/L	APHA, 23rd Edition, ICP Method 3120 B: 2017	
21.	Total Chromium	µg/L	APHA, 23rd Edition, 3500 Cr B: 2017	
22.	Hexavalent Chromium	µg/L		UV- Visible Spectrophotometer
23.	Copper	µg/L	APHA, 23rd Edition, ICP Method 3120 B: 2017	ICP-OES
24.	Cadmium	µg/L		
25.	Arsenic	µg/L		
26.	Lead	µg/L		
27.	Zinc	mg/L		
28.	Mercury	µg/L	EPA 200.7	
29.	Floating Material (Oil grease scum, petroleum products)	mg/L	APHA, 23rd Edition, 5520 C: 2017	Soxhlet Assembly
30.	Total Coliforms (MPN)	MPN/ 100ml	IS 1622: 2019	LAF/ Incubator

10.2 Result and Discussion

The quality of the Marine water samples collected from the locations of Kandla and Vadinar during the monitoring period has been summarized in the **Table 29**. The said water quality has been represented in comparison with the standard values as stipulated by CPCB for Class SW-IV Waters.

Table 28: Results of Analysis of Marine Water Sample for the sampling period

Parameters	Primary Water Quality Criteria for Class SW-IV Waters	Kandla																			Vadinar					
		MW-1			MW-2			MW-3			MW-4			MW-5			MW-6			MW-7			MW-8		
		Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Density (kg/m³)	-	1.018	1.023	1.021	1.02	1.024	1.021	1.02	1.023	1.02	1.019	1.023	1.02	1.02	1.023	1.021	1.02	1201	101.01	1.02	1.023	1.021	1.021	1.023	1.021
pH	6.5-9.0	7.14	8.19	7.62	7.89	8.33	8.15	7.03	8.19	7.61	7.8	8.88	8.39	7.59	9.51	8.31	7.81	8.61	8.04	7.12	8.23	8.00	7.25	8.59	8.11
Colour (Hazen)	No Noticeable	5	10	5.41	5	10	5.41	5	5	5	5	5	5	5	10	5.41	5	10	5.41	1	5	4.66	1	5	4.33
EC (µS/ cm)	-	51200	62600	53650	51400	58100	54208.33	51100	59400	55066.6	51500	60500	54841.66	49800	61500	54691.66	51400	58900	54500	51500	55500	54366.66	51600	55100	53833.33
Turbidity (NTU)	-	94	265	169.72	120	308	199.66	4.12	290	207.49	3.42	323	192.36	130	201	166.90	110	424	216.83	3.8	11.7	5.73	3.35	18.2	6.64
TDS (mg/L)	-	33326	42638	36817.66	32783	39638	37818.08	32156	41264	36193.25	33142	41884	37190.25	33586	42728	37819.16	32589	43544	37118.83	31542	37672	35128.91	32141	37296	35298.25
TSS (mg/L)	-	338	744	433.66	152	519	422.75	115	568	406.16	195	432	379.58	325	608	416.5	348	499	442.58	12	385	235.83	14	365	259.08
COD (mg/L)	-	32.7	68.1	54.30	30.9	72.11	54.55	30.2	89.4	57.69	30.89	70.54	54.55	31.5	88.5	61.29	32.4	80.9	61.16	46.89	57.9	52.19	35.5	57.84	50.18
DO (mg/L)	3.0 mg/L	5.5	6.9	6.2	6.1	6.7	6.3	5.1	6.8	6.15	5.6	7.2	6.26	5.6	7.3	6.46	5.4	6.8	6.12	6.1	7.6	6.866	5.2	7.8	6.65
BOD (mg/L)	5.0 mg/L	4.26	8.36	7.8	3.67	8.74	7.97	5.59	8.65	7.95	3.78	8.91	8.06	5.53	11.02	8.98	5.05	10.14	9.15	3.62	7.95	7.14	5.85	7.85	7.19
Oil & Grease (mg/L)	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Sulphate (mg/L)	-	2145.2	3444.7	2535.20	2467.1	3473.1	2693.72	2410.1	3160.3	2638.62	2456.3	3452.6	2854.31	2463.5	3344	2697.55	2415.6	3045.9	2644.17	1689.6	3041.8	2299.62	1348.7	3159.6	2505.27
Nitrate (mg/L)	-	3.125	5.611	4.023	2.268	4.847	3.43	3.4	5.426	4.23	2.98	5.486	4.60	3.671	5.2	4.409	3.357	4.659	4.10	1.658	3.41	2.88	1.523	3.42	2.46
Nitrite (mg/L)	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Phosphate (mg/L)		0.901	0.901	0.901	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Silica (mg/L)	-	1.69	4.23	2.7125	1.68	3.67	2.59	0.93	3.27	2.42	0.79	3.75	2.71	2.45	5.53	3.43	1.33	3.94	2.30	0.69	1.8	0.92	0.52	1.6	0.805
Sodium (mg/L)	-	9235	9754	9481.36	6534	9643	8998.72	9415	9887	9615.18	8426	9541	9056.54	9103	9654	9386.09	8975	9872	9353.45	9341	9845	9515.7	9246	9612	9453
Potassium (mg/L)	-	315	444	365.37	254	388	340.16	275	454	353.34	234	428	341.03	321	419	343.47	243.52	441	317.14	314	616	378.79	311	688	380.32
Hexavalent Chromium (mg/L)	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Odour	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Arsenic (mg/L)	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Cadmium (mg/L)	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Copper (mg/L)	-	BQL	BQL	BQL	0.0062	6.22	1.55	BQL	BQL	BQL	BQL	BQL	BQL	0.0066	6.68	2.67	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Iron (mg/L)	-	1.523	4.477	1.89	0.97	2.281	1.85	0.586	3.887	1.93	0.378	2.861	1.69	1.619	4.058	1.982	1.152	2.876	1.78	0.125	0.586	0.36	0.122	0.645	0.36
Lead (mg/L)	-	0.002	3.16	1.08	0.0029	3.85	1.26	0.002	2.95	0.98	0.002	2.984	1.00	0.002	2.94	0.95	0.002	3.36	1.09	0.002	2.564	0.95	0.002	2.984	1.16
Manganese (mg/L)	-	0.082	98.12	31.63	0.11	135.54	48.31	0.11	129.45	33.94	0.091	122.36	30.57	0.075	96.57	29.49	0.1	131.64	41.08	0.0425	97.62	30.67	0.088	99.45	32.82
Total Chromium (mg/L)	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Zinc (mg/L)	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Mercury (mg/L)	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Particulate Organic	-	0.69	4.82	1.17	0.51	1.27	0.74	0.38	3.92	0.8	0.72	2.86	0.95	0.95	3.26	1.42	1.12	4.28	1.56	0.06	0.87	0.635	0.51	0.82	0.626

Parameters	Primary	Kandla																		Vadinar					
Carbon (mg/L)																									
Total Coliform* (MPN/100ml)	500/100 ml	8	26	19.91	2	25	17.08	2	29	17.16	5	1600	146.46	10	27	16.41	4	25	17.66	6	18	10.36	9	24	16.83
Floating Material (Oil grease scum, petroleum products) (mg/L)	10 mg/L	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL

10.3 Data Interpretation and Conclusion

The Marine water quality of Deendayal Port Harbor waters at Kandla and Vadinar has been monitored for various physico-chemical and biological parameters during the monitoring period. The detailed interpretation of the parameters in comparison to the Class SW-IV for Harbour Waters is as follows:

- **Density** at Kandla was observed in the range of 1.018 to 1.024 kg/m³, with the average of 1.022 kg/m³. Whereas for the location of Vadinar, it was observed in the range of 1.02 to 1.023 kg/m³, with the average of 1.021 kg/m³.
- **pH** at Kandla was observed in the range of **7.03 to 9.51**, with the average pH as **8.02**. Whereas for the locations of Vadinar, it was observed in the range of be **7.12** to **8.59**, with the average pH as **8.05**. For the monitoring location of both the study areas, pH was found to comply with the norms of 6.5-9.0 except location MW-5 (Nakti Creek (nr Tuna Port)).
- **Color** range varied from 1 to 10 Hazen at all the monitoring locations in Kandla, and for Vadinar, it varied from 1 to 5 Hazen.
- **Electrical conductivity (EC)** was observed in the range of 49,800 to 62,600 µS/cm, with the average EC as 54493.05 µS/cm for the locations of Kandla, whereas for the locations of Vadinar, it was observed in the range of 51,500 to 55,500 µS/cm, with the average EC as 54,100 µS/cm.
- For all monitoring locations of Kandla the value of Turbidity was observed in the range of **3.42 to 424** NTU, with average value of 192.16 NTU. For Vadinar it ranges from **3.35 to 18.2** NTU, with average of 6.18 NTU. Materials that cause water to be turbid include clay, silt, finely divided organic and inorganic matter, soluble coloured organic compounds, plankton and microscopic organisms. Turbidity affects the amount of light penetrating to the plants for photosynthesis.
- For the monitoring locations at Kandla the value of **Total Dissolved Solids (TDS)** ranged from **32,156 to 43,544 mg/L**, with an average value of **37159.54** mg/L. Similarly, at Vadinar, the TDS values ranged from **31,542 to 37,672 mg/L**, with an average value of **35,213** mg/L.

- **TSS** values in the studied area varied between **115 to 744 mg/L** at Kandla and **12 to 385 mg/L** at Vadinar, with the average value of **416.87** mg/L and **247.45** mg/L respectively for Kandla and Vadinar.
- **COD** varied between **30.2 to 89.4 mg/L** at Kandla and **35.5 to 57.9 mg/L** at Vadinar, with the average value as **57.25** mg/L and **51.18** mg/L respectively for Kandla and Vadinar.
- **DO** level in the studied area varied between **5.1 to 7.3 mg/L** at Kandla and **5.2 to 7.8 mg/L** at Vadinar, with the average value of **6.25** mg/L and **6.75** mg/L respectively for Kandla and Vadinar. Which represents that the marine water is suitable for marine life.
- **BOD** observed was observed in the range of **3.67 to 11.02 mg/L**, with average of **8.32** mg/L for the location of Kandla and for the locations of Vadinar, it was observed in the range of **3.62 to 7.95 mg/L**, with an average value of **7.17** mg/L.
- **Sulphate** concentration in the studied area varied between **2145.2 to 3473.1 mg/L** at Kandla and **1348.7 to 3159.6 mg/L** at Vadinar. The average value observed at Kandla was **2677.26** mg/L, whereas **2402.45** mg/L was the average value of Vadinar. Sulphate is naturally formed in inland waters by mineral weathering or the decomposition and combustion of organic matter.
- **Nitrate** in the study area was observed in the range of **2.26 to 5.61 mg/L**, with the average of **4.13** mg/L. Whereas for the Vadinar the concentration of Nitrate was observed in the range of **1.523 to 3.42** mg/L, with the average **2.67** mg/L.
- **Phosphate** For the Kandla and Vadinar the concentration of Phosphate was observed Below Quantification Limit During whole monitoring period except MW-1 (Near Passenger Jetty One)
- **Silica** in the study area was observed in the range of **0.79 to 5.53 mg/L**, with the average of **2.69** mg/L. Whereas for the Vadinar the concentration of silica was observed in the range of **0.52 to 1.8** mg/L, with the average **0.86** mg/L.
- In the study area of Kandla the concentration of **Potassium** varied between **234 to 454 mg/L** and **311 to 688 mg/L** at Vadinar, with the average value as **343.42** mg/L and **379.55** mg/L respectively for Kandla and Vadinar.
- **Sodium** in the study area varied between **6534 to 9887 mg/L**, with average of **9315.22** mg/L, at Kandla whereas at Vadinar its value recorded within range of **9246 to 9845 mg/L,** with the average of **9484.35** mg/L.
- **Odour** was observed 1 for all locations of Kandla and Vadinar.
- **Iron** in the studied area varied between **0.378 to 4.47 mg/L**, with the average of **1.85** mg/L, at Kandla, and for Vadinar value were recorded within range of **0.122** to **0.645** mg/L, with average value of **0.366** mg/L.
- **Lead** concentration varied **0.002 to 0.00385 mg/L**, with an average of **0.00278** mg/L at Kandla. At Vadinar location within range of **0.00200** to **0.00298** mg/L with an average **1.06** mg/L
- **Manganese** in the studied area varied between **0.075 to 135.54 mg/L**, with the average of **35.84** mg/L, at Kandla and for Vadinar, recorded value was observed within the range of **0.042** to **99.45 mg/L**, with the average of **31.75** mg/L.

- **Particulate Organic Carbon** in the study area was observed in the range of **0.38 to 4.82**, with the average value of **1.11**. the maximum spike of 900 is only observed once in the period of April to May 2023 during whole monitoring period. Whereas for the Vadinar, the value observed was Within the range of **0.06** to **0.87**, with the average of **0.63**.
- **Oil & Grease, Nitrite, Hexavalent Chromium, Arsenic, Copper, Cadmium, Total Chromium, Zinc, Mercury and Floating Material (Oil grease scum, petroleum products)** were observed to have concentrations **"Below the Quantification Limits (BQL)"** for most of the locations of Kandla and Vadinar, majority of time during whole monitoring period.
- **Total Coliforms** were detected complying with the specified norm of 500 MPN/100ml for all the locations of Kandla and Vadinar, except on location MW-4 in the month of June-July 2024.

During the Monitoring period, marine water samples were analysed and found in line with Primary Water Quality criteria for class-IV Waters (For Harbour Waters) Except BOD.

To address the high Biochemical Oxygen Demand (BOD) levels near Kandla Port's creeks, a combined strategy is essential. Improving wastewater treatment systems and strictly enforcing pollution control regulations for industries and local communities is crucial to ensure that organic pollutants are removed before being released into the water. Since the narrow creek structure limits natural self-cleaning, it is also important to improve water circulation, which could be done through targeted dredging or adjusting the creek's shape to allow better water flow. In addition, encouraging sustainable practices among port operations and local residents will help reduce waste and prevent pollution at the source, supporting long-term improvements in water quality and marine health.

However, as a safeguard towards marine water pollution prevention, appropriate regulations on ship discharges and provision of reception facilities are indispensable for proper control of emissions and effluent from ships. Detection of spills is also important for regulating ship discharges. Since accidental spills are unavoidable, recovery vessels, oil fences, and treatment chemicals should be prepared with a view to minimizing dispersal. Proper contingency plans and a prompt reporting system are keys to prevention of oil dispersal. Periodical clean-up of floating wastes is also necessary for preservation of port water quality.

CHAPTER 11: MARINE SEDIMENT QUALITY MONITORING

11.1 Marine Sediment Monitoring

Marine sediment, or ocean sediment, or seafloor sediment, are deposits of insoluble particles that have accumulated on the seafloor. These particles have their origins in soil and rocks and have been transported from the land to the sea, mainly by rivers but also by dust carried by wind. The unconsolidated materials derived from pre-existing rocks or similar other sources by the process of denudation are deposited in water medium are known as sediment. For a system, like a port, where large varieties of raw materials and finished products are handled, expected sediment contamination is obvious.

The materials or part of materials spilled over the water during loading and unloading operations lead to the deposition in the harbour water along with sediment and thus collected as harbour sediment sample. These materials, serve as receptor of many trace elements, which are prone to environment impact. In this connection it is pertinent to study the concentration and distribution of environmentally sensitive elements in the harbour sediment. However, human activities result in accumulation of toxic substances such as heavy metals in marine sediments. Heavy metals are well-known environmental pollutants due to their toxicity, persistence in the environment, and bioaccumulation. Metals affect the ecosystem because they are not removed from water by self-purification, but accumulate in sediments and enter the food chain.

Methodology

As defined in the scope by DPA, the Marine Sediment sampling is required to be carried out once in a month at total eight locations, i.e., six at Kandla and two at Vadinar. The sampling of the Marine Sediment is carried out using the Van Veen Grab Sampler (make Holy Scientific Instruments Pvt. Ltd). The Van Veen Grab sampler is an instrument to sample (disturbed) sediment up to a depth of 20-30 cm into the sea bed. While letting the instrument down on the seafloor, sediment can be extracted. The details of locations of Marine Sediment to be monitored under the study are mentioned in **Table 30** as follows:

Table 29: Details of the sampling locations for Marine Sediment

Sr. No	Location Code		Location Name	Latitude Longitude
1.	Kandla	MS-1	Near Passenger Jetty One	23.017729N 70.224306E
2.		MS-2	Kandla Creek	23.001313N 70.226263E
3.		MS-3	Near Coal Berth	22.987752N 70.227923E
4.		MS-4	Khori Creek	22.977544N 70.207831E
5.		MS-5	Nakti Creek (near Tuna Port)	22.962588N 70.116863E
6.		MS-6	Nakti Creek (near NH-8A)	23.033113N 70.158528E
7.	Vadinar	MS-7	Near SPM	22.500391N 69.688089E
8.		MS-8	Near Vadinar Jetty	22.440538N 69.667941E

The map depicting the locations of Marine Sediment sampling at Kandla and Vadinar have been mentioned in **Map 18 and 19** as follows:

Map 18: Marine Sediment Monitoring Location at Kandla

Map 19: Marine Sediment Monitoring Locations at Vadinar

The list of parameters to be monitored under the projects for the Marine Sediment sampling been mentioned in **Table 30** as follows:

Table 30: List of parameters to be monitored for Sediments at Kandla and Vadinar

Sr. No.	Parameters	Units	Reference method	Instruments
1.	Texture		Methods Manual Soil Testing in India January 2011,01	Hydrometer
2.	Organic Matter	%	Methods Manual Soil Testing in India January, 2011, 09. Volumetric method (Walkley and Black, 1934)	Titration apparatus
3.	Inorganic Phosphates	mg/Kg	Practical Manual Chemical Analysis of Soil and Plant Samples, ICAR-Indian Institute of Pulses Research 2017	UV- Visible Spectrophotometer
4.	Silica	mg/Kg	EPA METHOD 6010 C & IS: 3025 (Part 35) – 1888, part B	
5.	Phosphate	mg/Kg	EPA Method 365.1	
6.	Sulphate as SO^{4-}	mg/Kg	IS: 2720 (Part 27) - 1977	
7.	Nitrite	mg/Kg	ISO 14256:2005	
8.	Nitrate	mg/Kg	Methods Manual Soil Testing in India January, 2011, 12	
9.	Calcium as Ca	mg/Kg	Methods Manual Soil Testing in India January 2011, 16.	Titration Apparatus
10.	Magnesium as Mg	mg/Kg	Method Manual Soil Testing in India January 2011	
11.	Sodium	mg/Kg	EPA Method 3051A	Flame Photometer
12.	Potassium	mg/Kg	Methods Manual Soil Testing in India January, 2011	
13.	Aluminium	mg/Kg	EPA Method 3051A	ICP-OES
14.	Chromium	mg/Kg		
15.	Nickel	mg/Kg		
16.	Zinc	mg/Kg		
17.	Cadmium	mg/Kg		
18.	Lead	mg/Kg		
19.	Arsenic	mg/Kg		
20.	Mercury	mg/Kg		

11.2 Result and Discussion

The quality of Marine Sediment samples collected from the locations of Kandla and Vadinar during the monitoring period of April 2024 to March 2025 has been summarized in the **Table 31.**

Table 31: Summarized result of Marine Sediment Quality

Parameters	Kandla																		Vadinar					
	MS-1			MS-2			MS-3			MS-4			MS-5			MS-6			MS-7			MS-8		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Inorganic Phosphate (kg/ ha)	4.41	1.75	2.87	10.27	2.14	4.87	23.58	3.12	9.81	8.63	2.88	4.69	15.6	2.56	6.74	17.8	1.71	6.765	3.54	1.82	2.28	2.65	1.06	1.77
Phosphate (mg/Kg)	1123.5	288.72	562.67	1862.2	329.62	873.52	1586.7	248.61	801.42	653.7	363.18	481.22	822.12	319.45	499.47	843.26	213.507	548.24	354.18	203.5	256.50	339.31	210.26	279.1
Organic Matter (%)	1.24	0.042	0.91	1.68	0.2	1.01	1.17	0.21	0.81	1.72	0.21	1.00	1.36	0.63	0.92	1.43	0.33	1.01	1.95	0.58	1.02	1.52	0.63	1.00
Sulphate as SO^{4-} (mg/Kg)	190.09	125.7	165.71	193.25	146.88	177.46	218.45	133.9	179.88	180.24	122.57	151.14	295.41	90.28	177.03	228.96	101.26	169.57	152.36	81.56	107.38	144.55	105.49	119.24
Calcium as Ca (mg/Kg)	3745	2045.86	3156.21	3929	2357.14	3374.45	4600	1789.52	3485.58	4332	1458.63	3633.65	5200	1456.37	3443.86	4799	2158.47	3658.14	3600	2100	2766.41	3800	2100	2807.21
Magnesium as Mg (mg/Kg)	2012	1568.34	1828.79	2740	1654.87	2167.55	2541	1785.24	2079.33	2999	1453.28	2490.21	2655	1421.1	2172.59	2789	1085.2	2038.13	1766	976	1324.26	2875	1080	1605.27
Silica (g/Kg)	582.9	514.09	545.36	540.12	456.2	513.83	542.19	421.3	503.83	546.62	290.78	453.22	562.13	236.4	447.86	564.17	323.56	474.12	527.8	281.5	440.32	534.29	402.5	483.86
Nitrite (mg/Kg)	0.76	0.25	0.56	0.84	0.35	0.70	0.81	0.36	0.59	0.79	0.41	0.62	0.89	0.41	0.68	0.89	0.29	0.67	1.24	0.1	0.48	0.6	0.24	0.38
Nitrate (mg/Kg)	21.48	6.11	11.31	18.36	6.87	10.76	29.52	4.88	13.72	23.63	5.13	11.28	19.67	5.42	9.21	18.72	7.08	11.25	17.81	6.88	12.37	13.3	4.92	8.72
Sodium (mg/Kg)	8974	3481	6743.75	12876	2356	7817.41	8651	2614	6459.33	15670	3125	9946.41	9149	1055	3661.66	13564	1256	7888.08	10975	5946	7934.08	12586	7713	9474.08
Potassium (mg/Kg)	2874	2084	2462.43	2584	1845.4	2282.27	3269	2375	2950.05	3684	3071.2	3427.54	2922	2549	2759.64	6376	2541.3	3495.67	5658	2350	3287.67	4681	1172	2777.67
Aluminium (mg/Kg)	7523.41	3.22	2825.32	8461.48	3.47	2954.44	9234.36	3.99	3243.54	10648.63	3.95	3826.43	8642.29	4.55	2906.9	12327.68	5.21	3643.27	11288.3	5.28	3543.59	12643.2	4.77	4179.45
Mercury (mg/Kg)	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
Texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Silt loam	Sandy loam	Silt loam	Sandy loam	Sandy loam	Sandy loam	Silt loam	Sandy loam	Silt loam	Sandy loam	Silt loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Loam	Loam	Loam

11.3 Data Interpretation and Conclusion

The Marine sediment quality at Kandla and Vadinar has been monitored for various physico-chemical parameters during the monitoring April 2024 to March 2025. The detailed interpretation of the parameters is given below:

- **Inorganic Phosphate** for the sampling period was observed in range of **1.71 to 23.58** Kg/ha for Kandla. Whereas for Vadinar the value observed Within range of **1.06** to **3.54** Kg/ha. For Kandla and Vadinar the average value of Inorganic Phosphate was observed **5.96** and **2.03** Kg/ha respectively.
- The concentration of **Phosphate** was observed in range of **213.50 to 1862.2 mg/Kg** for Kandla and for Vadinar the value observed within the range of **203.5** to **354.18** mg/Kg. For Kandla and Vadinar the average concentration of Phosphate was observed **627.75** and **267.80** mg/Kg respectively.
- The **Organic Matter** for the sampling period was observed in the range of **0.042 to 1.72** % for Kandla with the average value of **0.94** % and for Vadinar the value recorded Within range of **0.58 to 1.95** %, with average concentration as **1.01** %.
- The concentration of **Sulphate** was observed in the range of **90.28 to 295.41 mg/Kg** for Kandla and for Vadinar the value observed Within range of **81.56** to **152.36** mg/Kg. For Kandla and Vadinar the average value of Sulphate was observed **170.13** and **113.31** mg/Kg respectively.
- The value of **Calcium** was observed in the range of **1456.37 to 5200 mg/Kg** for Kandla and for Vadinar the value observed within the range of **2100** to **3800** mg/Kg. The average value of Calcium for the monitoring period was observed **3458.65** mg/Kg and **2786.81** mg/Kg at Kandla and Vadinar, respectively.
- The value of **Magnesium** for the sampling period was observed in the range of **1085.2 to 2999 mg/Kg** for Kandla and for Vadinar the value observed Within the range of **976** to **2875** mg/Kg. For Kandla and Vadinar the average value of Magnesium was observed **2129.43** mg/Kg and **1464.76** mg/Kg respectively.
- For the sampling period **Silica** was observed in the range of **236.4 to 582.9 mg/Kg** for Kandla with average value **489.70** mg/Kg and for Vadinar the value observed within the range of **281.5** and **534.29** mg/Kg with average **462.09** mg/Kg.
- The value of **Nitrate** was observed in the range of **4.88 to 29.52 mg/Kg** for Kandla with average value **11.25** mg/Kg and for Vadinar the value observed within the range of **4.92** to **17.81** mg/Kg. with average **10.54** mg/Kg.
- The value of **Nitrite** was observed in the range of **0.25 to 0.89 mg/Kg** for Kandla with average value **0.64** mg/Kg and for Vadinar the value observed to be within the range of **0.1** to **1.24** mg/Kg, with average **0.43** mg/Kg.
- The value of **Sodium** was observed in the range of **1055 to 15670 mg/Kg** for Kandla with average value **7086.11** mg/Kg and for Vadinar the value observed within the range of **5946** and **12586 mg/Kg**, with average **8704.08 mg/Kg**.
- The value of **Potassium** was observed in the range of **1845.4 to 6376 mg/Kg** for Kandla with average value **2896.26** mg/Kg and for Vadinar the value observed within range of **1172** to **5658** mg/Kg, with average **3032.67** mg/Kg.

- The value of **Aluminium**, was observed in the range of **3.22 to 12327.68 mg/Kg** for Kandla with average value **3233.33** mg/Kg and for Vadinar the value observed within the range of **4.77** to **12643.2** mg/Kg, with average **3861.52** mg/Kg.
- Mercury levels were measured at Kandla and Vadinar, and they were found to be "**below the quantification limit**" at both locations. Mercury was found to be below the quantitation limit most of the time during the monitoring period.
- Texture was observed to be "**Sandy Loam**" at location MS-1, MS-2, MS-4, MS-6 and MS-7 "**Silt loam"** at location MS-3 & MS-5 in Kandla. "**loam"** at location MS-8 in Vadinar during sampling period.

Heavy Metals

The sediment quality of Kandla and Vadinar has been compared with respect to the Average Standard guideline applicable for heavy metals in marine sediment specified by EPA have been mentioned in **Table 32.**

Table 32: Standard Guidelines applicable for heavy metals in sediments

Sr. No.	Metals	Sediment quality (mg/kg)			Source
		Not polluted	Moderately polluted	Heavily polluted	
1.	As	<3	3-8	>8	EPA
2.	Cu	<25	25-50	>50	
3.	Cr	<25	25-75	>75	
4.	Ni	<20	20-50	>50	
5.	Pb	<40	40-60	>60	
6.	Zn	<90	90-200	>200	
7.	Cd	-	<6	>6	
ND = Not Detected					

(Source: G Perin et al. 1997)

Table 33: Comparison of Heavy metals with Standard value in Marine Sediment

Parameters	Kandla																		Vadinar					
	MS-1			MS-2			MS-3			MS-4			MS-5			MS-6			MS-7			MS-8		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Arsenic (mg/Kg)	4.92	3.12	4.34	5.48	2.51	4.23	5.2	4.07	4.85	5.68	3.22	4.50	5.16	2.12	3.94	5.33	1.12	3.99	2.83	1.38	2.01	4.24	2.24	3.28
Copper (mg/Kg)	52.78	3.11	24.00	51.69	3.42	22.81	56.74	4.07	24.40	59.85	3.86	26.45	53.25	3.76	23.88	58.93	4.16	30.03	52.4	4.26	27.71	58.46	3.67	26.14
Chromium (mg/Kg)	7555.21	48.1	2733.22	6678.95	35.4	2397.40	9348.52	33.66	3228.10	8945.36	45.6	3206.68	8679.85	46.8	3052.02	9875.15	50.009	3429.67	11393.37	48.941	3944.06	12703.75	21.8	4243.68
Nickel (mg/Kg)	43.35	24.87	32.63	39.6	21.79	29.84	28.45	20.41	25.52	32.26	25.23	28.62	28.63	21.56	25.19	36.4	21.23	28.78	35.57	12.93	21.12	42.38	24.37	28.67
Lead (mg/Kg)	6.32	4.47	5.65	6.89	5.02	6.06	7.32	2.18	5.39	6.89	5.11	6.23	7.43	4.66	6.00	7.08	4.2	5.78	4.76	2.49	3.67	6.21	4.494	5.20
Zinc (mg/Kg)	72.65	55.87	65.03	62.45	51.27	56.10	69.54	45.7	60.26	84.62	42.68	69.51	65.78	49.82	57.15	66.66	40.65	57.42	48.86	21.55	32.62	67.22	35.07	44.07
Cadmium (mg/Kg)	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL

- **Arsenic** was observed in the range of **1.12 to 5.68 mg/Kg** for Kandla with average value **4.31** mg/Kg and for Vadinar the value observed within range of **1.38** to **4.24** mg/Kg, with average of **2.65** mg/Kg. during monitoring period majority of time arsenic concentration found within moderately polluted class on both study area.
- **Copper** was observed in the range of **3.11 to 59.85 mg/Kg** for Kandla with average value **25.26** mg/Kg and for Vadinar the value observed within the range of be **3.67** to **58.46** mg/Kg, with average **26.93** mg/Kg. With reference to the guidelines mentioned in table 32, the sediment quality with respect to copper falls in Moderately polluted class.
- **Chromium** was observed in the range of **33.66 to 9875.15 mg/Kg** for Kandla with average value **3007.85** mg/Kg and for Vadinar the value observed within the range of **21.8** to **12703.75** mg/Kg, with average **4093.87** mg/Kg. With reference to the guidelines mentioned in table 32, the sediment quality with respect to Chromium falls in Heavily polluted class.
- **Nickel** was observed in the range of **20.41 to 43.35 mg/Kg** for Kandla with average value **28.43** mg/Kg and for Vadinar the value observed within range of **12.93** to **42.38** mg/Kg, with average **24.89** mg/Kg. With reference to the guidelines mentioned in table 32, the sediment quality with respect to nickel falls in moderately polluted class.

- **Lead** was observed in the range of **2.18 to 7.43 mg/Kg** for Kandla with average value **5.85** mg/Kg and for Vadinar the value observed within the range of **2.49** and **6.21** mg/Kg, with average **4.43** mg/Kg. With reference to the guidelines mentioned in table 32, the sediment quality with respect to lead falls in not polluted class.
- **Zinc** was observed in the range of **40.65 to 84.62 mg/Kg** for Kandla with average value **60.91** mg/Kg and for Vadinar the value observed within the range of **21.55** to **67.22** mg/Kg, with average **38.34** mg/Kg. With reference to the guidelines mentioned in table 32, the sediment quality with respect to zinc falls in non-polluted class.
- **Cadmium** was observed **BQL** for both site Kandla and Vadinar during of April to March 2024-2025. With reference to the guidelines mentioned in table 32, the sediment quality with respect to cadmium falls in non-polluted class.

Analysis of the sediments indicates moderate pollution. However, it may be noted that, the sediments are highly dynamic being constantly deposited and carried away by water currents. Hence maintaining the quality of sediments is necessary as it plays a significant role in regulating the quality of the marine water and the marine ecology.

The presence of anthropic activity in the coastal areas has an effect upon the marine water and sediment. One of the primary risks associated with contaminated sediments is bioaccumulation in benthic organisms, which is a route of entry into the food chain. Generally adopted sediment remediation approaches include dredging, capping of contaminated areas, and monitored natural recovery (MNR). Dredging can remove contaminated sediments, but it requires large areas of land for sediment disposal. It is expensive and may cause secondary contamination of the water column during re-suspension. MNR relies on ongoing naturally occurring processes to decrease the bioavailability or toxicity of contaminants in sediment. These processes may include physical, biological, and chemical mechanisms that act together to reduce the environmental risks posed by contaminated sediments. MNR require longer monitoring time and can be even more expensive than for dredging and capping. Capping consists of in situ covering of clean or suitable isolating material over contaminated sediments layer to limit leaching of contaminants, and to minimize their re-suspension and transport. Hence appropriate remedial measures for the polluted sediment sites may be implemented, to reduce the concentration of the heavy metals.

CHAPTER 12: MARINE ECOLOGY MONITORING

12.1 Marine Ecological Monitoring

The monitoring of the biological and ecological parameters is important in order to assess the marine environment. A marine sampling is an estimation of the body of information in the population. The theory of the sampling design is depending upon the underlying frequency distribution of the population of interest. The requirement for useful water sampling is to collect a representative sample of suitable volume from the specified depth and retain it free from contamination during retrieval. Deendayal Port and its surroundings have mangroves, mudflats and creek systems as major ecological entities.

As defined in the scope by DPA, the Marine Ecological Monitoring is required to be carried out once a month specifically at eight locations, six at Kandla and two at Vadinar. The sampling of the Benthic Invertebrates has been carried out with the help of D-frame nets, whereas the sampling of zooplankton and phytoplankton has been carried out with the help of Plankton Nets (60 micron and 20 micron). The details of the locations of Marine Ecological Monitoring have been mentioned in **Table 34** as follows:

Table 34: Details of the sampling locations for Marine Ecological

Sr. No.	Location Code		Location Name	Latitude Longitude
1.	Kandla	ME-1	Near Passenger Jetty One	23.017729N 70.224306E
2.		ME-2	Kandla Creek (near KPT Colony)	23.001313N 70.226263E
3.		ME-3	Near Coal Berth	22.987752N 70.227923E
4.		ME-4	Khori Creek	22.977544N 70.207831E
5.		ME-5	Nakti Creek (near Tuna Port)	22.962588N 70.116863E
6.		ME-6	Nakti Creek (near NH - 8A)	23.033113N 70.158528E
7.	Vadinar	ME-7	Near SPM	22.500391N 69.688089E
8.		ME-8	Near Vadinar Jetty	22.440538N 69.667941E

The map depicting the locations of Marine Ecological monitoring in Kandla and Vadinar have been mentioned in **Map 20 and 21** as follows:

Map 20 Marine Ecological Monitoring: Locations at Kandla

Map 21: Marine Ecological Monitoring Locations at Vadinar

The various parameters to be monitored under the study for Marine Ecological Monitoring are mentioned in **Table 35** as follows:

Table 35: List of parameters to be monitored for Marine Ecological Monitoring

Sr. No.	Parameters
1.	Productivity (Net and Gross)
2.	Chlorophyll-a
3.	Pheophytin
4.	Biomass
5.	Relative Abundance, species composition and diversity of phytoplankton
6.	Relative Abundance, species composition and diversity of zooplankton
7.	Relative Abundance, species composition and diversity of benthic invertebrates (Meio, Micro and macro benthos)
8.	Particulate Oxidisable Organic Carbon
9.	Secchi Depth

Methodology

- **Processing for chlorophyll estimation:**
  Samples for chlorophyll estimation were preserved in ice box on board in darkness to avoid degradation in opaque container covered with aluminium foil. Immediately after reaching the shore after sampling, 1 litre of collected water sample was filtered through GF/F filters (pore size 0.45 µm) by using vacuum filtration assembly. After vacuum filtration the glass micro fiber filter paper was grunted in tissue grinder, macerating of glass fiber filter paper along with the filtrate was done in 90% aqueous Acetone in the glass tissue grinder with glass grinding tube. Glass fiber filter paper will assist breaking the cell during grinding and chlorophyll content was extracted with 10 ml of 90% Acetone, under cold dark conditions along with saturated magnesium carbonate solution in glass screw cap tubes. After an extraction period of 24 hours, the samples were transferred to calibrated centrifuge tubes and adjusted the volume to original volume with 90% aqueous acetone solution to make up the evaporation loss. The extract was clarified by using centrifuge in closed tubes. The clarified extracts were then decanted in clean cuvette and optical density was observed at wavelength 664, 665 nm.

- **Phytoplankton Estimation**
  Phytoplankton are free floating unicellular, filamentous and colonial eutrophic organisms that grow in aquatic environments whose movement is more or less dependent upon water currents. These micro flora acts as primary producers as well as the basis of food chain, source of protein, bio-purifier and bio-indicators of the aquatic ecosystems of which diverse array of the life depends. They are considered as an important component of aquatic flora, play a key role in maintaining equilibrium between abiotic and biotic components of aquatic ecosystem. The phytoplankton includes a wide range of photosynthetic and phototrophic organisms. Marine phytoplankton is mostly microscopic and unicellular floating flora, which are the primary producers that support the pelagic food-chain. The two most prominent groups of phytoplankton are Diatoms (*Bacillariophyceae*) and Dinoflagellates (*Dinophyceae*). Phytoplankton also include numerous and diverse collection of extremely small, motile algae which are termed micro

flagellates (naked flagellates) as well as Cyanophytes (Bluegreen algae). Algae are an ecologically important group in most aquatic ecosystems and have been an important component of biological monitoring programs. Algae are ideally suited for water quality assessment because they have rapid reproduction rates and very short life cycles, making them valuable indicators of short-term impacts. Aquatic populations are impacted by anthropogenic stress, resulting in a variety of alterations in the biological integrity of aquatic systems. Algae can serve as an indicator of the degree of deterioration of water quality, and many algal indicators have been used to assess environmental status.

- **Zooplankton Estimation**

  Zooplankton includes a taxonomically and morphologically diverse community of heterotrophic organisms that drift in the waters of the world's oceans. Qualitative and quantitative studies on zooplankton community are a prerequisite to delineate the ecological processes active in the marine ecosystem. Zooplankton community plays a pivotal role in the pelagic food web as the primary consumers of phytoplankton and act as the food source for organisms in the higher trophic levels, particularly the economically essential groups such as fish larvae and fishes. They also function in the cycling of elements in the marine ecosystem. The dynamics of the zooplankton community, their reproduction, and growth and survival rate are all significant factors determining the recruitment and abundance of fish stocks as they form an essential food for larval, juvenile and adult fishes. Through grazing in surface waters and following the production of sinking faecal matters and also by the active transportation of dissolved and particulate matter to deeper waters via vertical migration, they help in the transport of organic carbon to deep ocean layers and thus act as key drivers of 'biological pump' in the marine ecosystem. Zooplankton grazing and metabolism also, transform particulate organic matter into dissolved forms, promoting primary producer community, microbial demineralization, and particle export to the ocean's interior. The categorisation of zooplankton into various ecological groups is based on several factors such as duration of planktonic life, size, food preferences and habitat. As they vary significantly in size from microscopic to metazoic forms, the classification of zooplankton based on size has paramount importance in the field of quantitative plankton research.

- **Diversity Index**

  A diversity index is a measure of species diversity within a community that consists of co-occurring populations of several (two or more) different species. It includes two components: richness and evenness. Richness is the measure of the number of different species within a sample showing that more the types of species in a community, the higher is the diversity or greater is the richness. Evenness is the measure of relative abundance of the different species with in a community.

1. **Shannon-Wiener's index:**

   An index of diversity commonly used in plankton community analyses is the Shannon-Wiener's index (H), which emphasizes not only the number of species (richness or variety), but also the apportionment of the numbers of individuals among the species. Shannon-Wiener's index (H) reproduces community parameters to a single number by using an equation are as follow:

$$H' = \sum p_i * \ln(p_i)$$

Where, ∑ = Summation symbol,

pi = Relative abundance of the species,

ln = Natural logarithm

More diverse ecosystems are considered healthier and more resilient. Higher diversity ecosystems typically exhibit better stability and greater tolerance to fluctuations. e.g., The Shannon diversity index values between 2.19 and 2.56 indicate relatively high diversity within the community compared to communities with lower values. It suggests that the community likely consists of a variety of species, and the species are distributed somewhat evenly in terms of their abundance.

2. Simpson's index:

A reasonably high level of dominance by one or a small number of species is indicated by the range of **0.89 to 0.91**. The general health and stability of the ecosystem may be impacted by this dominance. Community disturbances or modifications that affect the dominant species may be more likely to have an impact. The dominating species determined by the Simpson's index can have big consequences on how the community is organised and how ecological interactions take place.

The formula for calculating D is presented as:

$$D = 1 - \sum (p_i \hat{} 2)$$

Where, ∑ = Summation symbol, pi = Relative abundance of the species

3. Margalef's diversity index:

The number of species is significantly related to the port's vegetation cover surface, depth, and photosynthetic zone. The habitat heterogeneity is a result of these three elements. Species richness is related to the number of distinct species present in the analysed area. Margalef's index has a lower correlation with sample size. Small species losses in the community over time are likely to result in inconsistent changes.

Margalef's index D_{Mg}, which is also a measure of species richness and is based on the presumed linear relation between the number of species and the logarithm of the number of individuals. It is given by the formula:

$$D_{Mg} = \frac{S-1}{lnN}$$

Where, N = total number of individuals collected

S = No. of taxa or species or genera

4. Berger-Parker index:

This is a useful tool for tracking the biodiversity of deteriorated ecosystems. Environmental factors have a considerable impact on this index, which accounts for the

dominance of the most abundant species over the total abundance of all species in the assemblage. The preservation of their biodiversity and the identification of the fundamental elements influencing community patterns are thus critical for management and conservation. Successful colonising species will dominate the assemblage, causing the Berger-Parker index to rise, corresponding to well-documented successional processes. The environmental and ecological features of the system after disturbance may therefore simply but significantly determine the identity of the opportunistic and colonising species through niche selection processes.

The Berger-Parker index is a biodiversity metric that focuses on the dominance or relative abundance of a single species within a community. It provides a measure of the most abundant species compared to the total abundance of all species present in the community. Mathematically, it can be represented as follows:

$$d = \frac{N_{max}}{\mathrm{N}_i}$$

Where, N_{max} = Max no of individuals of particular genera or species

$\sum N_i$ = Total no of individuals obtained.

The resulting value of the Berger-Parker index ranges between 0 and 1. A higher index value indicates a greater dominance of a single species within the community. Conversely, a lower index value suggests a more even distribution of abundance among different species, indicating higher species diversity. The range of the Berger-Parker index can be interpreted as when the index value is close to 0, it signifies a high diversity with a more even distribution of abundances among different species. In such cases, no single species dominates the community, and there is a balanced representation of various species.

5. Evenness index–

Evenness index determines the homogeneity (and heterogeneity) of the species' abundance. Intermediate values between 0 and 1 represent varying degrees of evenness or unevenness in the distribution of individuals among species. Value of species evenness represents the degree of redundancy and resilience in an ecosystem. High species evenness = All species of a community can perform similar ecological activities or functions= even utilization of available ecological niches = food web more stable = ecosystem is robust (resistant to disturbances or environmental changes). Intermediate values between 0 and 1 represent variable degrees of evenness or unevenness.

$$EI = \frac{H}{\ln(S)}$$

Where, H= Shannon value

ln(S) = the natural logarithm of the number of different species in the community

Relative Abundance: The species abundance distribution (SAD) from disturbed ecosystems follows even/ uneven pattern. E.g., If relative abundance is 0.15, then the found species are neither highly dominant nor rare.

$$RA = \frac{No.of\ Individuals\ of\ Sp.}{Total\ no.of\ Individual} * 100\%$$

The basic idea of index is to obtain a quantitative estimate of biological variability that can be used to compare biological entities composed of discrete components in space and time. Biodiversity is commonly expressed through indices based on species richness and species abundances. Biodiversity indices are a non-parametric tool used to describe the relationship between species number and abundance. The most widely used bio diversity indices are Shannon Weiner index and Simpson's index.

Monitoring Frequency:

Monitoring is required to be carried out once a month for both the locations of Kandla and Vadinar. Sample Collected from this location during the monitoring period April 2024 to March 2025.

12.2 Result and Discussion

The details of Marine Ecological Monitoring conducted for the locations of Kandla and Vadinar during the monitoring period has been summarized in the **Table 36.**

Table 36: Values of Biomass, Net Primary Productivity (NPP), Gross Primary Productivity (GPP), Pheophytin and Chlorophyll for Kandla and Vadinar

Sr. No.	Parameters	Kandla						Vadinar	
		ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek-near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
		Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.
1.	Biomass	134	151	89	132	116	124	101	157
2.	Net Primary Productivity	0.51	0.92	0.92	0.70	0.84	0.55	0.68	0.83
3.	Gross Primary Productivity	1.13	1.06	1.24	1.35	1.18	0.75	0.76	0.95
4.	Pheophytin	1.08	3.48	0.85	1.01	1.27	0.82	1.27	1.46
5.	Chlorophyll-a	0.90	1.14	1.56	1.29	1.65	1.39	1.63	1.29
6.	Particulate Oxidisable Organic Carbon	1.26	1.09	0.71	0.77	1.03	1.06	0.65	0.73
7.	Secchi Depth	0.58	0.55	0.59	0.60	0.58	0.73	1.17	1.40

- **Biomass:**
  With reference to **Table 37**, the average concentration of biomass during the monitoring period, for locations ME-1 to ME-6 was reported within the range of **89–151** mg/L, with the lowest biomass present in **ME-3 (near coal berth)** and the highest biomass present in **ME-2 (Kandla Creek)** during the sampling period. In Vadinar, the value of biomass was observed at **101** mg/L at ME-7 (near SPM) and **157** mg/L at ME-8 (near Vadinar Jetty) monitoring station.

- **Productivity (Net and Gross)**
  Gross primary productivity (GPP) is the rate at which organic matter is synthesised by producers per unit area and time (GPP). The amount of carbon fixed during photosynthesis by all producers in an ecosystem is referred to as gross primary productivity. During the Monitoring Period, the monitoring location of Kandla reported GPP value in range between **0.75 to 1.35 mg/L/48 Hr** where the highest value recorded

for ME-4 (Khori Creek) and lowest recorded at ME-6 (Nakti Creek near NH - 8A). In Vadinar, the value of **GPP** was observed **0.76** at ME-7 (Near SPM) and **0.95** mg/L/48 Hr at ME-8 (Near Vadinar Jetty) monitoring station.

Net primary productivity, is the amount of fixed carbon that is not consumed by plants, and it is this remaining fixed carbon that is made available to various consumers in the ecosystem. During the monitoring period of 2024 to 2025 the Net primary productivity of the monitoring location at Kandla from (ME-1 to ME-6) has been estimated to be between **0.51 to 0.92 mg/L/48 Hr**. While in Vadinar, the value of **NPP** was observed **0.68** at ME-7 (Near SPM) and **0.83** mg/L/48 Hr at ME-8 (Near Vadinar Jetty) monitoring station.

- **Pheophytin**

  The level of Pheophytin was detected in the range from **0.82 to 3.48 mg/m^3** where the highest value observed at ME-2 (Nakti Creek (Kandla Creek) and the lowest value observed at ME-6 (ME-6 (Nakti Creek near NH - 8A), While in Vadinar, the value of Pheophytin was observed **1.27** mg/m^3 at ME-7 and **1.46** mg/m^3 at ME-8 monitoring station.

- **Chlorophyll-a**

  In the sub surface water, the value of Chlorophyll-a reported in range from **0.90 to 1.65 mg/m^3**. The highest value observed at ME-5 (Nakti Creek- near Tuna Port), while the lowest value observed at ME-1 (Near Passenger Jetty One). In Vadinar, the value of chlorophyll-a was observed **1.63** mg/m^3 at ME-7 (Near SPM) and **1.29** mg/m^3 in ME-8 (Near Vadinar Jetty) monitoring station.

- **Particulate Oxidisable Organic Carbon**

  During the sampling period, the particulate oxidisable organic carbon falls within the range of **0.71 to 1.26 mg/L** from monitoring location ME-1 to ME-6 at Kandla, whereas for Vadinar, the value of POC observed **0.65** mg/L at ME-7 (Near SPM) and **0.73** mg/L in ME-8 (Near Vadinar Jetty) monitoring station.

- **Secchi Depth**

  In monitoring station of Kandla (ME-1 to ME-6) the level of Secchi Depth was observed between **0.55 to 0.73 ft** whereas at Vadinar, the value recorded at ME-7 i.e. Near SPM is **1.17** ft and in Near Vadinar Jetty is **1.40** ft.

Ecological Diversity

Phytoplankton: For the evaluation of the Phytoplankton population in DPA Kandla and Vadinar within the immediate surroundings of the port, sampling was conducted during the study period. Total 8 sampling locations were studied i.es. sampling locations (6 from Kandla and two from Vadinar).

The details of variation in abundance and diversity in phytoplankton communities is mentioned in **Table 37**.

Table 37: Phytoplankton variations in abundance and diversity in sub surface sampling stations

Genera	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek-near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Bacillaria sp.	181	253	160	198	223	252	180	166
Biddulphia sp.	189	237	271	134	121	152	183	190
Chaetoceros sp.	203	151	122	196	155	270	185	173
Chlamydomonas sp.	176	195	231	209	275	254	305	245
Cyclotella sp.	158	331	233	228	131	217	251	203
Coscinodiscus sp.	185	152	342	150	141	258	161	169
Ditylum sp	178	276	201	241	202	197	248	181
Fragilaria sp.	335	213	142	165	201	179	130	180
Bacteriastrum sp.	195	125	278	162	172	156	187	222
Pleurosigma sp.	218	208	240	126	231	207	134	208
Navicula sp.	169	200	186	184	246	247	0	179
Nitzschia sp.	178	155	171	161	234	160	182	184
Synedra sp.	182	215	154	168	266	157	220	157
Skeletonema sp.	206	130	0	196	279	150	170	234
Oscillatoria sp.	191	186	204	0	178	176	174	191
Thallassiosira	207	245	143	220	166	195	151	183
Gomphonema sp.	0	197	134	210	188	106	162	0
Density-Units/L	1525	1501	1415	1345	1445	1441	1433	1490
No. of genera	8	7	7	7	7	7	8	8

The phytoplankton community of the sub surface water in the Kandla and Vadinar was represented by, Diatoms, green algae and filamentous Cynobacteria. Diatoms were represented by 15 genera; green algae were represented by 1 genera and filamentous Cynobacteria were represented by 1 genera during the sampling period.

The density of phytoplankton of the sampling stations from ME-1 to ME-6 (Kandla) varying from **1345** to **1525** units/L, while for Vadinar its density of phytoplankton observed **1433** units/L at ME-7 and **1490** units/L at ME-8. During the sampling, all communities were contributing in phytoplankton on both location of Kandla & Vadinar except *Navicula sp.* And *Thalassiosira sp.*, Which Were absent at ME-7 and ME-8 repectively.

The details of Species richness Index and Diversity Index in Phytoplankton is mentioned in **Table 38**.

Table 38: Species richness Index and Diversity Index in Phytoplankton

Indices	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek-near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Taxa S	8	7	7	7	7	7	8	8
Individuals	1525.42	1501.33	1414.50	1345.42	1444.67	1440.50	1433.17	1490.17
Shannon diversity	2.00	1.88	1.80	1.81	1.88	1.83	1.87	1.96
Simpson 1-D	0.86	0.84	0.84	0.85	0.85	0.83	0.84	0.85
Species Evenness	0.98	0.96	0.94	0.92	0.95	0.94	0.95	0.98
Margalef richness	0.92	0.85	0.82	0.87	0.88	0.84	0.89	0.91
Berger-Parker	0.20	0.24	0.22	0.22	0.23	0.24	0.22	0.19
Relative abundance	0.53	0.49	0.51	0.55	0.53	0.51	0.53	0.52

- **Shannon- Wiener's Index (H):** During monitoring period 2024 to 2025, Average Shanon- Wierner's index of phytoplankton communities was in the range of **1.80 to 2.00** between selected sampling stations from ME-1 to ME-6. While for Vadinar, Average Shannon Wiener's index of phytoplankton communities recorded to be **1.87** at ME-7 and **1.96** at ME-8. The apportionment of the numbers of individuals among the species observed higher stability at all monitoring location of Kandla and Vadinar.
- **Simpson diversity index (1-D):** During the monitoring period **2024 to 2025,** average Simpson diversity index (1-D) of phytoplankton communities was ranged between **0.83 to 0.86** at all sampling stations in the Kandla creek and nearby creeks. Similarly, for Vadinar average Simpson diversity index (1-D) of phytoplankton communities was **0.84** at ME-7 and **0.85** at ME-8.
- **Margalef's diversity index** (Species Richness): During the monitoring period **2024 to 2025,** average margalef's diversity index of phytoplankton communities in Kandla and nearby creeks sampling stations was varying from **0.84 to 0.92.** While for Vadinar, average Margalef's diversity index (Species Richness) of phytoplankton communities observed **0.89** at ME-7 and **0.91** at ME-8.

- **Berger-Parker Index (d):** During the monitoring period **2024 to 2025,** average Berger-Parker Index (d) of phytoplankton communities was in the range of **0.20 to 0.24** between selected sampling stations from ME-1 to ME-6. at Kandla creek and nearby creeks. Average Berger-Parker Index (d) of phytoplankton communities in the sampling stations of Vadinar, was in the range of **0.22** to **0.19.** All the monitoring station signifies a low diversity with an even distribution among the different species.

- The Average **Species Evenness** is observed in the range of **0.92 to 0.96** for all the six-monitoring station of Kandla and for the Vadinar the average species evenness is observed in the range of **0.95** to **0.98**.

- During the sampling period, average **Relative Abundance** of phytoplankton communities was in range of **0.49 to 0.55** between selected sampling stations from ME-1 to ME-6 at Kandla creek and nearby creeks. Whereas for Vadinar the Average relative Abundance value **0.53** at ME-7 and **0.52** at ME-8. thus, it is concluded that the studied species can be stated as neither highly dominant nor rare.

The details of variation in abundance and diversity in zooplankton communities is mentioned in **Table 39**.

Table 39: Zooplankton variations in abundance and diversity in sub surface sampling stations

Genera	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek-near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Acartia sp.	1	1	1	1	2	2	2	1
Acrocalanus	1	1	1	1	1	1	1	1
Amoeba	1	1	1	2	2	1	1	1
Brachionus sp.	2	1	1	1	2	2	1	1
Calanus sp.	2	1	1	2	1	1	2	1
Cladocera sp.	1	2	2	1	1	1	1	2
Cyclopoid sp.	1	1	2	1	1	1	1	2
Copepod larvae	1	1	2	1	1	1	2	1
Diaptomus sp.	2	1	1	2	1	2	1	1
Eucalanus sp.	1	1	1	1	1	1	1	2
Mysis sp.	1	1	2	1	1	1	2	1
Paracalanus sp.	1	1	1	2	1	1	1	1
Density Unit/L	9	9	8	9	8	9	9	9
No. of genera	7	7	6	6	6	7	6	7

A total of 13 groups/taxa of zooplankton were recorded in Kandla and Vadinar during the study period which mainly constituted by *diaptomus*, *copepods*, *brachionus*, *cladocera*, fish and shrimp larval forms. *Amoeba* and *Cyclopoida* had the largest representation at all stations from (ME-1 to ME-8). The average density of Zooplankton of the sampling stations from ME-1 to ME-6 (Kandla) varying from **6** to **9** units/L, while for Vadinar its average density of zooplankton observed **9** units/L at ME-7 and **7** units/L at ME-8. During the sampling, all communities were contributing in zooplankton except *Oithana sp.* in Kandla and Vadinar.

The details of Species richness Index and Diversity Index in Zooplankton communities is mentioned in **Table 40**.

Table 40: Species richness Index and Diversity Index in Zooplankton

Indices	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek-near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Taxa S	7	7	6	6	6	7	6	7
Individuals	9	9	8	9	8	9	9	9
Shannon diversity	1.85	1.83	1.73	1.71	1.71	1.78	1.76	1.65
Simpson (1-D)	0.93	0.94	0.93	0.93	0.94	0.93	0.92	0.95
Species Evenness	0.96	0.95	0.93	0.94	0.92	0.95	0.96	0.86
Margalef	2.65	2.69	2.56	2.46	2.58	2.59	2.48	2.70
Berger-Parker	0.26	0.25	0.24	0.26	0.26	0.25	0.26	0.25
Relative abundance	75.79	78.05	77.23	74.00	78.66	76.59	72.62	80.36

- **Shannon- Wiener's Index (H):** During monitoring period 2024 to 2025, Average Shanon- Wierner's index of zooplankton communities was in the range of **1.71 to 1.85** between selected sampling stations from ME-1 to ME-6, at Kandla creek and its nearby creeks. While for Vadinar, average Shannon Wiener's index of zooplankton communities recorded to be **1.76** at ME-7 and **1.65** at ME-8. The apportionment of the numbers of individuals among the species observed higher stability at all monitoring location of Kandla and Near SPM (Vadinar).
- **Simpson diversity index (1-D):** During the monitoring period **2024 to 2025,** average Simpson diversity index (1-D) of zooplankton communities was ranged between **0.93 to 0.94** at all sampling stations in the Kandla creek and nearby creeks, for Vadinar average Simpson diversity index (1-D) of zooplankton communities was **0.92** at ME-7 and **0.95** at ME-8.
- **Margalef's diversity index** (Species Richness): During the monitoring period **2024 to 2025,** average margalef's diversity index of zooplankton communities in Kandla and nearby creeks sampling stations was varying from **2.46 to 2.69,** during the sampling period. While for Vadinar, average Margalef's diversity index (Species Richness) of zooplankton communities observed **2.48** at ME-7 and **2.70** at ME-8.

- **Berger-Parker Index (d):** During the monitoring period **2024 to 2025,** average Berger-Parker Index (d) of zooplankton communities was in the range of **0.24 to 0.26** between selected sampling stations from ME-1 to ME-6, at Kandla creek and nearby creeks. Average Berger-Parker Index (d) of zooplankton communities in the sampling stations of Vadinar, was in the range of **0.26** to **0.25.** All the monitoring station signifies a low diversity with an even distribution among the different species.

- The average **Species Evenness** is observed in the range of **0.92 to 0.96** for all the six-monitoring station of Kandla whereas, for the Vadinar the average species evenness was observed in the range of **0.96** to **0.86**, during the monitoring period.

- During the sampling period, **average Relative Abundance** of zooplankton communities was in range of **74** to **78.66** between selected sampling stations from ME-1 to ME-6. at Kandla creek and nearby creeks. Whereas for Vadinar the average relative abundance value **72.62** at ME-7 and **80.36** at ME-8, thus it can be concluded that the studied species is stated as neither highly dominant nor rare.

The details of variation in abundance and diversity in **Benthic organism** is mentioned in **Table 41.**

Table 41: Benthic Fauna variations in abundance and diversity in sub surface sampling

Genera	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek-near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Thiaridae	2	1	1	1	1	2	1	1
Mollusca sp.	1	1	1	1	1	1	1	1
Odonata sp.	2	2	1	2	1	2	1	1
Lymnidae	1	1	1	1	2	1	2	1
Planorbidae	2	2	1	2	1	1	1	2
Talitridae	2	2	1	1	1	2	1	1
Trochidae	1	1	2	1	2	1	1	2
Atydae	1	1	1	2	1	2	1	1
Gammaridae	2	1	1	1	1	1	2	1
Portunidae	1	1	1	2	1	1	1	1
Turbinidae	1	1	1	1	1	2	1	1
Palaemonidae	1	1	1	1	1	1	1	1
Density-m^3	8	7	7	8	7	7	7	7
No of genera	6	6	6	5	6	6	6	6

Few Benthic organisms were observed in the collected sample by using the Van-Veen grabs during the sampling conducted for DPA Kandla and Vadinar. Majority of the species were found under the Macro-benthic organisms during the sampling period were represented by *Atyde, Palaemonidae, Mollusca sp.*, etc. The average density of benthic fauna was varying from **7** to **8** m^3.

The details of Species richness Index and Diversity Index in Benthic Organisms is mentioned in **Table 42.**

Table 42: Species richness Index and Diversity Index in Benthic Organisms

Indices	ME-1 (Near Passenger Jetty One)	ME-2 (Kandla Creek)	ME-3 (Near Coal Berth)	ME-4 (Khori Creek)	ME-5 (Nakti Creek-near Tuna Port)	ME-6 (Nakti Creek near NH - 8A)	ME-7 (Near SPM)	ME-8 (Near Vadinar Jetty)
	Avg.	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Taxa S	6	6	6	5	6	6	6	6
Individuals	8	7	7	8	7	7	7	7
Shannon diversity	1.80	1.60	1.60	1.57	1.57	1.57	1.70	1.55
Simpson 1-D	0.94	0.93	0.95	0.93	0.95	0.93	0.95	0.93
Species Evenness	0.98	0.93	0.92	0.93	0.91	0.92	0.94	0.92

Margalef	2.54	2.38	2.44	2.21	2.43	2.32	2.62	2.29
Berger-Parker	0.25	0.28	0.28	0.26	0.26	0.28	0.27	0.28
Relative abundance	77.96	79.07	82.43	73.98	83.41	77.74	84.48	77.58

- **Shannon- Wiener's Index (H):** During monitoring period 2024 to 2025, Average Shanon- Wierner's index of benthic organism was in the range of **1.57 to 1.80** between selected sampling stations from ME-1 to ME-6, at Kandla creek and its nearby creeks. While for Vadinar, average Shannon Wiener's index of benthic organism recorded to be **1.70** at ME-7 and **1.55** ME-8. The apportionment of the numbers of individuals among the species observed higher stability at all monitoring location of Kandla and Vadinar.
- **Simpson diversity index (1-D):** During the monitoring period **2024 to 2025,** average Simpson diversity index (1-D) of benthic organism was ranged between **0.93 to 0.95** at all sampling stations in the Kandla creek and nearby creeks, Similarly, for Vadinar average Simpson diversity index (1-D) of benthic organism was **0.95** at ME-7 and **0.93** at ME-8.
- **Margalef's diversity index** (Species Richness): During the monitoring period **2024 to 2025,** average margalef's diversity index of benthic organism in Kandla and nearby creeks sampling stations was varying from **2.21 to 2.54**. While for Vadinar, average Margalef's diversity index (Species Richness) of benthic organism observed to be **2.62** at ME-7 and **2.29** at ME-8.
- **Berger-Parker Index (d):** During the monitoring period **2024 to 2025,** average Berger-Parker Index (d) of benthic organism was in the range of **0.25 to 0.28** between selected sampling stations from ME-1 to ME-6, at Kandla creek and nearby creeks. average Berger-Parker Index (d) of benthic organism in the sampling stations of Vadinar, was in the range of **0.27** to **0.28**. All the monitoring station signifies a low diversity with an even distribution among the different species.
- The average **Species Evenness** is observed in the range of **0.91 to 0.98** for all the six-monitoring station of Kandla and for the Vadinar the species evenness is observed in the range of **0.94** to **0.92.**
- During the sampling period, **average Relative Abundance** of Benthic organisms was in range of **77.74 to 83.41** between selected sampling stations from ME-1 to ME-6 at Kandla creek and nearby creeks. Whereas for Vadinar the Average relative abundance value **84.48** at ME-7 and **77.58** at ME-8, thus it is concluded that the studied species can be stated as neither highly dominant nor rare.

CHAPTER 13: SUMMARY AND CONCLUSION

13.1 Summary and Conclusion

The report, prepared by the Gujarat Environment Management Institute (GEMI), details the environmental monitoring and management plan for the Deendayal Port Authority (DPA) at Kandla and Vadinar. The monitoring covers the period from April 2024 to March 2025.

The primary objective is to systematically assess and monitor environmental parameters including ambient air, water (drinking and surface), soil, sediment, noise, and ecology to ensure compliance with environmental standards and statutory norms. Preventive and mitigation measures are provided in each section of this report.

Based on the results obtained for both study areas, Kandla and Vadinar, during the monitoring period from April 2024 to March 2025, the following observations are concluded.

- **Ambient Air Quality Monitoring**
  Particulate matter (PM_{10} and $PM_{2.5}$) levels exceeded the national ambient air quality standards (NAAQS) at most monitoring locations, especially at the coal storage area. The high particulate matter levels were attributed to Construction and Demolitionactivities, heavy vehicular traffic, loading/unloading of cargo, and dust from unpaved roads. For Gaseous monitoring, sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and carbon monoxide (CO) were generally within the NAAQS limits.
  The noise level was within the permissible limits for the industrial, commercial, and residential zones for daytime and nighttime except some locations.

- **DG Stack Monitoring**
  Monitoring of the diesel generator (DG) stacks was conducted at one location each in Kandla and Vadinar. Parameters like suspended particulate matter, SO_2, NO_x, CO, and CO_2 were measured and found to be within the prescribed emission limits.

- **Soil Monitoring**
  The pH in Kandla varies from slightly alkaline to strongly alkaline, while the soil at Vadinar was found to be moderately alkaline. The soil texture was observed as “sandy loam” to “loamy sand” at all the monitoring locations in Kandla, and the soil texture of Vadinar varies from “loam” to “slit loam. Kandla displays higher salinity and nutrient levels, while Vadinar exhibits lower nutrient levels. Vadinar generally shows moderate conditions with higher water holding capacity and more consistent soil composition. The presence of heavy metals such as aluminium, chromium, nickel, copper, zinc, lead, arsenic, and cadmium vary considerably at both study area.

- **STP Monitoring**
  After the effluent treatment in both the study areas, the treated water followed the GPCB discharge norms except for total coliform.

- **Drinking Water Quality Monitoring**
  Drinking water samples were collected from 20 locations across Kandla and Vadinar. Most water quality parameters like pH, color, turbidity, chloride, and total hardness were within the drinking water standards (IS 10500:2012). A few locations showed slightly elevated levels of electrical conductivity, salinity, and total dissolved solids, likely due to the coastal location. Additionally, the presence of total coliform was observed at monitoring locations in both Kandla and Vadinar.

- **Marine Water and Sediment Quality Monitoring**
  Marine water and sediment samples were collected from 6 locations in Kandla and 2 locations in Vadinar. The water quality parameters like pH, salinity, dissolved oxygen, and nutrients were within the acceptable limits for coastal waters. The sediment quality in terms of heavy metals and organic contaminants was also found to be within the prescribed standards.

- **Marine Ecology Monitoring**
  Monitoring of marine ecology was conducted at 6 locations in Kandla and 2 locations in Vadinar. The analysis indicates that both regions exhibit low diversity with an even distribution among species, as evidenced by the Berger-Parker Index and Simpson Diversity Index values. These indices suggest a stable ecosystem where no single species overwhelmingly dominates, nor are any species exceedingly rare. The even distribution of species, coupled with moderate levels of biomass and primary productivity, highlights the resilience of these ecosystems.

Overall, the report concludes that the environmental monitoring conducted by the DPA during the period of April 2024 to March 2025 indicates compliance with the applicable environmental regulations, with some exceptions related to particulate matter levels in the ambient air.

Annexure 1: Photographs of the Environmental Monitoring conducted at Kandla

Soil Monitoring

Soil Monitoring

Soil Monitoring

Marine Monitoring

Air Monitoring

Drinking Water Monitoring

Annexure 2: Photographs of the Environmental Monitoring conducted at Vadinar

Air Monitoring

Noise Monitoring

STP Monitoring

Drinking water Monitoring

Marine Monitoring

Soil Monitoring

Source: GEMI

Gujarat Environment Management Institute (GEMI)

(An Autonomous Institute of Government of Gujarat)

'An ISO 9001:2015, ISO 14001:2015 & ISO 45001:2018 Certified Institute

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"We Provide Environmental Solutions"

Annexure -E

Inception Report

On

Greenbelt Development in Deendayal Port Authority (DPA) and its surrounding areas (Phase-III) along with two years maintenance

Submitted to

Deendayal Port Authority
Administrative Office Building
Post Box No.50, Gandhidham (Kachchh)
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Inception Report

on

Greenbelt Development in Deendayal Port Authority (DPA) and its surrounding areas (Phase-III) along with two years maintenance

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Introduction

A greenbelt is a designated area of undeveloped, wild, or agricultural land surrounding urban areas, intended to limit urban sprawl, protect natural environments, improve air quality, and promote biodiversity. Greenbelt development involves creating and maintaining these areas, often through strategic planting of trees, shrubs, or other vegetation to form natural barriers between urban and rural landscapes.

Thus, greenbelt offers a number of benefits for population. Vegetation absorbs various pollutants from the environment and thus help in effective pollution control. However, economic development like industrialization, mining, infrastructural development, etc. have exerted pressure and led to reduction and fragmentation of natural vegetation cover day-by day across the globe. Industrial and infra-structural developmental activities are likely to pollute the environment with varying magnitudes. Nevertheless, the pre-eminence of resistance of each of the organisms helps themselves to overcome the hazards caused by such pollutants.

Therefore, the general concept of greenbelt has evolved to develop vegetation or green spaces alongside of industries, mines, thermal power stations, roadsides, and other developmental unit is an effective measure to rejuvenate the environment through vital vegetation cover that safeguard the health of human and other living organisms. Greenbelts in and around urban and industrial areas are important to the ecological health of any given region.

Rationale

GUIDE team visited the proposed Greenbelt development site at Kandla port with the officials from Kandla Port as part of site selection. Based on the field observation and its landscape, environment and ecology of the area, suitable plant species were identified to improve the local environment and for the Greenbelt development at the port area.

Project Site

Based on observation made by the GUIDE team and officials from Deendayal Port Authority, a site at Roadside Over Bridge (RoB) to oil jetty road and Gopalpuri The area proposed for green development of Deendayal Port is barren land without any vegetation. The soil of the area is black muddy and is high saline soil with saline ground water. The area is very dry and hot during the summer.

Scope of Work

The overall objective is to Development Greenbelt at Deendayal Port Area. The following activities under the Greenbelt development have been carried out:

1. Inventories the suitable sites for greenbelt development in and around the Deendayal Port at Kandla.
2. Carryout Soil and Moisture Conservation (SMC) of the selected sites.
3. Identify suitable plant species as per site scenario for the greenbelt plantation.
4. Adopting plantation technique and soil/manure amendments.
5. Regular monitoring (survival and growth) of the plantation.
6. Suggest measures for management and improvement of the greenbelt.

Approach and Methodology for Greenbelt Development

Following steps have been adopted for greenbelt development:

1. **Planning Phase**:

- Involves site selection, environmental assessments, and choosing appropriate plant species based on local ecosystems.
- DPA officials and environmental experts collaborate to design sustainable spaces that support biodiversity and recreation.
- Selecting native trees/suitable to the condition and local environment to ensure ecological compatibility and resilience.

2. **Implementation Phase**:

- Includes land preparation (clearing and levelling), planting trees and shrubs, and constructing pathways or recreational facilities.
- Sustainable practices are prioritized to minimize environmental disruption.

3. Maintenance Phase:

- Focuses on long-term care such as watering, pruning, pest control, and replanting.
- Regular monitoring ensures the health of vegetation and ecosystems.
- Community involvement and education are key to sustaining the greenbelt

Plantation techniques:

- Site development for a plantation includes clearance for weeds and it involves, bush cutting, soil and moisture conservation works and marking of pits for planting of saplings, etc.
- After clearing the land sites for pits, plantation have been marked on ground using a measuring tape to ensure the desired spacing.
- Pits of the size 45 cm x 45 cm and 45 cm depth have been dug for tree plantation. Pits have been deep enough to ensure that the roots of the plants do not curl up once the planting material is placed in it.
- Since the soil is highly saline, a fertile soil around 06 dumpers have been added for better survival.
- Charcoal have been added for better moisture conservation and survival.
- The pit has been filled a little above the ground level so that after the earth settles the upper surface of the pit is at same level as that of ground thus avoiding any water logging.
- The plantation has been carried out in two phases (1st in Gopal pruri-200 plants & 2nd Roadside Over Bridge (RoB)-Oil jetty road side-5000 plants)

Selection of Plant Species for Plantation: Various indigenous tree species suitable for the area have been identified and selected for plantation areas based on soil quality, available water facility, and other environmental parameters.

Management and Monitoring of Greenbelt: The plantation within the identified site will be managed and monitored for a minimum period of two years after the plantation. The management of plantation includes watering at regular intervals, during summer and winter periods and if required even during monsoon with dry spells.

Fig. Map of Plantation Area at Gopalpuri

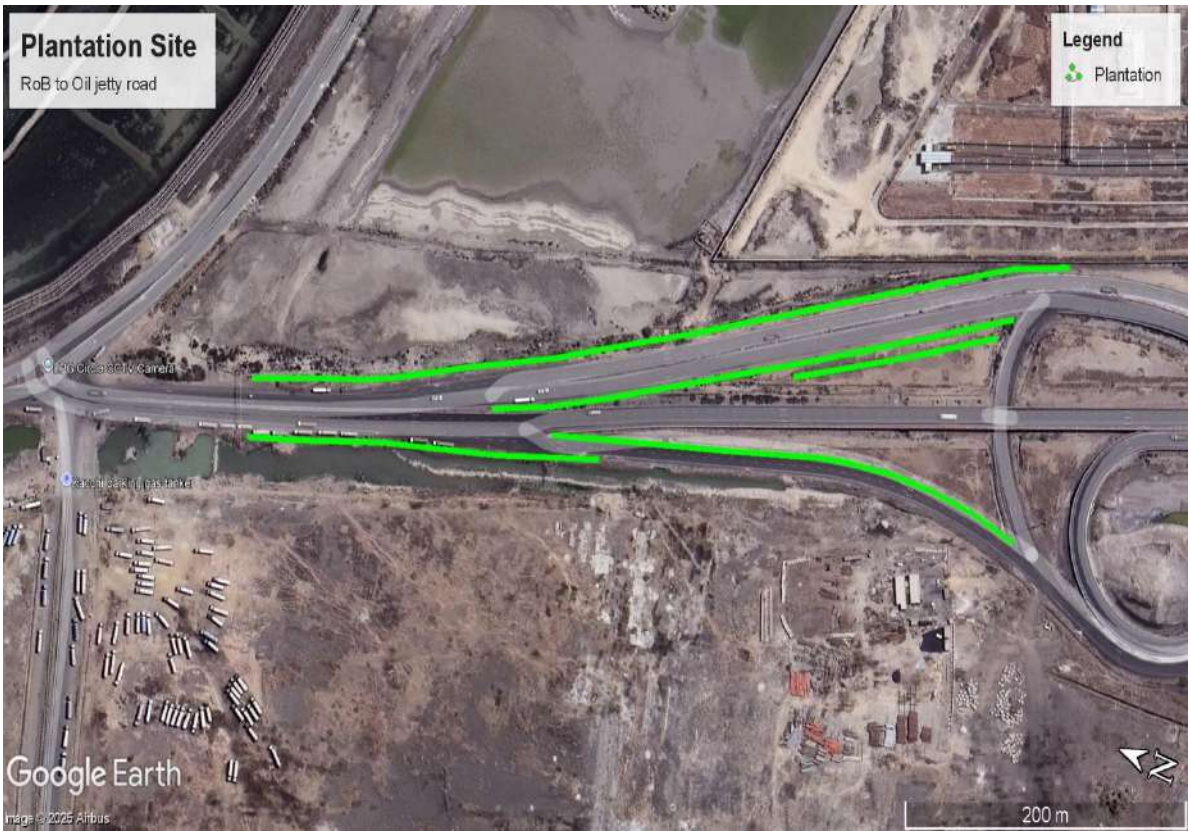

Fig. Map of Plantation Area RoB to Oil Jetty Road

Fig. Digging Out Trench for Plantation

Fig. Transportation of Plants to Site

Fig. Fertile Soil for Better Survival of Plants

Fig. Fertile Soil Filling to the pits

Fig. Addition of Charcoal for moisture conservation

Fig. Regular Watering of the Plants by Tanker

Annexure I
List of Plants for Plantation at site for Greenbelt Development
Site: Gopalpuri

Sr. No	Scientific name	Local name	No. of plants
Fruit Plants			
1	*Achras sapotta*	Chiku	3
2	*Citrus limonum*	Limbu	3
3	*Citrus medica*	Bijora	3
4	*Cocos nucifera*	Nariyel	3
5	*Eugenia jambolana*	Jambu	3
6	*Ficus carica*	Anjir	3
7	*Morus indica*	Shetur	5
8	*Phyllanthus emblica*	Amla	3
9	*Psidium guajava*	Jamfal	3
10	*Punica granatum*	Dadam	3
11	*Terminalia catappa*	Badam	5
12	*Pithecellobium dulce*	Gorsamli	3
13	*Tamarindus indica*	Khatiamli	5
14	*Carissa carandas*	Karmda	5
15	*Moringa oleifera*	Mitho sargavo	5
16	*Limonia acidissima*	Kothi	3
Medicinal Plant			
17	*Murraya koenigii*	Mitho limdo	5
18	*Plumbago zeylanica*	Chitrak	5
19	*Vitex negundo*	Nagod	8
20	*Nyctanthes arbor-tristis*	Parijat	8
21	*Justicia adhatoda*	Ardusi	5
22	*Butea monosperma*	Khakharo	5
23	*Hibiscus rosa-sinensis*	Jasud	5
24	*Bauhinia variegata*	Kanchnar	5
25	*Terminalia arjuna*	Arjun	5
26	*Azadirachta indica*	Limdo	5
27	*Ficus racemosa*	Umaro	5
28	*Aegle marmelos*	Bili	5
Air purifying plant			
29	*Cestrum diurnum*	Divsno raja	5
30	*Nerium odorum*	Karen	8
31	*Plumeria rubra*	Khadchampo	8
32	*Thespesia lampas*	Parspipalo	8
33	*Alstonia scholaris*	Saptaparni	8
34	*Plumeria rubra*	Kadam	5

Sr. No	Scientific name	Local name	No. of plants
35	*Ficus elastica*	Rabarplant	3
36	*Livistona chinensis*	Fenpalm	3
37	*Polyalthia longifolia*	Asopalav	8
38	*Roystonea regia*	Roayalpalm	2
39	*Pongamia glabra*	Karanj	8
40	*Delonix regia*	Gulmhor	5
41	*Ficus benjamina*	Ficus	5

Site: RoB to Oil Jetty Road

Sr. No.	Scientific Name	Local Name	No. of plants
1	*Conocarpus lancifolius*	*Conocarpus*	1700
2	*Peltophorum pterocarpum*	Peltophorum	660
3	*Millettia pinnata*	Karanj	660
4	*Delonix regia*	Gulmahor	660
5	*Tabubia rosea*	Tabubia	660
6	*Senna siamea*	*Kasid*	660

Annexure -F

Second Season Report

on

Studies on Dredged Materials for the presence of Contaminants and suggesting suitable disposal options

(As per EC & CRZ Clearance accorded by the MoEF & CC, GoI dated 19/12/2016 - Specific Condition No. vii)

DPA Work order No. EG/WK/4751/Part (EC&CRZ-1) / 84. Dt. 07.10.2024

Submitted by

Gujarat Institute of Desert Ecology

Mundra Road, Bhuj - Kachchh,

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Gujarat – 370201

2025

Dr. V. Vijay Kumar
Director

Gujarat Institute
Of Desert Ecology

CERTIFICATE

This is to state that the **Second Season Report** of the work entitled, **"Studies on Dredged Material for the presence of contaminants"** has been prepared in line with the Work order issued by DPT vide No. EG/WK/4751/Part (EC & CRZ-1). Dt.07.10.2024 as per the EC & CRZ Clearance accorded by the MoEF & CC, GoI dated 19/12/2016, Specific Condition No. vii. This work order is for a period of Three years from 2024 –2027 for the above-mentioned study.

.

Authorized Signatory

Gujarat Institute of Desert Ecology Bhuj

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PROJECT TEAM

Project Co-Ordinator **:** Dr. V. Vijay Kumar, Director

S. No	Name and Designation	Role	Background
1.	Dr. K. Karthikeyan Assistant Director	Principal Investigator	M.Sc., Ph.D. in Environmental Science; 15 years of experience in Marine Environmental Monitoring and Pollution Assessment studies.
2.	Dr. G. Jayanthi Scientist	Co- Investigator	MSc., MPhil., PhD in Botany; 13 years of Research and teaching experience inclusive of Post-Doctoral experience for 5 years.
3.	Dr. Krushnakant. D. Baxi Scientific Officer	Co- Investigator	Ph.D in Zoology (Marine Biology) with 5 years of experience
4.	Ds. Monika Sharma Sr. Scientific Asst.	Team member	M.Sc. in Environmental Sciences; 7 years of experience in Marine water and sediment analysis
5.	Ms. Chetna Hirani Scientific Asst.	Team member	M.Sc. in Chemistry; 4 years of experience in sediment and water analysis.
6.	Ms. Bulbul Kushvah	Team Member	M. Sc in Organic Chemistry; 1 year of experience in water and sediment analysis.

CONTENTS

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Chapter 1 Background

Among the twelve major ports across the nation, Deendayal Port Authority, formerly known as Deendayal Port Trust, erstwhile called as Kandla Port Trust, holds a prominent position as a significant maritime gateway in India, situated within Gujarat's Kutch district. This stands out as the largest Creek-based port, positioned at the southwestern tip of the Gulf of Kachchh, on India's north-western coastline within the state of Gujarat. Deendayal Port Authority (DPA) serves as a pivotal hub for maritime trade, facilitating the transportation needs of several hinterland states. It boasts excellent connectivity through an extensive rail and road network, functioning as a crucial gateway for the export and import activities of northern and western Indian states, including Jammu & Kashmir, Delhi, Punjab, Himachal Pradesh, Haryana, Rajasthan, Gujarat, as well as parts of Madhya Pradesh, Uttaranchal, and Uttar Pradesh. This port ranks among the largest and most essential ports in the country, playing a vital role in India's international trade and maritime infrastructure. The administration and operations of the port are overseen by the Deendayal Port Trust (DPT), an autonomous entity established under the Major Port Trusts Act of 1963.

The Deendayal Port Trust is entrusted with the comprehensive management, development, and administration of the port. The authority is comprised of a dedicated team of professionals and experts who work diligently to ensure the efficient operation of the port and all related activities. About 35% of the country’s total export takes place through the ports of Gujarat in which the contribution by Deendayal port is considerable. The port handled a total cargo of 105 MMTPA during 2016-17, 110 MMTPA during 2017-18, 115 MMTPA during 2018-19, 122.5 MMTPA during 2019-2020, 117.5 MMTPA during 2020-21, 137 MMTPA during 2022-23 and 132.37 during the year 2023-24. DPA is the only major Indian port to handle more than 127 MMT cargo throughput, and it has also registered the highest cargo throughput in its history. The port has handled a total of 3151 vessels during FY 2021-22. Over the years, the port has witnessed significant growth and development, becoming a crucial gateway for India's international trade. Deendayal Port has a strategic location on the

west coast of India, offering direct access to the Arabian Sea. It serves as a vital link for India's trade with countries in the Middle East, Africa, Europe, and Asia. The port handles a wide range of cargoes, including petroleum products, chemicals, coal, iron ore, fertilizers, salt, and general cargo.

Further, regular expansion of infrastructure and port facilities is under way to cater future logistic requirements. With such capacity, the Port ranks No. 1 among all the major ports in India for 12th Consecutive year. Further, a regular expansion of infrastructure and port facilities is under way to cater future logistic requirements. The port has high commercial importance in the Indian maritime trade as it handled 36.1 million tons (17%) of Cargo out of total Cargo of 213.1 million tons of the maritime Cargo of India during 2015. In addition, regular expansion of infrastructure and port facilities is under way to cater future logistic requirements.

Deendayal Port Authority (DPA) has taken up Development of 7 Integrated facilities, and the Ministry of Environment, Forest and Climate Change (MoEF & CC), has put up some conditions while according Environmental and CRZ clearance. One of the conditions is to carry out the *"Study on Dredged Material for presence of contaminants"* as accorded by the MoEF & CC, GoI dated 19/12/2016 - Specific condition no. vii)" which states that ***"Dredged materials should be analyzed for presence of contaminants and also to decide the disposal options. Monitoring of dredging activities should be conducted and the findings should be shared with the Gujarat SPCB and Regional Office of the Ministry"***.

1.1 Need of the study

Considering the aforementioned condition, DPA has assigned the task of carrying out the study to Gujarat Institute of Desert Ecology (GUIDE), Bhuj. This study will be attempted three times in a year at two specified locations. Further, the study will envisage the evaluation of physico-chemical constituents in the dredged materials in the dumped locations in the study area. GUIDE has been entrusted with the project, which has duration of three years (01.11.2024 – 31.10.2027) as specified in the work order. Accordingly, the study was initiated to evaluate the dredged materials for

potential contamination, employing a systematic investigation that encompasses the analysis of physical, chemical, and biological characteristics with special reference to pollutants including heavy metal, Petroleum hydrocarbon etc.

1.2. Scope of the study

a. To monitor the locations where dredged materials are dumped will be conducted.
b. Dredged materials in the area will be analyzed for the presence of contaminants in two different locations.
c. Detailed assessment of the dredged materials for physical, chemical and biological characteristics will be studied.
d. Suggesting suitable disposal options for the dredged material will be made.

1.3. Sampling locations for 2024-25

The study focused on investigating the presence of contaminants in the dredged materials during the year 2024-25. The specific locations for sampling can be found in Table 1 and Plate 1. The selection of these sampling sites was based on information supplied by the Hydraulic and Dredging Division to the Department of Port Administration (DPA), concerning the locations of dumping grounds. These location details were subsequently shared with the Gujarat Institute of Desert Ecology (GUIDE) via an email dated October 24, 2018. Three seasonal studies covering Location 1, Location 2 and Location 3 with the Second season of the study was conducted during 21.04.2025 – 23.04.2025.

Table 1: GPS Co-ordinates of sampling locations

Station	Latitude (N)	Longitude (E)
Location 1 (Offshore)	22° 51' 00" N	70° 10’ 00" E
Location 2 (Cargo jetty)	22°56' 31" N	70 13' 00" E
Location 3 (Phang Creek)	23° 04' 28" N	70°13’ 28" E

1.4. Details of work done during 2nd Quarter (May 2025 – July 2025)

During the Second season sampling conducted during this period of the project during April 2025. During the sampling, the surface and bottom marine water samples and bottom marine sediment samples were collected from the three designated locations, *i.e.,* Offshore, Cargo Jetty and Creek systems which was pre-designated locations as earmarked by CPWRS was conducted.

After the collection, the samples were preserved using standard protocols and stored in an Ice box and brought to the laboratory within 2-3 hrs of collection Comprehensive analysis was performed on all the samples, both water (36 samples) and sediment (18 samples), to determine various physical, chemical, and biological characteristics. The analysis followed the standard methods prescribed by the Integrated Coastal and Marine Area Management (ICMAM) in 2012. All samples were analysed in triplicates, and the obtained data was compared against the marine water limits specified by the Central Pollution Control Board (CPCB) and other relevant standards.

Plate 1: Map showing locations of proposed sampling (2024-2025)

Chapter 2 Physico-Chemical Characteristics of the Sediment

The sediment samples from the study area were collected for the purpose of characterization employing standard methodology and the analysis of the samples were also performed as per standard protocol and the data of sediment analysis is presented in this Chapter 1. The sediment samples were collected in pre-fixed stations using a Van-Veen type of grab sampler. After collection, the sediment samples were preserved with Rose Bengal and formalin to avoid decomposition of samples and processed for analysis and the samples after collection were brought to the laboratory on the same day of collection and air dried and used for further analysis for the test parameters (Table 2).

Table 2: Physico-chemical and biological characteristics of sediment samples

S. No.	Physico-chemical and biological parameters
1	pH (1: 10 suspension)
2	Salinity (ppt)
3	Sand (%)
	Silt (%)
	Clay (%)
4	Total organic carbon (%)
5	Phosphorus (mg/kg)
6	Sulphur (mg/kg)
7	Petroleum Hydrocarbon (µg/kg)
8	Cadmium (mg/kg)
9	Lead (mg/kg)
10	Chromium (mg/kg)
11	Copper (mg/kg)
12	Cobalt (mg/kg)
13	Nickel (mg/kg)
14	Zinc (mg/kg)
15	Magnesium (mg/kg)
16	Manganese
17	Macrobenthos

2.1. pH and Salinity (1: 10 suspension)

The pH of the sediment suspension is a measure of the activity of H+ ions within the sediment-water system. It indicates whether the sediment is acidic, neutral or alkaline in nature. Since ions are the carrier of electricity, the electrical conductivity (EC) of the sediment-water system rises according to the content of soluble salts. The EC measurement directly corresponds to the concentration of soluble salts in the sediment at any particular temperature. To conduct the analysis, ten grams of the finely sieved sediment was dissolved in 100ml of distilled water to prepare leachate. This leachate was taken for shaking using a rotator shaker for one hour to ensure proper homogenization of the suspension. Following this, the suspension was allowed to settle for two hours, and the supernatant was collected after filtration for the subsequent analysis of pH and salinity using the pH and EC meter (Make: Systronics 361) and Refractometer (Make: Atago) respectively. Each sample was analyzed in triplicates to ensure accuracy, and the mean values were considered for further evaluation.

2.2. Textural analysis (Sand/Silt/Clay)

Sediment samples were collected using Van Veen grab whereas intertidal sediments will be collected using a handheld shovel. After collection, the scooped samples are transferred to polythene bags, labelled and stored under refrigerated conditions. The sediment samples are thawed, oven dried at 40ºC and ground to a fine powder before analyses.

For texture analysis, specified unit of sediment samples were sieved using sieves of different mesh size as per Unified Sediment Classification System (USCS). Cumulative weight retained in each sieve will be calculated starting from the largest sieve size and adding subsequent sediment weights from the smaller size sieves. The percent retained will be calculated from the weight retained and the total weight of the sample. The cumulative percent will be calculated by sequentially subtracting percent retained from 100%.

2.3. Total organic carbon

Total organic carbon refers to the carbon content stored within sediment organic matter. It is derived from various sources such as the decomposition of plant and animal residues, root exudates, living and deceased microorganisms, sediment biota etc. To measure total organic carbon in sediment, a process of oxidation is employed using potassium dichromate in the presence of concentrated sulfuric acid. During the analysis, potassium dichromate generates nascent oxygen, which reacts with the carbon present in organic matter, resulting in the production of carbon dioxide (CO2). The excess volume of potassium dichromate is then titrated against a standardized solution of ferrous ammonium sulfate in the presence of phosphoric acid, using Ferroin indicator to detect the initial appearance of unoxidized ferrous iron. This titration allows the determination of the volume of potassium dichromate required to oxidize the organic carbon present in the sample.

2.3.1. Procedure

The determination of the percentage of total organic carbon in sediment involves oxidizing the organic matter within the sediment samples using chromic acid. The excess chromic acid is then estimated by titrating it against ferrous ammonium sulfate, with ferroin serving as an indicator. The step-by-step procedure is outlined as follows:

To begin, 1 gram of sediment sieved to a particle size of 0.5 mm is weighed and transferred into a 500 ml conical flask. Then, 10 ml of 1N $K_2Cr_2O_7$ is added to the flask with pipette followed by gentle swirling to ensure thorough mixing. Next, 20 ml of concentrated H2SO4 is added, and the sediment and reagents are mixed gently. This mixture is allowed to react for 30 minutes on a marble stone to avoid any damage caused by the release of intense heat from the sulfuric acid reaction. Afterward, 200 ml of distilled water is slowly added to the flask, along with 10 ml of concentrated orthophosphoric acid and approximately 0.2 grams of NaF. The sample and reagent mixture is left to stand for 1.5 hours, as the titration endpoint is better observed in a cooled solution. Just before the titration, 1 ml of ferroin indicator is added to the conical flask. The excess $K_2Cr_2O_7$ is then titrated with 0.5 N ferrous ammonium

sulfate until the color changes from yellowish green to greenish, and finally to a brownish-red color indicating the endpoint. A blank test without the sediment sample is also performed simultaneously for reference. Through this procedure, the percentage of total organic carbon in the sediment can be accurately determined.

2.4. Total Phosphorus

The determination of total phosphorus in sediment is commonly conducted using Bray's extraction method. This method involves the formation of specific-colored compounds by adding appropriate reagents to the solution, with the intensity of the color being directly proportional to the concentration of phosphorus being estimated. The color intensity is measured spectrophotometrically. In the spectrophotometric analysis, a light source emitting light of a specific wavelength (usually within a band width of 0.1 to 1.0 nm) in the ultraviolet region of the spectrum is used. The photoelectric cells in spectrophotometer measure the light transmitted by the solution allowing for quantitative analysis.

2.4.1.Procedure

To perform the analysis, 50 ml of the Bray's extractant is added to a 100 ml conical flask containing 5 grams of sediment sample. The flask is shaken for 5 minutes and then filtered. Exactly 5 ml of the filtered sediment extract is transferred to a 25 ml measuring flask using a bulb pipette. Subsequently, 5 ml of the molybdate reagent is added using an automatic pipette, followed by dilution to 20 ml with distilled water and shaken well. Furthermore, 1 ml of dilute Stannous Chloride solution is added, and the volume is made up to the 25 ml mark. Thorough shaking is performed to ensure proper mixing. The mixture is then allowed to develop color, and after 10 minutes, readings are taken in the spectrophotometer at a wavelength of 660 nm. Prior to the readings, the instrument is zeroed using a blank prepared similarly but without the sediment.

2.5. Total Sulphur

Total sulphur in the sediment extract was determined using a turbidimetric method with a spectrophotometer. A series of standards containing sulphur at concentrations of 2, 4, 6, 8, and 10 ppm were prepared from a stock solution. Each flask in the series received 25 ml of the respective standard solution, and 2.5 ml of conditioning reagent solution was added. Additionally, 5 ml of extraction solution was added to the mixture. To facilitate the reaction, 0.2-0.3 grams of barium chloride were included and thoroughly mixed. The volume was adjusted to 25 ml with distilled water, and readings were taken at 340 nm using a spectrophotometer.

For the sample analysis, 5 grams of marine sediment were placed in a 100 ml conical flask. To this, 25 ml of a 0.15% CaCl2 solution was added and shaken for 30 minutes. The mixture was then filtered through Whatman No. 42 filter paper. Subsequently, 5 ml of the sample aliquot was transferred into a 25 ml volumetric flask. Conditioning reagent (2.5 ml) and 0.2 to 0.3 grams of barium chloride powder were added, followed by making up the volume to 25 ml with distilled water. The flask contents were shaken for 2 minutes, and the absorbance was measured using the same procedure as the standard solutions.

2.6. Petroleum Hydrocarbons

To analyze petroleum hydrocarbons in sediment, the following procedure will be conducted. First, the sediment will undergo reflux with a mixture of KOH and methanol, allowing for the extraction of petroleum hydrocarbons. This reflux process helps release the hydrocarbons from the sediment matrix. Next, the sediment will be subjected to extraction using hexane, which selectively dissolves the hydrocarbons present in the sediment. The excess hexane will be carefully removed, leaving behind a residue containing the concentrated hydrocarbons of interest. To further purify the sample and remove any impurities, a clean-up procedure will be performed using silica gel column chromatography. This column chromatography process helps separate the hydrocarbons from other compounds present in the residue, resulting in a cleaner sample for analysis. Finally, the hydrocarbon content in the sediment will be

estimated by measuring fluorescence, following the standard method for petroleum hydrocarbon analysis. This fluorescence measurement allows for quantification and determination of the hydrocarbon levels present in the sediment sample. By following this procedure, accurate analysis of petroleum hydrocarbons in sediment can be achieved.

2.7. Heavy metals

Heavy metals, such as Cadmium (Cd), Lead (Pb), Chromium (Cr), Nickel (Ni), Cobalt (Co), Copper (Cu), Zinc (Zn), Manganese (Mn), and others, are of particular concern in relation to the environment. To release mineral elements from sediment samples, wet oxidation is commonly employed, utilizing oxidizing acids, such as tri/di-acid mixtures.

In the analysis procedure, a sediment sample weighing 1.0 gram is taken in a 100 ml beaker, which is covered with a watch glass. A mixture of Aqua regia (1:3 HNO_3:HCl) in the amount of 12 ml is added to the beaker. The beaker is then subjected to digestion for 3 hours at 100°C on a hot plate using a sand bath. Afterward, the samples are evaporated to near dryness, allowed to cool for 5 minutes, and then 20 ml of 2% nitric acid is added. The beaker is placed on a hot plate for digestion for 15 minutes, after which it is removed from the hot plate and allowed to cool. The mixture is then filtered using Whatman No. 42 mm filter paper. Finally, the volume is adjusted to 50 ml with 2% nitric acid to make up the final solution. The extracted sample is then aspirated into an Atomic Absorption Spectrometer (AAS) for analysis. By following this procedure, the heavy metal content in the sediment can be accurately analyzed using wet oxidation, filtration, and AAS techniques.

2.8. Results

2.8.1. Offshore

The sediment pH values across offshore stations ranged from 7.23 to 7.57, with a mean of 7.45 ± 0.13. These values indicate a generally neutral to slightly alkaline condition in the sediments, which is typical for marine environments. The lowest pH

recorded at Station 1A may indicate a slightly more acidic microenvironment, possibly due to organic matter degradation, while the highest pH at 1D suggests a more alkaline condition, potentially due to higher carbonate content. Salinity ranged widely from 6.00 to 20.00 PSU, with a mean of 12.50 ± 4.97. This variation points to different degrees of marine vs. freshwater influence across the sites. Station 1A had the highest salinity (20), indicating strong marine conditions, whereas Station 1C had the lowest salinity (6), suggesting a significant freshwater input, possibly from riverine discharge or runoff. Petroleum Hydrocarbons (PHC) concentrations varied between Below Detection Limit (BDL) and 12.21 µg/g, with a mean of 6.45 ± 5.04 µg/g. at 1A. PHC was not detected at 1B, 1C, or the control station, suggesting that contamination may be localized. Magnesium levels ranged from 437.40 to 789.75 mg/kg, with a mean of 627.75 ± 142.87 mg/kg. The highest value at Station 1E and lowest at 1B reflect variations in mineral composition and possibly input from weathered rock material or marine salts in sediments. In sediment texture, sand ranged from 13.10% to 44.80%, mean 32.53 ± 13.37%. The highest at 1E indicates coarser sediment, while the control site had the lowest. Silt varied from 7.50% to 33.10%, mean 20.75 ± 11.90%. 1D and 1E showed higher silt content, indicating low-energy depositional environments. Clay ranged between 22.10% and 78.30%, with a mean of 46.72 ± 24.96%. The control and 1B had the highest clay percentages, typical of finer sediment zones.

Total Organic Carbon (TOC) ranged from 0.21 to 0.45%, with a mean of 0.32 ± 0.09%. The highest TOC was at 1C, indicating relatively higher organic matter accumulation, potentially due to decaying biological material or sediment trapping. The control site had the lowest TOC, suggesting minimal organic input. Phosphorus levels varied between 13.51 and 33.96 mg/kg, with a mean of 20.59 ± 7.68 mg/kg. The maximum value at 1D may be attributed to anthropogenic inputs or biogenic activity, while the lowest at 1A shows a more baseline nutrient condition. Sulphur content was relatively uniform, ranging from 64.78 to 73.05 mg/kg, with a mean of 68.03 ± 2.90 mg/kg. The highest sulphur at 1C and lowest at the control indicate subtle differences in organic degradation and sulphide mineral formation. Nickel was

Below Detection Limit (BDL) at all stations, indicating absence or extremely low levels of this metal across offshore areas. Lead ranged from 9.75 to 49.90 mg/kg, with a mean of 26.38 ± 17.93 mg/kg at 1E points, while 1A had the lowest. Cadmium was BDL at all stations except 1E, which recorded 2.10 mg/kg, setting both the min and max value. This indicates localized contamination at 1E, raising environmental concerns. Chromium concentrations ranged from 20.60 to 32.70 mg/kg, with a mean of 26.62 ± 5.22 mg/kg. The highest value at 1D may indicate geological inputs or marine activity-related accumulation (Table 3).

Zinc values ranged from BDL to 17.80 mg/kg, mean 7.20 ± 9.25 mg/kg at 1A, while most other stations had very low or non-detectable levels. Copper was BDL at all stations, indicating no detectable contamination from copper-based antifouling agents or industrial discharge. Manganese ranged from 147.00 to 157.50 mg/kg, mean 151.36 ± 4.03 mg/kg. These values show consistent background levels across all sites, with slight natural variations. Cobalt showed high variability, ranging from BDL to 22.30 mg/kg, with a mean of 13.11 ± 9.37 mg/kg. The peak concentration at 1B indicates a possible localized contamination, while other stations varied in presence.

2.8.2. Cargo Jetty

The sediment pH in the cargo jetty region ranged from 7.18 to 7.55 with a mean value of 7.34 ± 0.12, indicating slightly alkaline conditions suitable for marine life. Salinity varied between 13 and 20 PSU with an average of 16.50 ± 2.88, suggesting a moderately saline environment influenced by marine waters (Table 4). Petroleum hydrocarbon levels were detected between 2.30 and 4.80 µg/g (mean 3.41 ± 1.27 µg/g), with some stations showing BDL, implying moderate but localized contamination, likely from shipping activities. Magnesium content was highly variable, ranging from 352.35 to 923.40 mg/kg, and averaging 599.93 ± 215.61 mg/kg, reflecting natural sediment composition and mineral inputs. Sediment texture showed sand content from 27.6% to 48.2% (mean 38.28 ± 8.45%), silt from 20.0% to 41.7% (mean 26.82 ± 7.95%), and clay from 25.6% to 52.3% (mean 34.90 ± 10.85%),

indicating a mix of moderately coarse to fine sediments likely deposited under varying energy conditions.

Total Organic Carbon (TOC) ranged from 0.54% to 0.75%, averaging 0.65 ± 0.08%, which reflects moderate organic matter content likely influenced by anthropogenic inputs and natural productivity. Phosphorus levels ranged significantly from 16.46 to 48.00 mg/kg (mean 26.05 ± 12.03 mg/kg), pointing to variable nutrient input across the area. Sulphur content exhibited an extremely wide range from 70.13 to 877.48 mg/kg (mean 213.22 ± 325.56 mg/kg), indicating possible organic matter degradation at some stations. Heavy metals showed mixed results: Nickel was BDL throughout, suggesting negligible contamination. Lead ranged from 15.85 to 23.90 mg/kg (mean 20.57 ± 2.93), showing low-level contamination. Cadmium was only detected at one station (5.25 mg/kg) and in the control (3.45 mg/kg), indicating localized enrichment (mean 4.35 ± 1.27 mg/kg). Chromium varied from 34.60 to 53.85 mg/kg (mean 42.29 ± 7.88 mg/kg), showing a moderate background level.

Zinc ranged between 37.60 and 57.05 mg/kg (mean 43.32 ± 7.57 mg/kg), while Copper showed a more pronounced variation from 2.70 to 14.50 mg/kg (mean 7.53 ± 4.19 mg/kg). Manganese values were relatively consistent, between 149.90 and 155.80 mg/kg (mean 153.99 ± 2.23 mg/kg). Finally, Cobalt concentrations ranged from BDL to 7.85 mg/kg (mean 5.53 ± 1.88 mg/kg).

2.8.3. Phang Creek

The sediment pH in Phang Creek ranged from 7.35 to 7.55 with a mean of 7.42 ± 0.08, indicating a slightly alkaline environment, typical of estuarine or marine-influenced systems. Salinity levels varied between 14 and 20 PSU (mean 17.17 ± 2.23), reflecting moderate marine influence with possible freshwater mixing. Petroleum hydrocarbons showed a wide range (2.87 to 14.52 µg/g, mean 6.51 ± 4.90 µg/g), with detection at most stations, suggesting localized hydrocarbon contamination, potentially from boat traffic or runoff. Magnesium content ranged significantly from 425.25 to 1166.40 mg/kg (mean 641.93 ± 292.15 mg/kg), indicating

variable sediment mineral composition, possibly influenced by upstream inputs and sediment type.

Sediment texture revealed sand content from 14.9% to 41.3% (mean 28.48 ± 9.83%), silt from 7.9% to 54.3% (mean 33.33 ± 19.21%), and clay from 15.3% to 73.7% (mean 38.18 ± 27.43%) as shown in Table 5, suggesting a diverse depositional environment ranging from coarser to finer sediments. Total organic carbon content varied from 0.27% to 0.57%, with a mean of 0.44 ± 0.12%, indicating moderate organic matter accumulation. Phosphorus levels were between 14.03 and 21.66 mg/kg (mean 17.07 ± 2.92), pointing to consistent nutrient input, while sulphur ranged from 57.70 to 78.85 mg/kg (mean 64.40 ± 7.43), indicating active organic matter decomposition and possibly reducing conditions.

Among heavy metals, Nickel and Cadmium were Below Detection Limits (BDL) across all stations, indicating no significant contamination. Lead was detected at all sites, ranging from 16.95 to 24.15 mg/kg (mean 20.88 ± 3.12), showing moderate levels likely from anthropogenic sources. Chromium ranged between 33.80 and 54.85 mg/kg (mean 45.65 ± 8.67), suggesting natural background levels with minor inputs. Zinc and Copper were present in the range of 28.80–46.65 mg/kg (mean 38.48 ± 7.71) and 13.15–17.00 mg/kg (mean 15.19 ± 1.65), respectively, indicating trace metal presence possibly from urban runoff or boat maintenance. Manganese showed a narrow range (150.45 to 155.60 mg/kg, mean 153.28 ± 1.88), while Cobalt varied widely from 3.90 to 15.25 mg/kg (mean 8.98 ± 4.83).

Table 3: Physico-chemical characteristics of sediment samples collected from Offshore location

S. No	Parameters	1A	1B	1C	1D	1E	Control 1
1	pH (1: 10 suspension)	7.23	7.41	7.42	7.57	7.52	7.56
2	Salinity	20	16	6	10	10	13
3	Petroleum Hydrocarbon	12.21	BDL	BDL	2.87	4.28	BDL
4	Magnesium	777.6	437.4	619.65	643.95	789.75	498.15
5	Sand (%)	41.8	20	31.9	43.6	44.8	13.1
	Silt (%)	27.7	7.5	14.7	32.9	33.1	8.6
	Clay (%)	30.5	72.5	53.4	23.5	22.1	78.3
6	Total organic carbon	0.33	0.3	0.45	0.24	0.36	0.21
7	Phosphorus	13.51	14.21	17.33	33.96	24.43	20.1
8	Sulphur	65.66	67.65	73.05	68.81	68.23	64.78
9	Nickel	BDL	BDL	BDL	BDL	BDL	BDL
10	Lead	9.75	15.4	18.4	48.55	49.9	16.3
11	Cadmium	BDL	BDL	BDL	BDL	2.1	BDL
12	Chromium	20.6	22.1	29.3	32.7	31.6	23.4
13	Zinc	17.8	0.8	BDL	BDL	BDL	3
14	Copper	BDL	BDL	BDL	BDL	BDL	BDL
15	Manganese	149.85	150.15	148.65	157.5	155	147
16	Cobalt	0.5	22.3	BDL	17.45	12.2	BDL

Table 4: Physico-chemical characteristics of sediment samples collected from Cargo jetty

S. No	Parameters	2A	2B	2C	2D	2E	Control 2
1	pH (1: 10 suspension)	7.32	7.38	7.29	7.18	7.29	7.55
2	Salinity	19	15	20	18	13	14
3	Petroleum Hydrocarbon	2.3	BDL	4.8	3.12	BDL	BDL
4	Magnesium	777.6	607.5	923.4	489.15	449.55	352.35
5	Sand (%)	48.2	48.1	37.1	37.2	27.6	31.5
	Silt (%)	26.2	25.4	27.5	20	20.1	41.7
	Clay (%)	25.6	26.5	35.4	42.8	52.3	26.8
6	Total organic carbon	0.69	0.57	0.72	0.75	0.54	0.63
7	Phosphorus	22.35	16.46	16.81	48	31.36	21.31
8	Sulphur	877.48	85.27	96.15	77.88	72.39	70.13
9	Nickel	BDL	BDL	BDL	BDL	BDL	BDL
10	Lead	23.9	19.95	23.2	21.25	19.25	15.85
11	Cadmium	5.25	BDL	BDL	BDL	BDL	3.45
12	Chromium	53.85	41.95	34.95	49.5	38.9	34.6
13	Zinc	42.9	37.6	38.2	57.05	46.3	37.85
14	Copper	10.15	5.1	6.75	14.5	5.95	2.7
15	Manganese	155.6	155.8	153.1	154.5	155.05	149.9
16	Cobalt	3.35	6.45	6.15	BDL	7.85	3.85

Table 5: Physico-chemical characteristics of sediment samples collected from Phang creek

S. No	Parameters	3A	3B	3C	3D	3E	Control 3
1	pH (1: 10 suspension)	7.39	7.45	7.55	7.35	7.4	7.35
2	Salinity	20	14	16	16	18	19
3	Petroleum Hydrocarbon	3.58	2.87	14.52	BDL	3.68	7.88
4	Magnesium	1166.4	801.9	425.25	425.25	498.15	534.6
5	Sand (%)	14.9	19.8	33	34.6	41.3	27.3
	Silt (%)	11.4	7.9	36.9	46.1	43.4	54.3
	Clay (%)	73.7	72.3	30.1	19.3	15.3	18.4
6	Total organic carbon	0.42	0.57	0.33	0.27	0.54	0.51
7	Phosphorus	14.03	16.46	19.41	16.11	14.73	21.66
8	Sulphur	78.85	62.17	57.7	64.29	60.53	62.83
9	Nickel	BDL	BDL	BDL	BDL	BDL	BDL
10	Lead	17.05	16.95	23.2	21.7	22.2	24.15
11	Cadmium	BDL	BDL	BDL	BDL	BDL	BDL
12	Chromium	35.8	33.8	54.85	50.05	48.8	50.6
13	Zinc	28.8	37.5	29.85	43.85	46.65	44.2
14	Copper	BDL	BDL	17	13.15	14.7	15.9
15	Manganese	151.7	150.45	153.85	155.6	154.35	153.75
16	Cobalt	12.85	BDL	6.95	3.9	5.95	15.25

Chapter 3 Biological Characteristics of the Sediment

3.1. Introduction

Earth's total volume of water is estimated at 1.386 billion km³, among that, the salty water contributes almost 97.5% and the rest 2.5% contains freshwater. The existence of oceans on the Earth makes appearing it as blue planet from the space. Indian Ocean is the 3rd largest ocean in the world which (with its sub seas) surrounds to India on three sides with average depth of 3,890 meters (12,760 ft). As having at long coastline of almost 8000 km, India has vast marine resources. The Indian ocean's connection is a very large scale, including the Red Sea, East Africa, the Persian Gulf, Southern Arabia, India and Other Indian sub continental countries. This connection network connected people from all the coastal areas of the Indian Ocean and beyond, trading in aromatics, textiles, spices, precious stones, industrial productions, grain and an incredible range of other commodities and substances. Gujarat state of India shows longest coastline compare to other Indian states. Gujarat coastline is famous for various coastal ecosystems and habitats such as estuary, coral reefs, marshes, mangroves, and lagoons, rocky and sandy areas. Gujarat coasts having different coastal ecosystems like mangrove, sandy shores, muddy shores, rocky shores, mixed shores, wet sand shore, coral reefs and intertidal mudflats (Brink, 1993; Parasharya and Patel, 2014). Gujarat state is the only state in India bestowed with two gulfs, Gulf of Kachchh and Gulf of Khambhat. The Kachchh, largest district of the country with an area of 45,652 sq.km. Deendayal Port Authority is (DPT) one among the 12 major ports of the country and it is located in India's western coastal region

3.2. Benthos

Benthic animals are considered as the organism which lives in the bottom layer of all types of ecosystems including saline water as well as in freshwater. Benthos is nothing but water bottom communities or the organisms (floral and faunal) live in a benthic region regarding the sediment, rock and other substratum. They include mollusca (gastropods and bivalves), coral, sponges, worms (mostly polychaetes and nematode), crustacean crabs, other crustaceans, echinoderms, oysters etc. They play an important

role in conversion of organic detritus from the sedimentary storage into the dissolved nutrients. Their distribution in water bodies can be varies and, on that basis, they can be classified into three types which are Endo-benthos, Epi-benthos (Pearson and Rosenberg, 1978) and Hyper-benthos (Mees and Jones,1997). Benthos could also recognize as one of the best indicators to assess the health and productivity of aquatic ecosystems. The benthic particularly macro benthic communities are an integral part of the coastal biotic components. They can serve as important food resource for the diverse groups of various organisms particularly bottom feeding animals. They are sensitive to wide range of environmental challenges including water movements, pollutants and living spaces (Martin et al., 2011). Their variations to tolerate changes in various environmental factors make them to be considered as an important bio-indicator for monitoring and research of marine environment.

3.3. Methodology

To study the benthic organisms, triplicate samples were collected at each station using Van-Veen grab which covered an area of $0.1m^2$. The wet sediment was sieved with varying mesh sizes (0.5 mm-macrofauna) for segregating the organisms. The organisms retained in the sieve were fixed in 5-7% formalin and stained further with Rose Bengal solution for easy spotting at the time of sorting. The number of organisms in each grab sample was expressed as number/ meter square (No/m^2). All the species were sorted, enumerated and identified to the advanced taxonomic level possible with the consultation of available literature. The works of Fauvel (1953), Day (1967) were referred for polychaetes; Barnes (1980) and Lyla *et al*. (1999) for crustaceans; Subba Rao *et al.* (1991) and Ramakrishna (2003) for molluscs.

Further, the data were treated with univariate statistical methods in PRIMER (Ver. 6.) statistical software (Clarke and Warwick, 1994)

a) Shannon – Wiener index

In the present study, the data were analyzed for diversity index (H') by following Shannon – Wiener's formula (1949):

$H' = -\sum^{S} Pi \log 2 Pi \ldots\ldots \quad i = 1$

which can be rewritten as

$$H' = \frac{3.3219\,(N \log N - \sum ni - \log ni}{N}$$

where, H'= species diversity in bits of information per individual

ni = proportion of the samples belonging to the ith species

(number of individuals of the ith species)

N = total number of individuals in the collection and

$\sum$ = sum

b) Species richness(S) was calculated using the following formula given by Margalef (1958)

c) Margalef index (d)

$d = (S-1) / \log N$

d) Pielou's evenness index

The equitability (J') was computed using the following formula of Pielou (1966):

$$J' = \frac{H'}{\log_2 S} \text{ or } \frac{H'}{\ln S}$$

Where, J' = evenness; H' = species diversity in bits of information per individual and S = total number of species.

3.4. Results on Species Composition, Population density and Biomass of Macrofauna of selected sites

3.4.1. Offshore

In Offshore region of Kandala port, total six sites were selected namely, (1A, 1B, 1C, 1D, 1E and 1- control). A total 5 groups/species (of benthic community) of benthic animals were observed in all stations at Offshore sites and they are Bivalves (Mollusca), Gastropods (Mollusca), Crustacean animals, Polychaeta worms (Annelida), *Pirenella cingulata* (gastropoda). All the data (Density and Biomass) expressed in (nos./m^2), (gm/m^2) respectively (Table 6).

Highest population density of benthic organisms was recorded in station 1D-Offshore(1500nos/m^2), whereas lowest in station 1E-Offshore(325nos/m^2). The density range of all stations varied from 325 to 1500nos./m^2. Bivalves and Gastropods were more abundant among all the benthic organisms might be sandy-muddy or rocky substratum in bottom part of Offshore region. Presence of Crustacean animals and *Pirenella cingulata that* indicated some part of substratum are muddy mix with rocky and habitat for them. The highest biomass value (expressed wet weight) of benthic fauna was observed in station 1C-Offshore (16.88gm/m^2) and lowest value was 1B-Offshore (2.29 gm/m^2) (Table 6). Lowest value of biomass is may be indication of competition between animals and predator pressure. Range of the Biomass was 2.29 to 16.88 gm/$m^{2.}$ Moderately Biomass value and also density value suggested mixing substratum, less availability of plenty food items and more predator pressure by higher animals. Intermediate association is also one responsible factor for the same. Variation in density and biomass in Offshore region because more influences by the Water Currents, Up welling - Down welling (Churning process of water) movements of water, Nutrients availability and Fluctuation in turbidity of water. Variation in substratum is also a one responsible factor for distribution of benthic organisms.

3.4.2. Cargo Jetty

In Cargo Jetty, frequently observed benthic groups were Bivalves and Gastropods less reported benthos were *Saccostrea sp* (Bivalvia), *Pirenella cingulta*, Polychaeta worms and Crustacean animals (Crabs, Barnacles etc.). The population density range noted between 75 to 525(nos/m^2) among all the stations (Cargo Jetty-2A, 2B, 2C, 2D, 2E &2-Control) during the study period. Highest and Lowest density were recorded in station 2Control- Cargo Jetty(525nos./m^2) and 2A-Cargo Jetty (75nos./m^2) respectively.

Biomass value indicated a highest value in station 2Control- Cargo Jetty (8.00gm/m^2) and lowest in 2A- Cargo Jetty (1.88gm/m^2) (Table 6). Average Biomass and Population density value of all station were 5.11gm/m^2, 325nos./m^2 respectively which indicated the low to moderate environment condition of biota, water quality as well as substratum (mostly rocky).

3.4.3. Phang creek

Six Stations of Phang creek were selected for the study namely 3A, 3B, 3C, 3D, 3E and 3-control-Phang Creek. In this Phang Creek benthic organisms were mostly represented by Polychaeta worms (annelids). Only three groups were present namely Polychaeta worms, Bivalve, Gastropods whereas *Pirenella cingulata, Crustacean animals* and *Saccostrea sp* were totally absent. Bivalve group was only noted in 3Control-Phang creek. Polychaeta worms ware more abundant because of suitable muddy environment. The population density was highest in station 3C -Phang Creek (300nos./m^2) and on the other side, lowest density was recorded in 3E-Phang Creek (25nos./m^2). Station 3D-Phang Creek comprises highest wet wt (3.13gm/m^2), whereas low value was recorded in 3A-Phang Creek(0.81 gm/m^2).

Overall result (Offshore, Cargo Jetty and Phang creek) of macrofaunal community showed highest population density in 1D-Offshore (1500nos/m^2) and high biomass was observed (16.88gm/m^2) in 1C-Offshore. Table 6 showed highest population values of Bivalves in 1D- Offshore and 2D-Cargo jetty (300nos/m^2) and same highest

value of Gastropoda showed in 1Control- Offshore (750nos/m^2). The lowest value comprised by the Polychaeta worms (Annelids worms) *and Saccostrea sp (Bivalves)* including some were totally absent in some sites. Some absent or less frequently observed benthos indicated extreme weather condition (may be suddenly change temperature of running season), more stress condition and unfavourable environment condition for their survival. Bivalves and Gastropods, dominant groups were preferred rocky, sandy or mix substratum, and any other hard substrata. Polychaete worms are preferred sandy-muddy substratum or sandy habitat mostly in Phang creek.

Table 6 showed that average population density and biomass higher in Offshore and after Cargo jetty where mostly rocky, sandy or some part covered with muddy area and algal growth providing a unique habitats for benthos. Low density and biomass was observed in mostly Phang creek area (Table 6 and Figure 2) which indicated stressful environment, seasonal effect, more anthropogenic activities and also might be some chemical and biological changes in water. The population density and biomass of benthic community largely affected by the symbiotic and intermediate relation between them or with other invertebrates and suitable rocky substratum or coral reef in bottom of sea. Availability of Plankton, as a food source, also affected the benthic animals (Table 6 and Fig. 1 & 2). Extremely mix weather condition (during June and July months) also more affected in Cargo jetty and Phang creek regions of Kandla port area.

In benthic communities, recorded species at all sites were *Pirenella cingulata, Clypeomorus bifasciata, Trochus sp, Radix sp, Donax sp, Turris sp, Marcia sp, Dosinia sp, Donax sp, Anadara sp, Turris sp, Solen, Nereis sp, Saccostrea sp, Optediceros breviculum etc. The percentage of occurrence (Table 6) was revealed highest group present by Gastropoda (78%) then following are Bivalves (67%), Polychaeta worms (Annelids worms) (61%), Crustacean animals (Crabs, Barnacles etc.) (28%), Saccostrea sp and Pirenella cingulata (22%). Detail status of Population density, Group composition and biomass of the benthic community of all selected sites were depicted in (Table 6) and (Figure 2).* Among all the stations, highest percentage

composition recorded by Gastropoda (35%) followed by Bivalves (28%), Pirenella cingulata (gastropoda) and others (Figure.2).

Phytoplankton abundance and their size, zooplankton body composition, patchy distribution of zooplankton, water currents, ebb and flow tides, and water churning process, changing in structure of muddy, rocky and sandy habitats are the main reasons for biomass and density fluctuation in Benthic communities. In Crustacean most commonly observed species are Crabs and attached Barnacles. Main Mollucsa families recorded Trochidae, Cerithidea, Turritellidae, Tellinidae, Donacidae and Bucciniae etc. *Nereis sp* of anneliids was mostly observed in samples. More number of the broken bivalves, debris, plant items, broken gastropods, small pebbles and soil particles are frequently observed during benthic organism's study.

3.4.4. Diversity Indices of Benthic Community

Table 7 showed various diversity indices calculation, showed that Shannon Diversity Index ranging from (0.00-1.36) indicated very low diversity. Highest diversity indices was recorded in Station 1D-Offshore (1.36) whereas Shannon indices nil (zero) observed in 3A, 3B, 3E(Phang creek). Comparatively less Shannon indices value very low in Phang creek area where number of benthos group/species present between 1 to 3 nos. The evenness values ranged between (0.49 to 1). The highest evenness value (1) is observed in stations Offshore 3A, 3B and 3E (Phang creek). Evenness value "1" indicated all organisms occurred in same area or mostly same group or very low in number. Simpson's Index value ranged between 0.00 to 0.74 indicated to lower to very less moderate diversity. The Margalef value showed range of 0.00 to 0.48 indicated high variation in species/group numbers (Table 7).

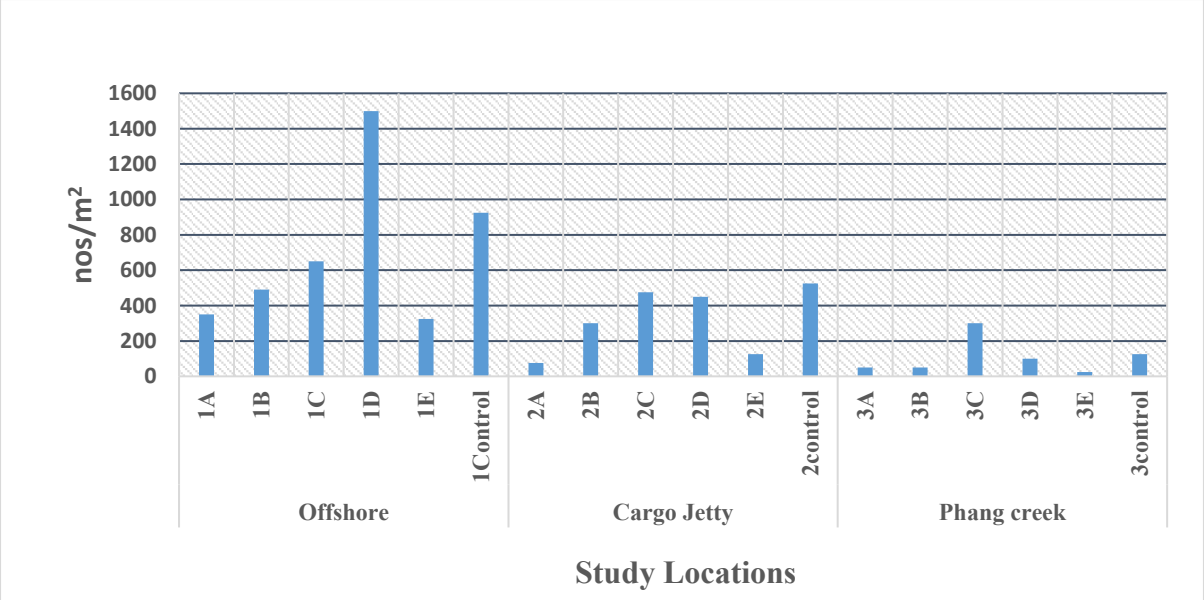

Figure 1. Population density of benthic organisms (nos/m^2) in various sites

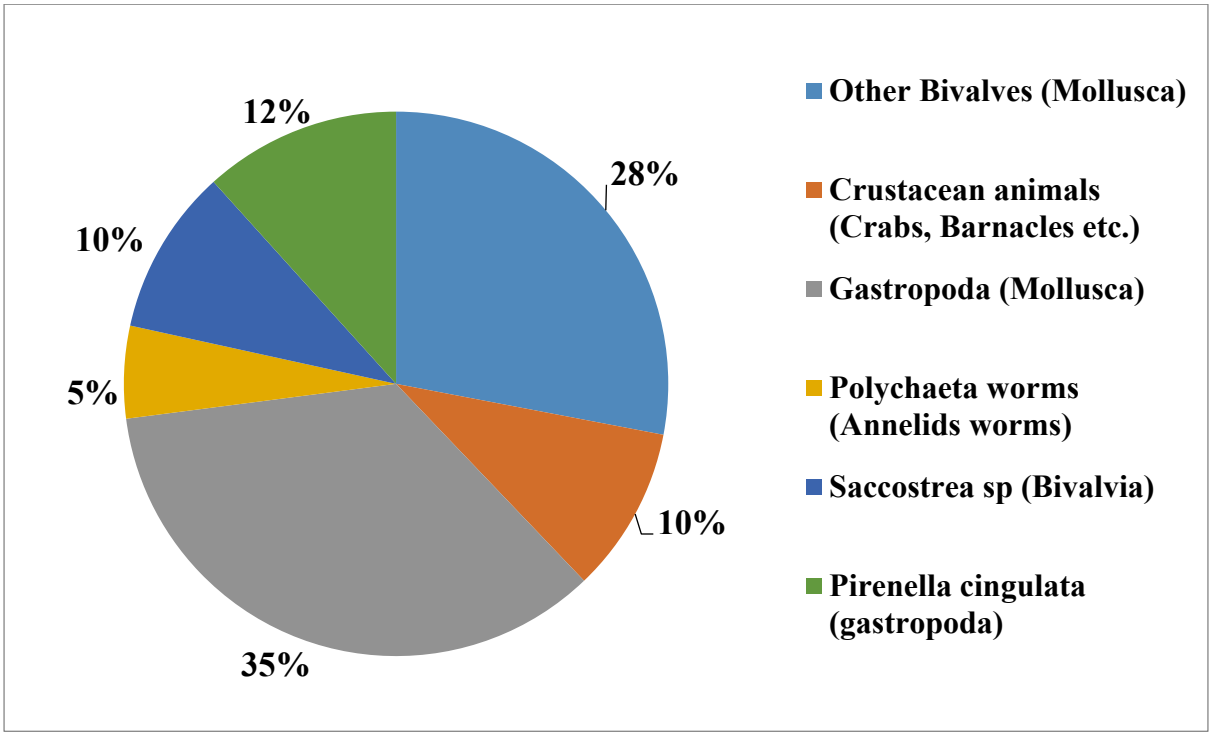

Figure 2. Percentage composition of benthic organisms in various sites

Table 6. Macrobenthos distribution in different sites of Deendayal Port

Name of Station	Offshore						Cargo Jetty						Phang creek						
	1A	1B	1C	1D	1E	1-Control	2A	2B	2C	2D	2E	2-Control	3A	3B	3C	3D	3E	3-Control	% of Occurrence
Nameof Benthic Groups																			
Other Bivalves (Mollusca)	250	165	250	300	125	100	25	0	75	300	25	250	0	0	0	0	0	50	67
Crustacean animals (Crabs, Mysis etc.)	50	125	100	375	0	25	0	0	0	0	0	0	0	0	0	0	0	0	28
Other Gastropoda (Mollusca)	50	75	0	525	75	750	50	50	125	125	50	175	0	0	250	50	0	50	78
Polychaeta wormsMarine Annelids	0	0	50	0	0	50	0	0	0	25	0	0	50	50	50	50	25	25	61
Saccostrea sp (Bivalvia)	0	0	0	0	0	0	0	250	275	0	50	100	0	0	0	0	0	0	22
Pirenella cingulata (gastropoda)	0	125	250	300	125	0	0	0	0	0	0	0	0	0	0	0	0	0	22
Total Population Density Nos/m^2	350	490	650	1500	325	925	75	300	475	450	125	525	50	50	300	100	25	125	
Biomass (wet weight) gm/m^2	2.96	2.29	16.88	9.75	3.98	8.14	1.88	4.21	5.86	6.92	3.84	8	0.81	0.88	3.06	3.13	1.06	1.72	

Table 7. Diversity indices of benthic faunal groups at various station of Deendayal Port –Kandla (Benthos)

	Offshore						Cargo Jetty						Phang Creek					
	1A	**1B**	**1C**	**1D**	**1E**	**1-control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2-contrl**	**3A**	**3B**	**3C**	**3D**	**3E**	**3cont**
Variables																		
Taxa_S	3	4	4	4	3	4	2	2	3	3	3	3	1	1	2	2	1	3
Individuals (Nos./m^2)	350	490	650	1500	325	925	75	300	475	450	125	525	50	50	300	100	25	125
Dominance_D	0.55	0.27	0.33	0.27	0.35	0.67	0.56	0.72	0.43	0.52	0.36	0.37	1.00	1.00	0.72	0.50	1.00	0.36
Shannon Diversity Index (H)	0.80	1.35	1.22	1.36	1.07	0.67	0.64	0.45	0.96	0.79	1.06	1.04	0.00	0.00	0.45	0.69	0.00	1.06
Simpson_1-D	0.45	0.73	0.67	0.74	0.65	0.33	0.44	0.28	0.57	0.48	0.64	0.63	0.00	0.00	0.28	0.50	0.00	0.64
Evenness_e^H/S	0.74	0.97	0.85	0.97	0.98	0.49	0.94	0.78	0.87	0.73	0.96	0.94	1.00	1.00	0.78	1.00	1.00	0.96
Menhinick	0.16	0.18	0.16	0.10	0.17	0.13	0.23	0.12	0.14	0.14	0.27	0.13	0.14	0.14	0.12	0.20	0.20	0.27
Margalef	0.34	0.48	0.46	0.41	0.35	0.44	0.23	0.18	0.32	0.33	0.41	0.32	0.00	0.00	0.18	0.22	0.00	0.41

Chapter 4 Physico-Chemical Characteristics of Marine Water

4.1. Introduction

In recent decades, there has been a notable deterioration in aquatic ecosystems primarily caused by the presence of a diverse array of organic and inorganic contaminants. Among these pollutants, heavy metals (HMs) and microplastics (MPs) have emerged as significant contributors to this environmental degradation (Frew et al., 2020; Saha et al., 2016). These substances are recognized for their capability to infiltrate and accumulate within the aquatic food chain, making them hazardous pollutants in aquatic environments (Olojo et al., 2005). Of particular concern are heavy metals due to their toxic nature, long-lasting presence, resistance to degradation, the potential for bioaccumulation, and the ability to magnify up the food chain, all of which have raised global alarms (Begum et al., 2013; Cai et al., 2017).

Heavy metal pollution in aquatic ecosystems can be attributed to a variety of sources, including natural factors such as atmospheric deposition and weathering (Ebrahimpour and Mushrifah, 2010; Hamidian et al., 2016) as well as human activities like mining, agricultural runoff, sewage discharge, industrial effluent release, gasoline leaks from fishing vessels, and accidental chemical waste spills (Arulkumar et al., 2017). It is essential to recognize that certain heavy metals, such as copper (Cu), iron (Fe), nickel (Ni), cobalt (Co), zinc (Zn), manganese (Mn), and chromium (Cr), play vital roles in physiological processes and are necessary for the proper biological functioning of organisms in trace amounts. However, exposure to nonessential heavy metals can lead to various health concerns, including renal, cardiovascular, nervous, and bone diseases, as well as immune-related issues (Abadi et al., 2018; Madreseh et al., 2018). It is crucial to acknowledge that all heavy metals become toxic when their concentration exceeds a certain threshold level (Makedonski et al., 2017). In light of these concerns, it is imperative to assess the various characteristics of water in order to determine the extent of pollutant presence in aquatic environments.

4.2. Materials and Methods

In this study, marine water and sediment samples were collected following standard protocols, and their analysis was conducted using established methods for marine water and sediment analysis as prescribed by APHA (2012), NIO manual (1982), and ICMAM Manual (2012). For general analysis, surface water samples were collected using a clean polyethylene bucket, while water samples from the bottom were collected using a weighted Niskin sampler. Water samples at a depth of 1 meter below the surface were collected using a 1-liter glass bottle sampler. Parameters such as pH, temperature, and salinity were measured on-site using handheld meters and verified in the laboratory.

The collected water samples were stored under refrigerated conditions until further analysis of other parameters. According to the standard protocol, fixatives and preservatives were added to the samples for specific parameters. For example, Winkler A&B solution was immediately added to measure dissolved oxygen, concentrated H2SO4 was used to bring the pH below 2 for chemical oxygen demand analysis, and nitric acid was used for the preservation of heavy metals. Formalin was added to marine water samples for planktonic analysis. In general, all water and sediment samples were stored in sterile polythene bottles and Ziplock bags and kept in an icebox to maintain suitable conditions until they were transported to the laboratory. The parameters to be analyzed (Table 8) and the methods used for the sample analysis are described below.

Table 8: Physico-chemical and biological characteristics of marine water samples

S. No	Physico-chemical and Biological parameters
1	pH
2	Temperature (°C)
3	Salinity (ppt)
4	Total Dissolved Solids (mg/L)
5	Turbidity (NTU)
6	Dissolved Oxygen (mg/L)
7	Bio-Chemical Oxygen Demand (mg/L)
8	Chemical Oxygen Demand (mg/L)
9	Phenolic compound (µg/L)

10	Petroleum Hydrocarbons (µg/L)
11	Oil and grease (mg/L)
12	Cadmium (mg/L)
13	Lead (mg/L)
14	Chromium (mg/L)
15	Copper (mg/L)
16	Cobalt (mg/L)
17	Nickel (mg/L)
18	Zinc (mg/L)
19	Manganese (mg/L)
20	Magnesium (mg/L)
21	Chlorophyll (mg/m^3)
22	Phaeophytin (mg/m^3)
23	Phytoplankton Phytoplankton cell counts (no/L) Total Genera (no.) Major Genera
24	Zooplankton Biomass ($ml/100m^3$) Population ($no/100m^3$) Total Group (no.) and Major Groups

4.2.1. pH, Temperature and Salinity

pH and temperature measurements were conducted using a Thermo Fisher pH/EC/Temperature meter. Prior to use, the instrument was calibrated with standard buffers. For pH determination, an appropriate volume of the sample was titrated against silver nitrate (20 g/l), with potassium chromate serving as an indicator. The chlorinity of the sample was estimated, and salinity values were derived using a specific formula.

4.2.2. Total Dissolved Solids (TDS)

To confirm the readings obtained from the handheld meter, the samples underwent a gravimetric procedure. Approximately 100 ml of the water sample was taken in a beaker and filtered. The filtered sample was then completely dried in a hot air oven at 105°C. The TDS values were calculated by measuring the difference between the initial and final weight of the dried sample.

4.2.3. Turbidity

For turbidity measurement, a sample tube (Nephelometric cuvette) was filled with distilled water and inserted into the sample holder. The lid of the sample compartment was closed, and the meter reading was adjusted to zero by manipulating the 'SET ZERO' knob. The sample tube containing the 40 NTU standard solution was then placed in the tube, and the meter reading was set to 100. Similar measurements were carried out for other standard solutions. To determine the turbidity of the marine water sample, the sample tube was filled with the water sample, and the corresponding reading was recorded.

4.2.4. Dissolved Oxygen (DO)

To determine the Dissolved Oxygen (DO) levels in a water sample obtained from a marine environment, the following procedure was employed. Collect sea water sample, ensuring that the sampling container is clean and free from any potential contaminants that may affect the accuracy of the results. Subsequently, transfer the water sample into a Winkler's bottle or a suitable container, taking care to eliminate any trapped air bubbles. It is crucial to completely fill the bottle to minimize any headspace that could potentially alter the DO readings. Next, add the appropriate volumes of Winkler's reagents, such as manganese sulfate and alkali-iodide-azide, to the water sample as per the specific instructions of the Winkler's method. Gently and thoroughly mix the contents of the bottle to ensure uniform distribution of the reagents without introducing any air bubbles. Allow the bottle to stand undisturbed for a designated incubation period, typically around 30 minutes, to enable the necessary reactions to occur. After the incubation period, perform a titration using a standardized sodium thiosulfate ($Na_2S_2O_3$) solution until a faint yellow color appears, indicating the complete consumption of dissolved oxygen in the sample. Record the volume of sodium thiosulfate solution used for titration, which represents the amount of dissolved oxygen present in the water sample. To account for any dissolved oxygen in the reagents, it is essential to conduct the same procedure with blank samples that do not contain the water sample. This allows for an accurate calculation of the DO levels

in the original water sample. Finally, employ the appropriate formula provided by Winkler's method to calculate the DO concentration in the water sample.

4.2.5. Biochemical Oxygen Demand (BOD)

To determine the Biochemical Oxygen Demand (BOD), the following procedure was employed using the direct unseeded method. Collect representative sea water sample from the desired location, ensuring the sampling container is clean and uncontaminated. Fill a BOD bottle with the water sample, leaving minimal headspace to prevent air contact that could affect BOD measurements. It's important to completely fill the bottle to minimize air bubbles. Record the initial Dissolved Oxygen (DO) level in the water sample using a dissolved oxygen meter or appropriate measurement method. Seal the BOD bottle tightly with the stopper to prevent air exchange. Incubate the sealed BOD bottle in a controlled environment, such as a BOD incubator, at a specified temperature (typically 20°C), for a designated incubation period, usually around 5 days. Throughout the incubation period, keep the BOD bottle in darkness to minimize the impact of photosynthetic activity. After the incubation period, measure the final DO level in the water sample using the same method or instrument as the initial measurement. Calculate the BOD by subtracting the final DO level from the initial DO level, accounting for any necessary dilution or blank corrections. This difference represents the amount of oxygen consumed by the organic matter in the water sample during the incubation period.

4.2.6. Chemical Oxygen Demand (COD)

The Chemical Oxygen Demand (COD) test is a widely used method for quantifying the levels of organic and inorganic pollutants in water samples. The first step involves collecting representative water samples from the target site, ensuring proper labeling and record-keeping. Subsequently, these samples are placed into digestion vials or tubes, to which digestion reagents, typically potassium dichromate and sulfuric acid, are added. This step initiates the oxidation of organic matter in the sample. The sealed vials or tubes are then subjected to high-temperature heating,

typically around 150-160°C, for a predetermined period, usually around 2 hours. This heating process breaks down complex organic compounds into simpler forms. After digestion, the samples are allowed to cool to room temperature. To determine the COD concentration, a colorimetric measurement is taken. A suitable reagent is added to the digested samples, reacting with any residual potassium dichromate, and generating a color change proportional to the COD concentration. This color intensity is measured using a colorimeter or spectrophotometer, and the results are calibrated using known COD standards. The final calculations yield the COD value, typically expressed in milligrams of oxygen per liter (mg/L) of the sample.

4.2.7. Phenolic compounds

To analyze phenolic compounds in water, the following procedure was followed. A 500 ml water sample containing phenols was treated with 4-aminoantipyrine, which converted the phenols into an orange-colored antipyrine complex. This complex was then extracted using 25 ml of chloroform. The absorbance of the extracted complex was measured at 460 nm using phenol as a standard for comparison. This measurement allowed for the quantification of phenolic compounds present in the water sample.

4.2.8. Petroleum Hydrocarbons (PHc)

The analysis of Petroleum Hydrocarbons (PHc) in a water sample involved the following protocol. One liter seawater sample was extracted using organic solvent, hexane. The mixture was then separated into an organic layer and an aqueous layer. The organic layer, containing the petroleum hydrocarbons, was isolated. To remove any remaining water, the organic layer was dried using anhydrous sulphate. The volume of the organic layer was subsequently reduced to 10 ml at a temperature of 30°C under low pressure. The fluorescence of the extracted organic compound was measured at 360 nm (with excitation at 310 nm) using Saudi Arabian crude residue as a standard. This residue was obtained by evaporating the lighter fractions of crude oil at 120°C. By comparing the fluorescence intensity of the extract with that of the

standard, the concentration of petroleum hydrocarbons in the water sample could be determined.

4.2.9. Oil and Grease

To determine the content of Oil and Grease in a sample, the following procedure was followed. Approximately 500 ml of the sample was transferred to a separating funnel, and the sample bottle was rinsed with 30 ml of trichlorotrifluoroethane. The rinsing solvent was then added to the separating funnel. Next, 5 ml of 1:1 hydrochloric acid (HCl) was added to the mixture, and the contents were vigorously shaken for about 2 minutes. If a soluble emulsion was formed, the sample container was shaken for an additional 5 to 10 minutes. After shaking, the layers in the separating funnel were allowed to separate, and the lower layer (organic layer) was discarded.

The solvent layer was drained through a funnel containing a filter paper moistened with solvent, and it was collected in a clean distillation flask that had been pre-weighed. The solvent was then distilled from the flask using a water bath set at 70°C. The resulting residue was carefully transferred into a clean, pre-weighed, and dried beaker, using the minimum amount of solvent necessary. The beaker was placed on a water bath at 70°C for 15 minutes to evaporate off all the solvent. After the evaporation process, the beaker was cooled in a desiccator for 30 minutes to reach a consistent temperature, and its weight was then measured.

4.2.10. Heavy metals

Heavy metals are a significant concern, especially in coastal environments, since it is biomagnifying from lower organisms to higher organisms through water and sediment. Common heavy metals of concern include Cadmium (Cd), Lead (Pb), Chromium (Cr), Copper (Cu), Cobalt (Co), Nickel (Ni), Zinc (Zn), Magnesium (Mg) and Manganese (Mn). To release mineral elements from sediment and analyze them, a wet oxidation process is typically employed using oxidizing acids, such as a mixture of Tri / Di-acids.

The procedure begins by weighing 0.5 grams of the sediment sample and placing it in a 100 ml beaker, which is covered with a watch glass. Then, 12 ml of Aqua regia (a mixture of 1 part HNO3 and 3 parts HCl) is added to the beaker. The beaker is placed in a digestion apparatus and heated at 100°C for 3 hours on a hot plate using a sand bath. The sample is evaporated until it is nearly dry, and then allowed to cool for 5 minutes. Next, 20 ml of 2% nitric acid is added to the cooled sample in the beaker, and the mixture is further digested on the hot plate for 15 minutes. After digestion, the beaker is removed from the hot plate and allowed to cool. The sample is then filtered using a Whatman No. 42 mm filter paper to remove any solid particles. To make up the final volume, the filtrate is diluted with 2% nitric acid to a total volume of 50 ml. The resulting extracted sample is then aspirated into an Atomic Absorption Spectrometer (AAS) for analysis of the heavy metal concentrations.

4.3. Results

In this First season study conducted in the present year, we closely monitored three distinct locations: Offshore, Cargo Jetty, and Phang Creek. A comprehensive analysis of physico-chemical characteristics in marine water samples was conducted at each of these sites. The collected data is thoughtfully presented in Tables 9-11. These findings serve as a significant source of information regarding the precise physico-chemical conditions prevailing at each of these locations. Consequently, they play a pivotal role in enhancing the comprehension of the environmental factors that exert influence on the quality of marine water in these specific areas. The description of the data in each station is detailed as below.

4.3.1. Offshore

Temperature ranged from 24.70°C at Station 1D (BW) to 25.40°C at Station 1C (SW), with a mean of 25.01 ± 0.22°C, showing stable offshore thermal conditions. pH varied between 7.53 at Control 1 (BW) and 7.83 at Stations 1D (SW) and 1E (SW), with a mean of 7.77 ± 0.08, indicating slightly alkaline conditions. Salinity ranged from 35

PSU at Station 1A (BW) to 39 PSU at Stations 1B (SW) and 1C (SW), mean 36.83 ± 1.40 PSU, reflecting strong marine influence.

Total Dissolved Solids (TDS) were lowest at 38.44 ppt at Station 1C (BW) and highest at 42.34 ppt at Station 1A (SW), with a mean of 39.88 ± 1.07 ppt, consistent with high-salinity seawater. Turbidity showed high variability, ranging from 111 NTU at Station 1C (SW) to 486 NTU at Control 1 (BW), mean 237.17 ± 112.37 NTU, indicating fluctuations in suspended matter. Dissolved Oxygen (DO) was lowest at 5.80 mg/L at Station 1B (BW) and highest at 6.80 mg/L at Station 1C (SW), mean 6.35 ± 0.28 mg/L, showing generally good oxygenation. Biochemical Oxygen Demand (BOD) ranged from 2.10 mg/L at Control 1 (BW) to 2.90 mg/L at Station 1E (BW), mean 2.38 ± 0.22 mg/L, indicating low organic load. Chemical Oxygen Demand (COD) was lowest at 24.00 mg/L at Stations 1B (BW) and 1D (BW) and highest at 40.00 mg/L at Control 1 (SW), mean 31.33 ± 5.00 mg/L, suggesting moderate oxidizable material.

Phenolic compounds were lowest at 10.04 µg/L at Station 1E (BW) and highest at 59.29 µg/L at Station 1B (SW), mean 25.64 ± 13.77 µg/L. Petroleum hydrocarbons ranged from 2.48 µg/L at Control 1 (BW) to 24.58 µg/L at Station 1C (BW), mean 14.84 ± 5.90 µg/L, indicating localized oil contamination. Oil and grease varied between 1.60 mg/L at Station 1A (SW) and 16.00 mg/L at Control 1 (BW), mean 9.10 ± 4.47 mg/L. Magnesium was lowest at 1215.00 mg/L at Station 1B (SW) and highest at 2430.00 mg/L at Station 1E (BW), mean 1741.50 ± 324.92 mg/L, reflecting natural mineral variability.

For metals, Nickel, Zinc, Copper, and Cobalt were below detection limits at all stations. Lead was detected only at 0.54 mg/L in Station 1A (SW) and 0.56 mg/L in Station 1A (BW), mean 0.55 ± 0.01 mg/L. Cadmium ranged from 0.19 mg/L at Station 1C (BW) to 0.45 mg/L at Station 1A (BW), mean 0.32 ± 0.18 mg/L, present in few sites. Chromium varied from 0.24 mg/L at Station 1C (SW) to 0.60 mg/L at Station 1C (BW), mean 0.41 ± 0.16 mg/L, showing trace presence. Manganese was

lowest at 0.01 mg/L at Station 1B (SW) and highest at 0.70 mg/L at Station 1C (BW), mean 0.26 ± 0.19 mg/L, influenced by sediment interaction (Table 9)

4.3.2. Cargo Jetty

Temperature ranged from 25.1°C at Station 2A (BW) to 26.8°C at Station 2D (SW), with a mean of 25.99 ± 0.51°C (Table 10), showing stable but slightly warmer water at some sites, possibly due to shallow depth or localized heating. pH varied slightly between 7.67 at Control 2 (BW) and 7.80 at Station 2A (SW), mean 7.76 ± 0.046, indicating a healthy alkaline balance for marine waters. Salinity ranged from 35.0 PSU at Station 2C (BW) to 39.0 PSU at Station 2B (SW), mean 36.71 ± 1.32 PSU, consistent with marine influence.

Total Dissolved Solids (TDS) were lowest at 39.51 ppt at Control 2 (BW) and highest at 46.44 ppt at Station 2D (SW), mean 42.60 ± 2.24 ppt, reflecting normal seawater conditions with some variability. Turbidity showed wide variation from 192 NTU at Station 2A (SW) to 533 NTU at Control 2 (BW), mean 303.42 ± 117.97 NTU. Dissolved Oxygen (DO) ranged from 5.2 mg/L at Station 2D (BW) to 6.9 mg/L at Station 2B (SW), mean 6.18 ± 0.49 mg/L, with lower levels near the berth possibly due to organic matter decay. Biochemical Oxygen Demand (BOD) varied from 2.1 mg/L at Stations 2B (BW) and 2E (BW) to 3.1 mg/L at Station 2A (SW), mean 2.49 ± 0.34 mg/L, suggesting generally low organic pollution. Chemical Oxygen Demand (COD) was lowest at 22 mg/L at Control 2 (SW) and highest at 34 mg/L at Station 2B (SW), mean 28.50 ± 3.43 mg/L, indicating moderate oxidizable organic matter.

Phenolic compounds ranged widely from 4.61 µg/L at Station 2B (SW) to 58.07 µg/L at Control 2 (BW), mean 28.34 ± 17.28 µg/L. Petroleum hydrocarbons were lowest at 1.85 µg/L at Station 2E (SW) and highest at 21.52 µg/L at Station 2D (SW), mean 11.32 ± 7.79 µg/L, showing localized oil contamination. Oil and grease varied from 3.2 mg/L at Control 2 (SW) to 19.6 mg/L at Station 2D (SW), mean 10.97 ± 5.97 mg/L, with elevated levels near operational areas. Magnesium ranged between 1215 mg/L at Stations 2A (SW), 2C (SW), and Control 2 (SW) to 1944 mg/L at Station 2C

(BW) and 2E (SW), mean 1559.25 ± 282.97 mg/L, reflecting natural seawater mineral composition.

For metals, Nickel and Zinc were below detection limits at all stations. Lead ranged from 0.06 mg/L at Station 2B (BW) to 3.2 mg/L at Station 2A (BW), mean 1.78 ± 1.03 mg/L, indicating localized contamination. Cadmium varied between BDL and 0.90 mg/L at Station 2E (SW), mean 0.51 ± 0.34 mg/L, showing occasional detection. Chromium ranged from 0.40 mg/L at Station 2A (SW) to 2.00 mg/L at Control 2 (BW), mean 1.14 ± 0.47 mg/L, indicating moderate presence. Manganese was lowest at 0.05 mg/L at Control 2 (BW) and highest at 0.50 mg/L at Station 2E (SW), mean 0.20 ± 0.14 mg/L. Cobalt ranged from 0.80 mg/L at Control 2 (BW) to 2.12 mg/L at Station 2D (SW), mean 1.48 ± 0.57 mg/L.

4.3.3. Phang Creek

Temperature ranged from 24.2°C at Station 3E (BW) to 25.8°C at Stations 3E (SW) and Control-3 (SW), with a mean of 25.10 ± 0.47°C, reflecting stable conditions with slight spatial variation. pH varied between 7.70 at Station 3E (BW) and 7.80 at Stations 3B (BW), 3C (SW), and 3E (SW), mean 7.763 ± 0.037, indicating slightly alkaline water suitable for aquatic life. Salinity ranged from 36 PSU at Station 3B (SW) to 40 PSU at Stations 3D (BW), 3E (BW), and Control-3 (BW), mean 38.75 ± 1.22 PSU, reflecting strong marine influence (Table 11).

Total Dissolved Solids (TDS) were lowest at 39.32 ppt at Station 3B (BW) and highest at 49.54 ppt at Station 3E (BW), mean 44.12 ± 3.50 ppt, indicating variability in mineral content. Turbidity ranged from 216 NTU at Station 3A (SW) to 557 NTU at Station 3D (BW), mean 379.00 ± 99.31 NTU, suggesting higher suspended solids near berthing areas. Dissolved Oxygen (DO) was lowest at 5.2 mg/L at Control-3 (BW) and highest at 5.9 mg/L at Stations 3B (SW) and 3C (SW), mean 5.64 ± 0.21 mg/L, showing generally moderate oxygenation. Biochemical Oxygen Demand (BOD) varied between 2.2 mg/L at Station 3C (BW) and 3.0 mg/L at Station 3B (SW), mean 2.54 ± 0.26 mg/L, indicating low organic load. Chemical Oxygen Demand (COD) was lowest at 26 mg/L at Station 3D (SW) and highest at 44 mg/L at

Station 3E (BW), mean 34.67 ± 5.55 mg/L, suggesting moderate oxidizable organic matter.

Phenolic compounds ranged from 17.64 µg/L at Station 3C (SW) to 59.97 µg/L at Station 3C (BW), mean 33.66 ± 10.37 µg/L. Petroleum hydrocarbons were lowest at 2.63 µg/L at Station 3B (BW) and highest at 24.52 µg/L at Station 3C (BW), mean 15.20 ± 6.43 µg/L, indicating localized oil contamination. Oil and grease ranged from 2.4 mg/L at Control-3 (SW) to 13.2 mg/L at Station 3D (SW), mean 8.37 ± 3.54 mg/L, suggesting moderate hydrocarbon residues. Magnesium was lowest at 1215 mg/L at Station 3C (SW) and highest at 1944 mg/L at Stations 3A (SW), 3C (BW), and 3E (BW), mean 1620.00 ± 299.11 mg/L, reflecting seawater mineral content.

For metals, Nickel, Zinc, Copper, and Cobalt were below detection limits at all stations. Lead was detected between 0.415 mg/L at Station 3A (SW) and 0.965 mg/L at Station 3B (BW), mean 0.665 ± 0.259 mg/L, indicating low-level contamination. Cadmium ranged from 0.045 mg/L at Station 3C (BW) to 1.265 mg/L at Station 3B (BW), mean 0.551 ± 0.469 mg/L, showing localized presence. Chromium varied between 1.39 mg/L at Station 3C (BW) and 4.125 mg/L at Station 3E (BW), mean 2.453 ± 0.821 mg/L, indicating trace metal inputs. Manganese ranged from 0.065 mg/L at Station 3A (SW) to 0.880 mg/L at Station 3E (SW), mean 0.492 ± 0.306 mg/L, with higher values possibly from sediment resuspension.

Table 9: Physico-chemical characteristics of the marine water from sampling location 1 (Offshore)

S. No	Parameters	1A		1B		1C		1D		1E		Control 1	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	25.3	25	25.2	24.9	25.4	24.8	25	24.7	25	25.1	25	24.7
2	pH	7.72	7.72	7.80	7.79	7.82	7.81	7.83	7.82	7.83	7.81	7.77	7.53
3	Salinity (ppt)	37	35	39	39	39	36	36	36	36	37	36	36
4	Total Dissolved Solids (mg/L)	42.34	39.72	40.38	40.03	40.55	38.44	38.93	38.49	40.30	39.66	40.47	39.26
5	Turbidity (NTU)	149	189	119	223	111	211	140	239	288	328	363	486
6	Dissolved Oxygen(mg/L)	6.6	6.2	6	5.8	6.8	6.7	6.2	6.3	6.3	6.4	6.5	6.4
7	Bio-Chemical Oxygen Demand (mg/L)	2.3	2.2	2.6	2.3	2.4	2.5	2.4	2.2	2.4	2.9	2.2	2.1
8	Chemical Oxygen Demand (mg/L)	32.00	28.00	30.00	24.00	36.00	32.00	28.00	24.00	32.00	38.00	40.00	32.00
9	Phenolic Compounds (µg/L)	38.81	10.85	59.29	19.94	19.4	24.29	14.38	20.62	34.87	10.04	28.36	26.86
10	Petroleum Hydrocarbons (µg/L)	15.24	10.86	22.45	12.84	11.85	24.58	12.84	20.84	16.85	14.57	12.63	2.48
11	Oil and grease (mg/L)	1.6	3.2	4.0	7.6	8.4	13.2	10.8	11.2	14.4	9.6	9.2	16.0
12	Magnesium (mg/L)	1458	2187	1215	1701	1701	1944	1458	1701	1701	2430	1701	1701
13	Nickel (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
14	Lead (mg/L)	0.54	0.56	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
15	Cadmium (mg/L)	BDL	0.445	BDL	BDL	BDL	0.19	BDL	BDL	BDL	BDL	BDL	BDL
16	Chromium (mg/L)	BDL	BDL	BDL	BDL	BDL	0.6	0.275	BDL	BDL	0.405	0.52	0.235
17	Zinc (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
18	Copper (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Manganese (mg/L)	0.25	0.23	0.01	BDL	BDL	0.7	0.15	BDL	0.16	0.365	0.26	0.21
20	Cobalt (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Note: BDL denotes Below Detection Limit.

Table 10: Physico-chemical characteristics of the marine water from sampling location 2 (Cargo Jetty)

S. No	Parameters	2A		2B		2C		2D		2E		Control 2	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	25.2	25.1	26.4	25.8	26.4	25.7	26.8	25.8	26.2	25.9	26.4	26.2
2	pH	7.8	7.74	7.81	7.79	7.82	7.77	7.78	7.76	7.76	7.73	7.69	7.67
3	Salinity (ppt)	38.00	36.00	39.00	38.00	38.00	35.00	36.00	35.50	37.00	36.00	37.00	35.00
4	Total Dissolved Solids (mg/L)	42.61	41.53	44.87	44.16	40.88	39.79	46.44	45.57	41.35	41.64	42.87	39.51
5	Turbidity (NTU)	192	228	258	206	196	226	264	266	358	463	451	533
6	Dissolved Oxygen(mg/L)	.6.6	6.5	6.9	6.2	6.6	6.5	6.5	5.2	6.1	5.9	6	5.6
7	Bio-Chemical Oxygen Demand (mg/L)	3.1	2.5	2.8	2.1	2.4	2.5	2.3	2.2	2.2	2.1	2.9	2.8
8	Chemical Oxygen Demand (mg/L)	32	28	34	30	28	28	24	32	30	26	22	28
9	Phenolic Compounds (µg/L)	55.22	14.79	4.61	10.72	9.91	26.59	24.56	24.42	38.13	33.38	39.62	58.07
10	Petroleum Hydrocarbons (µg/L)	13.57	20.25	10.87	14.58	13.54	20.48	21.52	BDL	1.85	2.16	3.45	2.21
11	Oil and grease (mg/L)	10.8	16.4	6	10	15.6	3.6	19.6	17.2	16.4	3.6	3.2	9.2
12	Magnesium (mg/L)	1215	1701	1701	1458	1215	1944	1701	1215	1944	1701	1215	1701
13	Nickel (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
14	Lead (mg/L)	1.165	3.2	1.62	0.06	BDL	0.065	2.405	1.565	2	2.79	2.035	2.62
15	Cadmium (mg/L)	0.045	0.86	0.715	BDL	BDL	BDL	0.11	BDL	0.885	0.41	BDL	0.515
16	Chromium (mg/L)	0.4	0.85	1.095	0.975	0.775	0.685	0.95	1.78	1.155	1.96	1.455	1.58
17	Zinc (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
18	Copper (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Manganese (mg/L)	BDL	0.175	0.18	0.105	0.215	BDL	0.11	BDL	0.475	0.085	0.365	0.05
20	Cobalt (mg/L)	BDL	1.79	2.045	BDL	BDL	BDL	2.12	BDL	1.055	1.085	BDL	0.8

Note: BDL denotes Below Detection Limit

Table 11. Physico-chemical characteristics of the marine water from sampling location 3 (Phang Creek)

S. No	Parameters	3A		3B		3C		3D		3E		Control 3	
		SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
1	Temperature (^{0}C)	25.2	25	24.9	24.7	24.9	24.7	25.4	25.1	25.8	24.2	25.8	25.5
2	pH	7.74	7.72	7.79	7.8	7.8	7.78	7.79	7.78	7.8	7.7	7.75	7.71
3	Salinity (ppt)	39	37	36	39	39	39	39	40	39	40	38	40
4	Total Dissolved Solids (mg/L)	40.78	39.32	40.01	40.09	48.52	47.48	45.16	45.11	45.66	49.54	45.08	42.74
5	Turbidity (NTU)	216	392	300	372	388	434	258	557	446	510	316	359
6	Dissolved Oxygen(mg/L)	5.8	5.7	5.9	5.6	5.9	5.7	5.8	5.5	5.7	5.4	5.5	5.2
7	Bio-Chemical Oxygen Demand (mg/L)	2.5	2.3	3	2.8	2.3	2.2	2.3	2.6	2.9	2.7	2.5	2.4
8	Chemical Oxygen Demand (mg/L)	42	38	36	34	32	28	26	34	28	44	36	38
9	Phenolic Compounds (µg/L)	32.97	30.26	30.12	39.48	17.64	59.97	22.79	40.03	31.61	33.78	35.01	30.26
10	Petroleum Hydrocarbons (µg/L)	BDL	2.63	12.48	10.87	20.05	24.52	12.87	23.57	12.78	20.48	14.87	12.085
11	Oil and grease (mg/L)	10.4	12.0	11.6	7.6	5.2	11.2	13.2	8.4	2.8	7.2	2.4	8.4
12	Magnesium (mg/L)	1944	1701	1215	1944	1944	1701	1458	1458	1215	1944	1701	1215
13	Nickel (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
14	Lead (mg/L)	0.415	0.795	BDL	0.965	BDL	BDL	BDL	BDL	BDL	0.485	BDL	BDL
15	Cadmium (mg/L)	BDL	0.685	BDL	1.265	0.245	0.045	BDL	BDL	0.515	BDL	BDL	BDL
16	Chromium (mg/L)	3.245	2.405	1.61	1.925	3.22	1.39	1.43	2.565	2.575	4.125	2.785	2.155
17	Zinc (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
18	Copper (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
19	Manganese (mg/L)	0.065	0.875	0.665	0.205	0.42	0.605	BDL	BDL	0.365	0.74	0.88	0.1
20	Cobalt (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Note: BDL denotes Below Detection Limit

Chapter 5 Biological Characteristics of Marine Water

5.1. Introduction for Plankton

Plankton is defined as all those living organisms which are suspended and drifting in water. Phytoplanktons are the primary producers in marine ecosystems and form the basis of the food web. The animal portion of plankton is known as Zooplankton, which are pelagic animals and unable to maintain their position by swimming against the physical movement of water. Size is very important to understanding about the classification of both zooplankton and phytoplankton. Based on size, various categories of plankton are smallest one Picoplankton (0.2-2 µm), Nanoplankton (2-20 µm), Microplankton (20-200 µm), Mesoplankton (200 µm-2 mm), Macroplankton (2-20 mm) and Megaplakton(> 20 mm) . The planktonic communities encompass of aquatic organisms which drift passively and also have limited mobility to move contrary of the water mass. Plankton are divided in two parts which are phytoplankton and zooplankton (Brink. 1993). The tiny flora or plants are called as Phytoplankton, and weak swimming tiny fauna or animals are called as Zooplankton. Phytoplankton are the primary producers in marine ecosystems and form the basis of the food web. Zooplankton are pelagic animals play a role in the food chain in aquatic ecosystem to provide a food resource to various organisms. Major phytoplankton in sea water is Diatoms (Tiwari and Nair, 1998; Thakur et al, 2015), Cocolithophores, Sillicoflagellates, Blue green algae (Cyanobacteria) and Dinoflagellates. Zooplankton comprises the second level in the food chain and includes Tintinnids, Foramonifers, Radiolarians, Amphipoda, Copepoda, Calanoida, Chaetognaths, larvae of benthic invertebrates and fish larvae etc. (Gajbhiye and Abidi, 1993; Thirunavukkarosu, 2013; Chakrabarty et al. 2017). Interspecific competition among the Zooplankton; Inter-relationship for prey and predator between zooplankton and their mostly predator animals; Grazing ratio of primary-secondary consumers; Suspension of sediment; Fluctuation in Phytoplankton abundance; Waves, Currents and Tidal turbulence effect; Fluctuation in Chlorophyll a and Nutrients; Input of Organic and other Pollution creating sources; Fish potential ratio; Monsoon effect; Suddenly changes in

atmosphere; Peak time of every seasons and it's effect; Vertical migration of Zooplankton; Food selection pattern of predator; Collection time and number of collected samples, mixing of water column, high surface action, Seasonal up welling and down welling process in water column

5.1.1. Phytoplankton

Phytoplankton are single celled marine algae with great difference in shape, size and form, either use flagella for movement in water or just drift with currents (Zohari et al, 2014). These photosynthetic organisms need sunlight for photosynthesis. Diatoms dominate the phytoplankton biomass in highly productive areas of the ocean. The diatoms are one of the most important phytoplankton as a primary producer of marine ecosystem. They are estimated to produce 20-25 % of the world total net primary production (Werner, 1977).

With trapping carbon in the process of photosynthesis, they can control the atmospheric carbon dioxide and help in combating the global climate change. With this, they have significant role in the management of nutrients cycles in the ocean systems. Their role as primary producers in aquatic ecosystem, in the process of nutrients cycling in the ocean systems, also in calcification, silicification, nitrogen-fixing, etc. made them important marine component for marine life study. Their sensitiveness for various anthropogenic activities in the marine environment such as Eutrophication, introduction of invasive species, overfishing etc, make them one of the best indicators to analyse these activities.

5.1.2. **Zooplankton**

The faunal species particularly microscopic fauna, living inside the water bodies are known as zooplankton. Zooplankton is tiny-small animals found in all water bodies particularly the pelagic and littoral zone in the ocean. They are classified by size and or by development stages. Zooplankton community is composed of both primary consumers (which eat phytoplankton) and secodanry (which feed on the other zooplankton). Crustaceans zooplankton are Arthropods whose body is covered with chitinous exoskeleton for protection. Nearly all fish depend on zooplankton for food in both larval stages and entire life period (Madin et al., 2001). They are attractive,

various and plentiful group of faunal species which can swim or generally drift with water currents but have no potential to swim against water currents (Alcaraz and Calbet, 2003). The important role of them is to be a major link in the marine life in between marine microalgae or phytoplankton and fish. Although they can be classified according to their habitat and depth, distribution, size and duration of planktonic life period (Omori and lkeda, 1984), generally, it is considered as there are two types of zooplanktons. Holoplanktons are those which live permanently in the planktonic form, while meroplanktons are the temporary members in this form. The potential of zooplankton to respond quickly to environment changes and short generation life span, make them important bioindicator of water pollution and all variation occurred in their living environment. Their study is the important part for getting knowledge of the functioning of marine ecosystems (Mees and Jones, 1997).

5.2. Methodology

5.2.1 Estimation of Chlorophyll and Phaeophytin

Estimating Chlorophyll and Phaeophytin was done using known volume of water (500 ml) was filtered through a 0.45µm Millipore membrane filter paper and the pigments retained on the filter paper were extracted in 90% acetone overnight at 50°C. The extinction of the acetone extract was measured using fluorimeter before and after treatment with dilute acid (0.1N HCI).

5.2.2. Phytoplankton sampling and analysis

Phytoplankton samples were collected in the ten prefixed sampling sites using a standard plankton net with a mesh size of 51 µm. Plankton nets are with a square mouth covering an area of 0.900 cm^2 (30 cm square mouth) fitted with a flow meter (Hydrobios). Nets were towed from a moving boat for 10 minutes and the plankton adhering to the net was concentrated in the net bucket. Plankton soup from the net bucket was transferred to a pre-cleaned and rinsed container and preserved with 5% neutralized formaldehyde. The containers were appropriately labelled. The initial and final flow meter reading was noted down for calculating the amount of water filtered to estimate plankton density. As per flow meter reading, a total amount of 165m^3 of

water was filtered by the net. One liter of water was separately collected for density estimation to counter check density estimation obtained by the flow meter reading. Quantitative analysis of phytoplankton (cell count) was carried out using a sedge wick-Rafter counting chamber. One ml of soup added to a Sedgwick counting chamber was observed under an inverted compound microscope. The number of cells present in individual cells of the counting chambers (1/1000) was noted and identified up to a generic level. Several observations were fixed to represent the entire quantity of the soup (generally more than30 times) and the recorded data were used to calculate the density (No/l) using the formula, $N = n \times v/V$ (where N is the total no/l; n is an average number of cells in 1 ml; v is the volume of concentrate; V is the total volume of water filtered). The phytoplankton diversity richness and evenness were past software.

5.3. Results of Chlorophyll and Phaeophytin in three locations

The concentration of phytopigments is inversely proportional to the turbidity of the waters and in general, waters owing to the high turbidity restricts sunlight penetration essential for nutrient uptake by phytoplankton and thus inhibiting primary production.

5.3.1. Offshore

Chlorophyll-a ranged from 0.43 mg/m³ at Station 1C (SW) to 0.84 mg/m³ at Station 1A (BW), mean 0.56 ± 0.10 mg/m³, suggesting low to moderate phytoplankton biomass. Phaeophytin ranged between 0.20 mg/m³ at Station 1C (BW) and 0.88 mg/m³ at Station 1C (SW), mean 0.43 ± 0.18 mg/m³, with higher levels indicating older phytoplankton communities or post-bloom phases as shown in Table 12.

5.3.2. Cargo jetty

The Table 13 shows the Chlorophyll-a ranged from 0.30 mg/m³ at Control 2 (SW) to 0.70 mg/m³ at Station 2B (BW), mean 0.52 ± 0.12 mg/m³, indicating low to moderate phytoplankton biomass. Phaeophytin varied widely from 0.30 mg/m³ at Station 2A (SW) to 2.50 mg/m³ at Station 2D (SW), mean 0.65 ± 0.60 mg/m³, with higher values suggesting older phytoplankton populations or degraded organic matter.

5.3.4. Phang Creek

Chlorophyll-a ranged from 0.117 mg/m³ at Control-3 (SW) to 0.571 mg/m³ at Station 3A (BW), mean 0.330 ± 0.149 mg/m³, indicating low phytoplankton biomass (Table 14) Phaeophytin was lowest at 0.140 mg/m³ at Station 3E (BW) and highest at 0.428 mg/m³ at Station 3A (SW), mean 0.240 ± 0.088 mg/m³, suggesting relatively young phytoplankton populations.

Table 12: Chlorophyll and Phaeophytin concentration observed in the Offshore site

Parameters	1A		1B		1C		1D		1E		1 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	0.517	0.835	0.523	0.611	0.428	0.523	0.564	0.482	0.523	0.517	0.612	0.571
Phaeophytin	0.341	0.323	0.284	0.202	0.410	0.881	0.424	0.641	0.442	0.364	0.329	0.480

Table 13: Chlorophyll and Phaeophytin concentration observed in the Cargo Jetty site

Parameters	2A		2B		2C		2D		2E		2 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	0.523	0.659	0.646	0.687	0.394	0.577	0.551	0.441	0.435	0.618	0.305	0.434
Phaeophytin	0.320	0.810	0.370	0.390	0.496	0.392	2.483	0.338	0.472	0.512	0.731	0.464

Table 14: Chlorophyll and Phaeophytin concentration observed in the Phang Creek site

Parameters	3A		3B		3C		3D		3E		3 Control	
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Chlorophyll	0.469	0.571	0.306	0.529	0.435	0.211	0.353	0.353	0.246	0.224	0.117	0.142
Phaeophytin	0.428	0.352	0.168	0.252	0.269	0.308	0.192	0.146	0.245	0.140	0.207	0.178

5.4. Phytoplankton

The study was conducted at 3 sites (or regions) at Kandla Port and near area where dredging activities is going on Creek and the stations are Offshore, Cargo Jetty and Phang Greek.

5.4.1. Offshore

In this site, frequently observed species were *Actinocyclus sp, Coscinodiscus centralis, Coscinodiscus wailesii, Coscinodiscus rediatus, Coscinodiscus granii, Thalassionema frauenfeldii colony, Thalassionema nitzschioides colonies, Odontella sinensis, etc.* whereas less observed species were *Biddulphia sp*, *Entomoneis sp*, *Gyrosigma sp, Navicula sp, Nitzschia sp, Protoperidinium sp* and *Triceratium sp etc.* Total 32 (out of 42) Phytoplankton were recorded in this Offshore area. Highest population density was recorded at site 1A-Offshore (100480nos./m^3) and lowest density was recorded at site 1B-Offshore (62400nos./m^3). The maximum number of species observed in site 1B-Offshore (20 nos.) followed by 1control (19nos.), 1A, 1D, 1E and 1C (14nos.). The population density greatly varied between (62400nos./m^3 to 100480nos./m^3). *Synedra ulna, Navicula sp, Nitzschia sp Entomoneis sp, Thalassiosira sp.* were recorded which are sometimes considering for pollution indicator species in water. Green algae were also recorded in some location of Offshore which may be indication of freshwater or polluted water mixing with seawater. . The Dinoflagellates like *Protoperidinium sp* was also observed during microscopic analysis that may be indication of water circulation from deep water to upper surface. Highest population density contributor species was *Coscinodiscus wailesii* (range 5120 to 12000nos./m^3).

5.4.2. Cargo jetty

Total 26 Phytoplankton were recorded in this Cargo Jetty area. The population density greatly varied between 35040 nos/m^3 to 117120 nos/m^3. Highest density recorded at 2D-Cargo Jetty (117120nos./ m^3) and lowest value was at 2C-Cargo Jetty (35040nos./m^3). The lowest number of species noted in the site 2E-Cargo Jetty(13 nos.) whereas highest in 2control-CargoJetty (19nos.). In this Cargo Jetty station

commonly or frequently observed species were *Actinocyclus sp, Coscinodiscus centralis, Coscinodiscus radiatus, Coscinodiscus wailesii, Coscinodiscus granii, Odontella sinensis, Ditylum brightwelli, Synedra ulna, Thalassionema frauenfeldii colonies Thalassiosira sp* etc. The rarely found species were Blue Green algae, Green algae, *Odontella sp*, *Rhizosolenia imbricata, Synura alga Colonies Triceratium favus etc*. *Synura alga Colonies* (Chrysomonad algae) were also recorded.

5.4.3. Phang Creek

The population density of phytoplankton ranged from 28800nos./m^3 to 56320nos./m^3 same way species availability ranged from 09 to 20 nos. Maximum and Minimum value of population density were recorded in site 3A-Phang Creek (56320nos./m^3) and 3C-Phang Creek (28800 nos./m^3) respectively. Highest number of species recorded in site 3control-Phang Creek (20nos.) and lowest in site 3C-Phang Creek (09nos.). Total recorded phytoplankton was 28 in this creek area. *Actinocyclus sp, Coscinodiscus centralis, Coscinodiscus wailesii, Coscinodiscus radiatus, Coscinodiscus granii, Pleurosigma sp, Synedra ulna, Thalassionema frauenfeldii colonies etc.* were frequently noticed during microscopic work whereas less observed species were *Biddulphia sp*, *Coscinodiscus asteromphalus*, *Cylindrotheca sp*, *Planktoniella blanda*, *Thalassionema nitzschioides colonies*, *Trieres mobiliensis, Trachyneis aspera* and some unidentified phytoplanktons. Green algae *were also recorded*, which are generally found in fresh water and estuarine area.

Overall view of Phytoplankton showed that a total 42 species of Marine phytoplankton were identified during summer season (June month) of the year 2025. Among them,21-Centric diatoms, 15-Pennate diatoms, 2-Dinoflagellates, 1-Green algae, 1-Blue green algae, 1-Chrysomonad algae and 1-silicoflagellates and some are not identified phytoplanktons were included in unidentified group. Some species like *Actinoptychus sp*, *Biddulphia sp*, Coscinodiscus asteromphalus, Cyclotella sp, *Dinophysis sp* (Dinoflagellate cysts), *Grammatophora sp* chain, *Navicula lyra*, *Planktoniella blanda*, *Planktoniella sol*, *Protoperidinium sp*, *Pseudo-nitzschia sp*, *Trachyneis aspera* were rarely recorded during sample analysis. Input of the fresh

water indicated by the presence of some common fresh water species like *Green algae* and *Blue green algae.* Presence of *Dinoflagellates (Dinophysis sp and Protoperidinium sp)* indication of bottom water circulation up to surface water layer in some level. *Synura alga Colonies* (Chrysomonad algae) were also recorded in Phang creek region. Highest phytoplankton density was observed at the site 2D-Cargo Jetty (117120nos./m^3) and lowest was observed at site 3C-Phang creek (28800 nos./m^3) (Table 15). Total number of highest species observed at site 1B-Offshore and 3control-Phang creek (20nos.) and lowest in site 3control-Phang creek (09nos).

The high population density composed by species like Actinocyclus sp, *Coscinodiscus centralis, Coscinodiscus radiates, Coscinodiscus wailesii, Coscinodiscus granii Thalassionema frauenfeldii colonies, Thalassionema nitzschioides colonies, Odontella sinensis, Thalassionema frauenfeldii colonies, Thalassiosira sp, Trieres mobiliensis (*Table 15). This result indicated that genus *Coscinodiscus sp. Actinocyclus sp, Thalassionama sp, Trieres sp.* were very common with good numbers in all sites. In some sites, least number of species and low density of phytoplankton might be responsible due to some factors like extreme cool or hot weather because of rainy season, mixing of water, high pre-predation ratio, marine pollution (anthropogenic pressure), high turbidity, total suspended solids, water current and suddenly changes in environment conditions etc. Diatoms, type of phytoplankton, constitute major part in total phytoplankton composition The individual density of species of sites viz. has been depicted in Table 3. All values of phytoplankton density, list of phytoplankton and others shown in (Table 15).

Diversity Indices of Phytoplankton

According to Table 16, diversity indices calculation for phytoplankton showed that the Shannon Index ranged from (1.50 to 2.39) indicated low level to moderate level of diversity range. High Shannon Index was recorded at 3B, 3D and 3E-Phang creek (2.39) where species numbers were recorded nearly sixteen and low at 3C-Phang creek (1.50) where 09 species were recorded. Lowest evenness recorded at site 1E-

Offshre (0.36) whereas highest was in at 2C-Cargo Jetty (0.77). Dominance_D index ranged from 0.11 to 0.31 where higher value in 3C-Phang creek (0.31) and lowest was at in 2C-Cargo jetty (0.11). Value of Margalef D (0.78 to 1.77) showed more to moderate variation in species numbers. (Table 16.).

Table 15. Density of Phytoplankton at different sites of Deendayal Port

Name of Sites	Offshore						Cargo Jetty						Phang Creek					
	1A	1B	1C	1D	1E	1 control	2A	2B	2C	2D	2E	2 control	3A	3B	3C	3D	3E	3 control
Genus of Phytoplankton																		
Actinocyclus sp	3200	2400	3680	2400	5600	2880	5600	8000	6400	800	2400	3680	2560	4000	1600	1920	1440	1920
Actinoptychus sp	0	0	1600	0	0	0	3200	0	0	0	0	0	0	0	0	0	0	0
Biddulphia sp	0	320	0	0	640	0	0	0	0	0	0	0	0	0	0	320	0	0
Biddulphia sp chain	0	0	0	0	0	160	0	0	0	0	0	0	0	0	0	0	0	0
Blue green algae (unidentified)	0	0	0	0	0	0	0	0	0	0	320	0	0	0	0	0	0	0
Coscindiscus radiatus	24000	9600	24000	16000	16000	12800	20000	19200	4800	20000	8000	16000	8000	4800	5600	8000	4800	8000
Coscinodiscus asteromphalus	0	0	0	0	0	1600	0	0	0	0	0	0	1600	0	0	0	0	
Coscinodiscus centralis	1600	3200	1440	2560	3520	2080	3200	3200	2080	1920	2080	1920	3360	1280	1440	1920	1120	3360
Coscinodiscus granii	9600	8000	16800	11200	9600	8800	8000	9600	4320	24000	3200	8000	8000	7200	4000	3840	6400	7200
Coscinodiscus wailesii	32000	21600	23200	12800	21600	25600	16800	5760	3520	43520	16000	16000	17600	12000	14400	6400	8640	12000
Cyclotella sp	0	0	0	0	0	0	800	0	0	0	0	0	0	0	0	0	0	0
Cylindrotheca sp	0	0	0	0	0	0	0	0	0	0	0	0	0	1600	0	0	0	0
Dinophysis sp (Dinoflagellate cysts)	0	0	0	0	0	320	0	0	0	0	0	0	0	0	0	0	0	0
Ditylum	12000	4000	0	0	0	0	1600	4800	0	3200	0	2400	0	1600	0	640	1600	1600

brightwelli																		
Entomoneis sp	0	0	160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grammatophora sp chain	0	0	0	0	0	160	0	0	0	0	0	0	0	0	0	0	0	0
Green algae (unidentified)	800	640	0	0	0	0	0	320	160	0	0	0	1600	0	0	0	1600	320
Gyrosigma sp	0	0	0	640	320	320	0	960	2400	0	1600	320	0	0	0	320	480	320
Navicula lyra	480	0	480	0	0	0	0	0	0	0	0	480	0	0	0	0	0	0
Navicula sp	0	1600	0	0	0	0	800	0	0	480	0	1600	320	0	0	0	320	320
Nitzschia sp	0	1600	0	0	320	0	160	800	2400	0	320	0	2400	0	0	480	0	320
Odontella sinensis	4800	3200	4800	4800	0	2400	1600	0	800	6400	0	640	1600	2400	0	2400	0	480
Odontella sp	0	0	0	0	0	0	0	0	0	5600	0	0	0	0	0	0	0	0
Planktoniella blanda	0	640	0	3200	0	0	0	0	0	0	0	0	0	1600	0	0	0	0
Planktoniella sol	0	800	0	0	0	0	0	0	0	0	0	0	0	0	0	640	0	800
Planktoniella sp	0	0	0	0	0	0	0	0	0	0	0	0	160	0	0	0	0	0
Pleurosigma sp	0	0	320	800	0	320	1600	1600	320	0	0	0	0	1600	640	640	640	320
Protoperidinium sp	0	320	0	0	0	320	0	0	0	0	0	0	0	0	0	0	0	0
Pseudo-nitzschia sp chain	0	0	0	0	0	320	0	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia imbricata	0	0	0	0	0	0	0	0	0	640	0	0	0	0	0	0	0	0
Surirella sp.	0	0	0	0	0	0	2400	1760	0	0	0	160	320	0	320	0	480	0
Synedra ulna	3200	800	0	2400	800	640	800	1600	2400	1600	640	2400	3200	4000	480	2400	2400	3200
Synura alga Colonies	0	320	1600	0	4800	0	0	0	0	0	0	640	0	0	0	0	0	0
Thalassionema frauenfeldii colonies	4000	0	7200	4800	8000	4000	5600	4800	3200	4800	8000	4800	4000	4000	320	800	5600	1600
Thalassionema nitzschioides colonies	0	800	0	0	0	0	0	0	0	0	0	160	0	0	0	640	0	640
Thalassiosira	800	1600	1600	640	800	800	5600	800	1600	960	1120	2400	0	800	0	800	2400	800

sp																		
Thalassiosira aculeata	0	0	0	0	0	0	1600	2400	0	0	2400	320	800	320	0	2400	800	0
Trachyneis aspera	0	0	0	0	0	0	0	0	0	0	0	0	800	0	0	0	0	1600
Triceratium favus	1600	480	0	800	480	320	0	0	640	0	0	320	0	480	0	0	0	480
Triceratium sp	0	480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trieres mobiliensis	2400	0	800	640	320	640	5600	3200	0	3200	640	320	0	0	0	0	2400	640
Unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0	800	0	0	0	0
Density of Phytoplankton (diff. sites wise.)(no/m^3)	100480	62400	87680	63680	72800	644480	84960	68800	35040	117120	46720	62560	56320	48480	28800	34560	41120	45920
Total= 1121920 no/m^3																		
Total No Of Genus/Species=**42**																		

Table 16. Diversity Indices of Phytoplankton at different sites at Kandla Port

	Offshore						Cargo jetty						Phang Creek					
	1A	**1B**	**1C**	**1D**	**1E**	**1-control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2-contrl**	**3A**	**3B**	**3C**	**3D**	**3E**	**3-control**
Variables																		
Taxa_S	14	20	14	14	14	19	18	16	14	14	13	19	16	16	9	17	16	20
Individuals (Nos/m^2)	100480	62400	87680	63680	72800	64480	84960	68800	35040	117120	46720	62560	56320	48480	28800	34560	41120	45920
Dominance_D	0.19	0.17	0.19	0.15	0.18	0.23	0.13	0.14	0.11	0.22	0.19	0.16	0.16	0.12	0.31	0.12	0.12	0.14
Shannon Diversity Index (H)	2.00	2.22	1.91	2.14	1.97	1.93	2.39	2.32	2.38	1.88	1.99	2.17	2.21	2.39	1.50	2.39	2.39	2.34
Simpson_1-D	0.81	0.83	0.81	0.85	0.82	0.77	0.87	0.86	0.89	0.78	0.81	0.84	0.84	0.88	0.69	0.88	0.88	0.86
Evenness_e^H/S	0.53	0.46	0.48	0.61	0.51	0.36	0.61	0.64	0.77	0.47	0.56	0.46	0.57	0.68	0.50	0.64	0.68	0.52
Menhinick	0.04	0.08	0.05	0.06	0.05	0.07	0.06	0.06	0.07	0.04	0.06	0.08	0.07	0.07	0.05	0.09	0.08	0.09
Margalef	1.13	1.72	1.14	1.18	1.16	1.63	1.50	1.35	1.24	1.11	1.12	1.63	1.37	1.39	0.78	1.53	1.41	1.77

5.4. Zooplankton

The study was conducted at 3 sites in Kandla Port and nearby areas where dredging activities are going on. The three selected study stations are Offshore, Cargo Jetty and Phang Greek.

5.4.1. Offshore

Acartia sp, Ammonia beccarii (Foraminifera), Calanoida (unidentified), Clausocalanus sp (Calanoida), Cyclops sp (Cyclopoida), Foraminifera(unidentified), Nauplius larvae of Crustacea, Parvocalanus sp (Calanoida), Subeucalanus sp (Calanoida), Tintinnopsis orientalis (Tintinnida), Tintinnopsis sp (Tintinnida), Veliger larvae of Bivalve etc. were the mostly common zooplankton and throughout observed in all sites of Offshore area. Highest population density was recorded at site 1C-Offshore (138240nos./100m^3) where number of species was (39nos.) and lowest density in 1Control-Offshore (60000nos./100m^3) where number of species was recorded (33nos.). High biomass was observed in the site 1Control-Offshore (15.31 ml/100m^3) and low biomass was recorded in site 1B-Offshore (8.77 ml/100m^3). The range of the population density, biomass and number of species were (60000 to 138240 nos./100m^3), (8.77 to 15.31 ml/100m^3) and (29 to 43 nos.) respectively in all sites.

Less observed species were Bryozoan*, Arcella sp (Amoebozoa), Bulimina sp (Foraminifera), Calcarina sp (Foraminifera), Cibicides sp (Foraminifera), Embryonic stage (Crustacea),* Gastrula larva of Echinodermata, *Harpacticus sp (Harpacticoida), Spiroloculina sp (Foraminifera) etc.* Total 68 zooplankton was recorded in Offshore area adding that more composition of zooplankton by the Phylum Arthropoda(Crustacea), Foraminifera and Sponge Spicules (Porifera) and Tintinnida.

5.4.2. Cargo Jetty

The population density of zooplankton varied from 55200 nos./100m^3 to 106240 nos./100m^3. Maximum density was noticed in site 2D-Cargo Jetty (106240nos./100m^3) and minimum was at site 2Control-Cargo Jetty (55200nos./100m^3). Maximum number of species (35nos.) found 2E - Cargo Jetty minimum number of species was observed in site 2A, 2B-Cargo Jetty (27nos.). Biomass ranged between 13.89 to 65.79 ml/100m^3 where highest biomass noted in site2C-Cargo Jetty and lowest in 2D-Cargo Jetty.

Frequently observed species were Ammonia beccarii (Foraminifera), *Calanoida (Unidetified), Cyclops sp (Cyclopoida) Bolivina sp (Foraminifera), Globigerina sp (Foraminifera), Microsetella sp (Harpacticoida), Ostracoda, Sponge Spicules, Tintinnopsis orientalis (Tintinnida), Veliger larvae of Bivalve etc.* whereas less observed species were *Acartia ohtsukai (Calanoida), Amphipoda (Crustacea), Calcarina sp (Foraminifera), Cyphonautes larva (Bryozoan), Egg capsules of Littorinids (animal), Heteropoda shells (gastropods), Leprotintinnus nordqvistii (Tintinnida), Nodosaria sp (Foraminifera), Quinqueloculina sp (Foraminifera)* etc. Total (60) zooplanktons were recorded in Cargo Jetty.

5.4.3. Phang Creek

This Creek area was represented by the zooplankton fauna majority of them were Ammonia beccarii (Foraminifera) Calanoida (unidentified), Cyclops sp (Cyclopoida) Copepoda eggs sacs, Foraminifera (unidentified), Globigerina sp (Foraminifera) Gastrula larva of Echinodermata, Globigerina sp (Foraminifera), Leprotintinnus pellucidus (Tintinnida) Ostracoda , Sponge spicules, *Leprotintinnus sp* (Tintinnida)*, Tintinnopsis orientalis (Tintinnida).*Very less time or rarely recorded species were Calcarina sp (Foraminifera), Centropages sp (Calanoida), Cyclopoida (unidentified), Cyphonautes larva (Bryozoan), Egg (unidentified), Euterpina sp (Harpacticoida), Gastropoda shells (empty), Harpacticoida (unidentified), Lagena sp (Foraminifera), Microsetella sp (Harpacticoida), Textularia sp (Foraminifera) etc.

The range of zooplankton biomass was between 9.38 to 38.46 ml/100m^3. Highest Biomass was recorded in site 3A-Phang creek (38.46 ml/100m^3) and lowest in site 3C-Phang creek (9.38 ml/100m^3). Maximum and Minimum species count was at in site 1E-Offshore (43nos.) and 2B and 2C-Cargo Jetty (27nos.) respectively. Population density was maximum recorded in site 3A-Phang Creek (87840 nos./100m^3) and minimum in site 3E-Phang Creek (53600 nos./100m^3). In site 3E-Phang creek comparatively low density according to other sites may be because of high predator pressure or some environment changes.

Overall assessment of zooplankton showed that the total number of 84 Zooplankton recorded during this season. Out of these (64) zooplankton, 68 zooplankton recorded in Offshore region, 60 zooplankton at Cargo Jetty and 67 zooplankton in Phang Creek region. The recorded zooplankton of all 3 stations mainly representing Phylum Arthropoda (Crustacea),

Protozoa (mainly foraminifera and tintinnids), Porifera (sponge spicules). Crustacean zooplankton was the dominant due to the dominance of different larval stages and Copepods which mainly feed phytoplankton. More larval stage of crustacean and other animals observed in samples that indicated reproduction and development season of animals from larval to mature animal. Generally, zooplankton population dynamics and studies emphasize is given up to group level rather than to species level because of microscopic size of zooplankton so to the difficulty in identifying the zooplankton as some species are considered as a groupor genus level. The most dominant or frequently observed species(all 3 station) were *Acartia sp* (Calanoida), *Ammonia beccarii* (Foraminifera) Calanoida (unidentified), *Canthocalanus sp* (Calanoida), *Cyclops sp* (Cyclopoida), *Clausocalanus sp* (Calanoida), *Tintinnopsis orientalis* (Tintinnida), Foraminifera (unidentified), *Leprotintinnus sp* (Tintinnida), Ostracoda, *Globigerina sp* (Foraminifera), Ostracoda, Sponge Spicules, Zoea larva of Crab etc. Foraminifera and Ostracoda belonging to the meroplankton were present at all three stations.

Overall range of all three sites Population density, Biomass and Number of species were (53600 to 138240no/100 m^3), (8.77 to 65.79 ml/100m^3) and (27 to 43nos) respectively. Average high biomass noted at Cargo Jetty (161.66 ml/100m^3) followed by Phang creek (93.45 ml/100m^3) than Offshore (52.25 ml/100m^3) (Table 17, 18, 19). Highest population density was recorded in site 1C-Offshore (138240nos/100m^3) and lowest was recorded in site 3E- Phang creek(53600nos/100m^3). Among all recorded zooplankton, majority dominance occurrence was by the Copepoda, Crustacean larvae, Spong Spicules, Foraminifera (Protozoa), Ostracoda, Tintinnids (Protozoa), Zoea larva of Crab. The small Fish was also recorded in Offshore and Cargo Jetty region.

Maximum zooplankton faunal composition was dominated by the Phylum Arthropoda, Mollusca, Protozoa, Porifera, Foraminifera. The Fish (Ichthyoplankton) was also recorded in some sites of Offshore and Cargo jetty. The Zooplankton of Chaetognatha,, Amoebozoa were only represented by the species namely *Sagitta sp (arrow worm), Arcella sp.* respectively. Veliger larva of Bivalve and Heteropods shells include in Phylum Mollusca. The Echinodermata phylum represented by the Ophiopluteus larva and Gastrula larva of Sea star. The Bryozoan represented by the Cyphonautes larva and some bryozoan.

In Offshore**,** maximum Occurrence (%) was by the *Tintinnopsis orientalis (Tintinnida)* (12.62%) and minimum by some unidentified species (0.05%). In Cargo Jetty, maximum Percentage of Occurrence (%) by the *Tintinnopsis orientalis (Tintinnida)* (8.62%) and minimum by the Nodosaria sp (Foraminifera) and small Fish (0.07%). In Phang Creek maximum Occurrence by the *Tintinnopsis orientalis* (Tintinnida) (8.12%) and minimum (0.08%) by the Mysida (Malacostraca, Crustacea), *Textularia sp* (Foraminifera), *Quinqueloculina sp* (Foraminifera), Protozoea larva (Decapoda), *Centropages sp* (Calanoida) and some unidentified zooplankton (Tables 17 - 19).

During microscopic sample analysis more number of species varieties of Foraminifera, Sponge spicules, Crustacean larva, Copepoda and Tintinnids were observed. These all three are very important for paleontological study aspects and also for evolutionary, ecological and environmental rebuilding. Some species of Ostracoda, Foraminifera and Sponge spicules are considered in microfossils materials. Some deep-sea species also recorded that is indication of water circulation pattern. Data on zooplankton density, list of zooplankton is shown in Tables 17 -19.

Plankton identification, both zooplankton and phytoplankton, were done by using relevant identification and taxonomic keys and with standard literatures, monographs and research articles.(Kasturirangan, 1963; APHA, 1992; Mitra et al., 2003;Goswami, 2005; Carling et al.,2004; Mandal, 2004; Hussain & Kalaiyarasi, 2013; Guglielmo et al., 2015; Hussain et al., 2016; Sreenivasulu et al., 2017; NIO,1998; NIO,2002) and others.

5.4.4. Diversity Indices of Zooplankton

Table 20 shows diversity indices of zooplankton. The Shannon-wiener diversity index (H') fluctuated between 2.62 to 3.29 indicated moderate to quite high range of diversity added indication of healthy body of water with a maximum value in site 2C-Cargo Jetty (3.29) where number of species noted (33nos.) and minimum value in site 1A-Offshore (2.62) where species number was (29nos). Range of the evenness was 0.47 to 0.81 where lowest and highest recorded in site 1A- Offshore and 2C-Cargo Jetty (0.81) respectively. Range of Simpson index was 0.88 to 0.96. The range value of Margalef indices was 2.34 to 3.58 that means high species number variations (Table 20)..

Table 17. Density of Zooplankton at Offshore site of Deendayal Port

Name of Genera/Group	1A	1B	1C	1D	1E	1 Control	Individual total density (no/100m^3)	% of Occurrence (Site-wise)
Acartia sp (Calanoida)	2400	2400	800	320	800	480	7200	1.14
Ammonia beccarii (Foraminifera)	800	640	480	480	640	480	3520	0.56
Arcella sp (Amoebozoa)	0	0	640	4000	0	0	4640	0.74
Bolivina sp (Forminifera)	320	0	1600	800	0	640	3360	0.53
Bryozoan	0	0	0	0	0	640	640	0.10
Bulimina sp (Foraminifera)	0	0	0	0	640	0	640	0.10
Calanoida (Unidetified)	8000	4000	8000	4000	4000	3200	31200	4.95
Calcarina sp (Foraminifera)	0	0	0	0	0	480	480	0.08
Canthocalanus sp (Calanoida)	1440	0	1760	800	1440	800	6240	0.99
Cibicides sp (Foraminifera)	0		0	0	0	1600	1600	0.25
Clausocalanus sp (Calanoida)	1280	1280	3200	1920	1280	2080	11040	1.75
Copepoda eggs sacs	2400	0	8000	4000	8000	3200	25600	4.06
Cyclops sp (Cyclopoida)	3840	6400	4800	11200	8000	0	34240	5.44
Discorbis sp (Foraminifera)	0	0	0	0	800	0	800	0.13
Egg (unidentified)	0	0	0	0	480	0	480	0.08
Egg capsules of Littorinids (animal)	0	0	4000	0	2400	0	6400	1.02
Embryonic stage (Crustacea)	0	0	0	0	320	0	320	0.05
Euterpina sp (Harpacticoida)	480	0	2400	480	0	0	3360	0.53
Favella sp (Tintinnida)	0	0	0	0	0	800	800	0.13
Fish (small)	800	0	0	0	0	0	800	0.13
Foraminifera(unidentified)	8000	4000	3200	8000	5600	4000	32800	5.21
Gallitella sp (Foraminifera)	0	0	800	0	0	0	800	0.13
Gastrula larva of Echinodermata	0	0	0	480	0	0	480	0.08
Globigerina sp (Foraminifera)	0	2240	1440	1600	2080	2400	9760	1.55
Harpacticoida (unidentified)	0	1600	0	0	320	0	1920	0.30
Harpacticus sp (Harpacticoida)	0	640	0	0	0	0	640	0.10
Heteropoda shells (gastropods)	320	1600	1600	0	0	2400	5920	0.94
Labidocera sp (Calanoida)	800	0	0	0	0	0	800	0.13
Lagena sp (Foraminifera)	0	0	800	640	0	0	1440	0.23
Leprotintinnus pellucidus (Tintinnida)	0	0	0	320	800	0	1120	0.18
Leprotintinnus sp (Tintinnida)	800	1600	0	3200	2240	0	7840	1.24
Leprotintinnus simplex	1440	1600	0	480	1600	0	5120	0.81

(Tintinnida)								
Megacyclops sp (Cyclopoida)	4800	0	3200	0	800	0	8800	1.40
Mesocyclops sp (cyclopoida)	0	0	0	0	2560	0	2560	0.41
Microsetella sp (Harpacticoida)	2400	1600	1600	0	480	1600	7680	1.22
Mysida (Malacostraca, Crustacea)	0	0	0	480	800	0	1280	0.20
Nauplius larva of Copepoda	0	0	12000	8000	6400	3200	29600	4.70
Nauplius larvae of Barnacles	0	0	800	800	0	640	2240	0.36
Nauplius larvae of Crustacea	12000	10400	17600	11200	8000	4800	64000	10.16
Nonion sp (Foraminifera)	0	0	0	1600	0	800	2400	0.38
Oithona nana (Cyclopoida)	1600	2400	2400	0	1920	0	8320	1.32
Oithona similis (Cyclopoida)	0	3200	2400	960	2240	0	8800	1.40
Oithona sp (Cyclopoida)	1600	11200	1920	1600	3200	0	19520	3.10
Ophiopluteus Larva (Echinodermata)	0	2560	0	0	480	320	3360	0.53
Ostracoda	0	0	2400	7200	960	3200	13760	2.18
Paracalanus parvus (Calanoida)	0	0	1920	2400	3200	0	7520	1.19
Paracalanus sp (Calanoida)	0	2560	0	0	0	1920	4480	0.71
Parvocalanus sp (Calanoida)	1120	3200	2400	3200	4000	4000	17920	2.84
Polychaete larvae (Annelids)	800	640	640	800	640	960	4480	0.71
Protozoea larva (Decapoda)	0	800	0	0	640	0	1440	0.23
Quinqueloculina sp (Foraminifera)	0	0	480	800	0	800	2080	0.33
Rosalina sp (Foraminifera)	0	0	960	0	0	0	960	0.15
Rotaliida (foraminifera)	0	0	0	0	1600	0	1600	0.25
Sagitta sp (arrow worm)	640	800	1600	1600	0	1600	6240	0.99
Spirillina sp (Foraminifera)	320	320	800	1280	640	800	4160	0.66
Spiroloculina sp (Foraminifera)	0	1120	0	0	0	1920	3040	0.48
Sponge Spicules	0	6400	4000	3360	5600	1920	21280	3.38
Subeucalanus sp (Calanoida)	2400	1600	1600	0	1600	1600	8800	1.40
Temora sp (Calanoida)	0	0	0	2400	0	800	3200	0.51
Thermocyclops sp (Cyclopoida)	0	0	2400	0	3360	0	5760	0.91
Tintinnopsis cylindrica (Tintinnida)	0	0	1600	0	800	0	2400	0.38
Tintinnopsis orientalis (Tintinnida)	8000	8000	28000	16000	17600	1920	79520	12.62
Tintinnopsis sp (Tintinnida)	27200	4800	1600	9600	14400	0	57600	9.14
Tintinnopsis tubulosa	0	0	0	0	640	0	640	0.10

(Tintinnida)								
Triloculina sp (Foraminifera)	0	0	0	800	0	0	800	0.13
Veliger larvae of Bivalve	480	800	2400	1440	800	4000	9920	1.57
Zoea larva of Crab	800	0	0	640	0	0	1440	0.23
Unidentified	0	0	0	320	0	0	320	0.05
Total No. Of Genera/Groups=68								
Site-wise Total Density (no/100m^3)	97280	90400	138240	119200	124800	60000	**Total Density =629920**	**100%**
Biomass (ml/100m^3)	**10.71**	**8.77**	**9.09**	**9.23**	**11.90**	**15.31**		

Table 18. Density of Zooplankton at Cargo Jetty site of Deendayal Port

Name of Genera/Group	2A	2B	2C	2D	2E	2 Control	Individual total density (no/100m^3))	% of Occurrence (Site-wise)
Acartia ohtsukai (Calanoida)	0	0	0	0	800	0	800	0.19
Acartia sp (Calanoida)	0	1600	1600	480	0	320	4000	0.93
Ammonia beccarii (Foraminifera)	800	1280	800	480	800	1120	5280	1.23
Amphipoda (Crustacea)	0	0	0	0	480	0	480	0.11
Arcella sp (Amoebozoa)	800	0	480	0	0	800	2080	0.48
Bolivina sp (Forminifera)	2400	800	0	320	2400	320	6240	1.45
Bulimina sp (Foraminifera)	0	320	480	0	480	480	1760	0.41
Calanoida (Unidetified)	3200	3200	3200	20000	6400	0	36000	8.36
Calcarina sp (Foraminifera)	0	0	0	1280	0	0	1280	0.30
Canthocalanus sp (Calanoida)	2400	1600	1440	0	0	960	6400	1.49
Clausocalanus sp (Calanoida)	1600	0	0	1600	0	0	3200	0.74
Copepoda eggs sacs	0	0	4000	4800	0	2400	11200	2.60
Cyclopoida (unidentified)	1600	4000	0	0	0	0	5600	1.30
Cyclops sp (Cyclopoida)	0	2400	3200	3520	3200	2400	14720	3.42
Cyphonautes larva (Bryozoan)	0	0	0	1600	0	0	1600	0.37
Egg capsules of Littorinids (animal)	0	0	0	800	800	800	2400	0.56
Euterpina sp (Harpacticoida)	1600	0	0	1600	0	0	3200	0.74
Fish (small)	0	0	320	0	0	0	320	0.07
Foraminifera(unidentified)	1600	4800	4800	1600	12000	3200	28000	6.50
Gastrula larva of Echinodermata	0	0	0	0	800	0	800	0.19
Globigerina sp (Foraminifera)	2560	3200	2400	2080	4800	2400	17440	4.05
Globigerinoides sp (Foraminifera)	0	0	0	0	0	3200	3200	0.74
Heteropoda shells (gastropods)	0	0	0	0	320	320	640	0.15
Hydrozoa (Cnidaria)	0	0	0	640	0	0	640	0.15
Labidocera sp (Calanoida)	1600	0	0	640	0	800	3040	0.71
Lagena sp (Foraminifera)	1600	0	0	0	0	0	1600	0.37
Leprotintinnus nordqvistii (Tintinnida)	0	0	0	0	640	0	640	0.15
Leprotintinnus pellucidus (Tintinnida)	0	0	1920	0	480	800	3200	0.74
Leprotintinnus sp (Tintinnida)	2400	0	2400	1600	1600	2400	10400	2.42
Leprotintinnus simplex (Tintinnida)	0	0	1600	960	1920	1920	6400	1.49
Microsetella sp (Harpacticoida)	0	800	1600	1600	1600	800	6400	1.49
Mysida (Malacostraca,	1600	1600	0	0	0	1600	4800	1.11

Crustacea)								
Nauplius larva of Copepoda	5600	5600	3200	0	0	1280	15680	3.64
Nauplius larvae of Barnacles	0	800	1600	0	2400	0	4800	1.11
Nauplius larvae of Crustacea	800	800	4000	0	2400	3200	11200	2.60
Nodosaria sp (Foraminifera)	0	0	0	320	0	0	320	0.07
Nonion sp (Foraminifera)	0	1600	640	0	1600	2400	6240	1.45
Oithona brevicornis (Cyclopoida)	0	0	0	1600	0	0	1600	0.37
Oithona nana (Cyclopoida)	0	1600	1600	2400	0	0	5600	1.30
Oithona similis (Cyclopoida)	0	1600	0	0	0	0	1600	0.37
Oithona sp (Cyclopoida)	4000	0	1600	4800	1600	0	12000	2.79
Ophiopluteus Larva (Echinodermata)	0	0	480	1600	0	0	2080	0.48
Ostracoda	4000	4800	4000	2560	3200	4000	22560	5.24
Paracalanus parvus (Calanoida)	0	0	0	1600	1600	0	3200	0.74
Parvocalanus sp (Calanoida)	0	0	800	8000	1920	0	10720	2.49
Polychaete larvae (Annelids)	800	0	0	0	0	0	800	0.19
Quinqueloculina sp (Foraminifera)	0	0	0	0	800	800	1600	0.37
Rotaliida (foraminifera)	0	0	1280	0	960	2400	4640	1.08
Sagitta sp (arrow worm)	2400	0	0	1600	1600	800	6400	1.49
Spirillina sp (Foraminifera)	320	640	480	960	480	320	3200	0.74
Spiroloculina sp (Foraminifera)	480	0	640	0	0	640	1760	0.41
Sponge Spicules	7200	5600	4000	4800	4000	2400	28000	6.50
Subeucalanus sp (Calanoida)	0	1600	1600	0	1600	1600	6400	1.49
Temora sp (Calanoida)	0	0	0	0	1600	0	1600	0.37
Tintinnopsis cylindrica (Tintinnida)	0	0	2400	0	480	0	2880	0.67
Tintinnopsis orientalis (Tintinnida)	5600	2560	2240	16000	5600	5120	37120	8.62
Tintinnopsis sp (Tintinnida)	5600	3840	0	9600	4800	1600	25440	5.91
Triloculina sp (Foraminifera)	1600	800	0	480	0	0	2880	0.67
Veliger larvae of Bivalve	1600	320	2400	4000	0	0	8320	1.93
Zoea larva of Crab	0	4000	640	320	1600	1600	8160	1.90
Total No. Of Genera/Groups=60								
Site-wise Total Density (no/100m^3)	65760	61760	63840	106240	77760	55200	**Total Density =430560**	**100%**
Biomass (ml/100m^3)	**27.27**	**35.00**	**65.79**	**13.89**	**15.22**	**26.92**		

Table 19. Density of Zooplankton at Phang Creek site of Deendayal Port

Name of Genera/Group	3A	3B	3C	3D	3E	3 Control	Total density (no/100m3)	% of Occurrence (Site-wise)
Acartia sp (Calanoida)	0	800	1600	0	640	320	3360	0.85
Ammonia beccarii (Foraminifera)	800	480	800	320	960	1600	4960	1.26
Arcella sp (Amoebozoa)	800	0	4000	960	1600	4000	11360	2.88
Bolivina sp (Forminifera)	640	480	1600	0	0	960	3680	0.93
Bolivinita sp (Foraminifera)	800	0	0	0	0	0	800	0.20
Calanoida (Unidetified)	2400	3200	4800	3200	2560	3200	19360	4.91
Calcarina sp (Foraminifera)	0	0	0	320	0	0	320	0.08
Canthocalanus sp (Calanoida)	960	640	0	640	1600	0	3840	0.97
Centropages sp (Calanoida)	0	0	0	320	0	0	320	0.08
Clausocalanus sp (Calanoida)	0	0	0	0	800	2240	3040	0.77
Copepoda eggs sacs	4800	3520	0	4000	2400	0	14720	3.73
Cyclopoida (unidentified)	0	0	0	4000	800	0	4800	1.22
Cyclops sp (Cyclopoida)	3200	1920	640	1600	1600	0	8960	2.27
Cyphonautes larva (Bryozoan)	320	0	320	0	0	0	640	0.16
Discorbis sp (Foraminifera)	0	0	0	0	0	640	640	0.16
Egg (unidentified)	480	0	0	0	0	0	480	0.12
Egg capsules of Littorinids (animal)	0	0	0	0	0	640	640	0.16
Euterpina sp (Harpacticoida)	0	800	0	0	0	0	800	0.20
Favella sp (Tintinnida)	0	3200	0	0	0	0	3200	0.81
Foraminifera(unidentified)	4800	2400	12000	5600	4000	4800	33600	8.52
Gastropoda shells (empty)	0	0	4000	0	0	0	4000	1.01
Gastrula larva of Echinodermata	800	0	480	320	0	480	2080	0.53
Globigerina sp (Foraminifera)	3200	1440	2400	0	1920	3520	12480	3.17
Globigerinoides sp (Foraminifera)	0	0	0	0	0	1440	1440	0.37
Harpacticoida (unidentified)	800	0	0	320	0	0	1120	0.28
Heterolaophonte (Harpacticoida)	0	0	0	480	0	0	480	0.12
Heteropoda shells (gastropods)	0	0	0	800	0	0	800	0.20
Labidocera sp (Calanoida)	0	0	0	2400	0	0	2400	0.61
Lagena sp (Foraminifera)	320	0	1600	0	0	0	1920	0.49
Leprotintinnus nordqvistii (Tintinnida)	0	1600	0	0	0	0	1600	0.41
Leprotintinnus pellucidus (Tintinnida)	2720	1440	2240	3200	2240	3360	15200	3.86
Leprotintinnus sp (Tintinnida)	3200	1600	5600	2240	4800	4800	22240	5.64
Leprotintinnus simplex (Tintinnida)	2400	960	3360	2400	1600	1600	12320	3.13

Lucifer sp (Decapoda)	0	1600	0	320	0	0	1920	0.49
Megacyclops sp (Cyclopoida)	0	0	0	0	800	0	800	0.20
Mesocyclops sp (cyclopoida)	1600	1920	0	0	0	0	3520	0.89
Microsetella sp (Harpacticoida)	0	0	800	0	0	480	1280	0.32
Mysida (Malacostraca, Crustacea)	0	0	320	0	0	0	320	0.08
Nauplius larva of Copepoda	3200	2400	800	0	0	0	6400	1.62
Nauplius larvae of Barnacles	1600	800	480	640	1600	0	5120	1.30
Nauplius larvae of Crustacea	8000	4000	800	1600	1600	2560	18560	4.71
Nonion sp (Foraminifera)	800	0	0	480	0	640	1920	0.49
Oithona sp (Cyclopoida)	0	1600	800	0	0	0	2400	0.61
Ophiopluteus Larva (Echinodermata)	0	0	0	320	320	0	640	0.16
Ostracoda	3200	800	9600	1600	1440	1920	18560	4.71
Paracalanus sp (Calanoida)	2400	960	0	1920	1600	0	6880	1.75
Parvocalanus sp (Calanoida)	0	960	1920	2560	2400	1600	9440	2.39
Polychaete larvae (Annelids)	0	800	0	800	640	800	3040	0.77
Protozoea larva (Decapoda)	0	0	0	0	320	0	320	0.08
Pseudodiaptomus sp (Calanoida)	0	2400	0	800	0	0	3200	0.81
Quinqueloculina sp (Foraminifera)	0	0	320	0	0	0	320	0.08
Rotaliida (foraminifera)	3200	1600	1920	0	1600	2400	10720	2.72
Sagitta sp (arrow worm)	1600	0	0	0	0	1600	3200	0.81
Spirillina sp (Foraminifera)	800	640	480	480	960	640	4000	1.01
Spiroloculina sp (Foraminifera)	1120	320	0	640	960	0	3040	0.77
Sponge Spicules	4800	8000	5600	960	3200	4800	27360	6.94
Subeucalanus sp (Calanoida)	0	0	0	0	160	0	160	0.04
Textularia sp (Foraminifera)	0	0	320	0	0	0	320	0.08
Thermocyclops sp (Cyclopoida)	0	1440	0	0	0	0	1440	0.37
Tintinnopsis cylindrica (Tintinnida)	800	0	0	1600	0	0	2400	0.61
Tintinnopsis orientalis (Tintinnida)	9600	4000	4000	1600	7200	5600	32000	8.12
Tintinnopsis sp (Tintinnida)	9600	0	800	4000	0	2880	17280	4.38
Tintinnopsis tubulosa (Tintinnida)	480	0	0	0	0	0	480	0.12
Triloculina sp (Foraminifera)	0	1600	800	0	0	0	2400	0.61
Veliger larvae of Bivalve	1600	800	480	480	960	1920	6240	1.58
Zoea larva of Crab	0	0	0	0	320	320	640	0.16
Unidentified	0	0	0	320	0	0	320	0.08
Total No. Of Genera/Groups=67								

Site-wise Total Density (no/100m^3)	87840	61120	75680	54240	53600	61760	**Total density =394240**	**100%**
Biomass (ml/100m^3)	**9.38**	**10.00**	**38.46**	**17.14**	**15.00**	**20.83**		

Table 20. Diversity indices of Zooplankton at different sites of Deendayal Port

	Offshore						Cargo jetty						Phang Creek					
	1A	**1B**	**1C**	**1D**	**1E**	**1-control**	**2A**	**2B**	**2C**	**2D**	**2E**	**2-contrl**	**3A**	**3B**	**3C**	**3D**	**3E**	**3-control**
Variables																		
Taxa_S	29	30	39	39	43	33	27	27	33	34	35	33	35	34	32	36	31	29
Individuals (nos. /m^2)	97280	90400	138240	119200	124800	60000	65760	61760	63840	106240	77760	55200	87840	61120	75680	54240	53600	61760
Dominance_D	0.12	0.06	0.08	0.06	0.06	0.04	0.06	0.06	0.04	0.08	0.06	0.04	0.05	0.05	0.07	0.05	0.05	0.05
Shannon Diversity Index(H)	2.62	3.05	3.06	3.10	3.21	3.27	3.06	3.05	3.29	2.91	3.18	3.27	3.18	3.27	2.96	3.23	3.15	3.11
Simpson_1-D	0.88	0.94	0.92	0.94	0.94	0.96	0.94	0.94	0.96	0.92	0.94	0.96	0.95	0.95	0.93	0.95	0.95	0.95
Evenness	0.47	0.70	0.55	0.57	0.58	0.80	0.79	0.78	0.81	0.54	0.68	0.79	0.69	0.77	0.60	0.70	0.75	0.77
Menhinick	0.09	0.10	0.10	0.11	0.12	0.13	0.11	0.11	0.13	0.10	0.13	0.14	0.12	0.14	0.12	0.15	0.13	0.12
Margalef	2.44	2.54	3.21	3.25	3.58	2.91	2.34	2.36	2.89	2.85	3.02	2.93	2.99	2.99	2.76	3.21	2.76	2.54

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Annexure -G

List of CSR Works for the year 2025(April to Till November-2025)		
Sr.No	**Name of work**	**Approved cost (Rs in Lakhs)**
1	Request for construction of relocatable of sports arena at Gandhidham Military Station,HQ 98 Artillery Brigade Military Station Gandhidham	₹ 28.00
2	Proposal for construction of Police Community Hall at Police Headquarters Shinay.Office of the Superintendent of Police, East – Kutch Gandhidham.	₹ 100.00
3	Proposal for providing AWG system at their check posts located in the Runn of Kutch,Commandant BSF Station Gandhidham	₹ 82.70
4	Proposal for providing 4000 pieces of Tripal/Tarpaulin,Matri Sena Charitable Trust	₹ 32.00
5	Proposal for Upgrading Satellite Eye Hospital at Bhuj.1.Request for financial support for the addition of cornea and retina outpatient departments (OPD), a spectacle dispensing unit, and a medicine counter as part of our OPD activities, & equipment purchase.	₹ 35.08
6	Proposal for financial assistance for purchase of C Arm and OT table to start Orthopedic at St. Joseph's Hospital Gandhidham,ST. Joseph's Hospital Trust, Gandhidham.	₹ 28.78
7	Proposed to establish a women empowerment center, through Ujjas Mahila Sangh,Gandhidham	₹ 119.48
8	CSR Grant for 'Strengthening of School Ecosystem at Primary School Level in Kachchh District,Ladies Environment Action Foundation (LEAF), Gandhinagar	₹ 50.00
9	Proposal for recharge Ponds and Solar based initiatives.Providing solar street lights, home lighting and solar lights for boats, specially targets sea farming families in the Tuna & Vandi village within Gandhidham block of Kutch district,Baif Institute for sustainable livelihoods and development, (BISLAD)Pune- Maharashtra.	₹ 30.00
10	Proposal for the Financial assistance for Ramakrishna Mission Centre for Human Excellance and Social Sciences also called 'Viveka Thirtha', New Town Kolkata. Human Excellence building ,Ramakrishna Mission, West Bengal	₹ 150.00
11	Funding for Distribute Biomass Green Cook Stove free of cost across Gujarat state.,Ramdas Athawale Foundation Ahemdabad	₹ 27.00
12	Request to Allotment of Fund for Development of School premises and providing furniture etc from CSR Fund.,Shree J.H Shukla Madhyamik Shala	₹ 25.92
13	Re-accreditation of sport academy under Khelo India Scheme.Request for Infrastructure for the proposals i) seating gallery & amenities ii) up gradation of existing hostel for elite athletes iii) surrounding road & infrastructure, etc.,Usha School Athletics, Kerala.	₹ 69.00
14	Proposal for Skill Development Training Program for Unemployed and Underprivileged Youth under CSR Initiative of Deendayal Port Authority (DPA) through Centre of Excellence in Maritime and Shipbuilding (CEMS),Mumbai	₹ 124.00
15	Submission of application along with requisite documents for construction of Kabrastan and fund for basic amenities under CSR,Etihadul Muslemin E Hind Trust, Anjar	₹ 50.00
16	Request Letter for the purchase of stainless steel Water Cooler with filter and dispenser for the school,Sunflower School, Gandhidham	₹ 3.19
17	Proposal for Placement Linked Skill and Capacity Building Training on Tourism and Hospitality Request for funding under Corporate social Responsibility (CSR) initiative,Pragati Edutech, Guwahati	₹ 50.00
18	Fund for establishment of New Facilities and upgradation of existing facilities at 'Adhar Sankul (Excluding cost of Building Construction.),'Adhar Sankul' Manav Seva Trust, Gandhidham.	₹ 75.00
19	Earnest Appeal to Contribute under CSR Activities for the construction of sainik school at silvassa in the name of NETAJI CHANDRA BOSE MILITARY ACEDEMY,VidhyaBharti Gujarat Pradesh, Ahemdabad.	₹ 445.23
20	Construction of an educational and social purpose building having 28 rooms & 2 halls.Shree Akhil Kutch Samasta Meghvanshi Gurjar Meghwal Charitable Trust, Bhuj.	₹ 75.00
21	Request to allotment of fund for development of school premises and providing furniture from CSR fund.Sunrise Global School, Gandhidham	₹ 12.60
22	Financial assistance to construction of Building Mind Power development centre for specially visually impaired children. With Equipments, Furniture CCTV, Airconditioner etc.,Shri Navchetan Adhjan Mandal, Madhapar	₹ 107.00

23	Proposal for DPA support Kutch Muslim Shifa Hospital,Muslim Shifa Medical Trust-Bhuj	₹	200.00
24	Request for help from CSR for providing Kits to the Children . List of government schools in khambhaliya taluka,for school Bags/Kits etc. They have requested for 1000 kits ,District Primary Education Officer, Devbhumi Dwarka-Khambhaliya	₹	4.00
25	Project proposal is for Education,Health and Livelihood project in kutch area Electric vehicle project for migrant community school,mobile health van project proposal, school structure project,tailoring training project, computer class for bhadreshwar centre, school-toilet-project, vermin compose unit, fisherman livelihood project.Yusuf Meherally Centre, Bhadreshwar-Kutch	₹	97.67
26	Request for renovation and construction of the shed work above G.F. slab, both side jali for shed, repairing work, painting.Missionaries of Charity, Bhachau (Mother Teresa's distitudi's home)	₹	55.00
27	River Reincarnation Project of the Bhukhi River.Krushi Research Innovation and Development Association, Mumbai (KRIDA)	₹	400.00
28	Providing Financial Assistance to R.D.S Kalavad Taluka Meghwar Seva samaj Education and Charitable Trust, Kalavad,SWA Ramji Daya Somaiya Shri Kalavad Taluka Meghwar Seva Samaj Education and Charitable trust, Kalavad	₹	75.00
29	CSR funding towards cure of Baby Aasmika Das diagnosed with Spinal Muscular Atrophy (SMA Type-1).	₹	20.00
30	CSR Funding for Providing Nutrition Kit to T.B. Patients under TB Mukat Bharat Abhiyan as Nishyray Mitra.	₹	14.02
31	Financial assistance under the CSR initiative to facilitate the urgent upgradation of the training and parade ground at the 176 BN BSF campus, Bhuj, Frontier Headquarters, Border Security Force (BSF)	₹	171.90
32	Financial assistance under the CSR initiative for Construction of a Martyr's Column at the 176 BN BSF campus, Bhuj, Frontier Headquarters, Border Security Force (BSF)	₹	32.20

Annexure -H

CE
May posted in Civil Engineering Deptt/ Chairman's office, after observance & due formalities there.

Date: 25th August

To,

The Secretary,
Deendayal Port Authority,
Gandhidham, Kutch

Subject: Duty Report for the post of Chief-Manager (Environment & Safety) on contractual basis at DPA – reg.

Sir,

I Dr. Utkarsh S. Mukkannawar, have been selected and offered the position of Chief Manager (Environment & Safety) on contractual basis under professional functionaries category vide Letter No. GA/PS/4292(PF)/2025/1347 with effective from 12th August'2025.

As per terms clause no 19, I "have to report for medical examination before the Chief Medical Officer, DPA at Gopalpuri Hospital....."

Accordingly, I hereby submit and enclose my medical examination Report as clinically healthy and "FIT to Join".

Further, I hereby submit my duty report today i.e., 25th August 2025 (FN) along with duly signed acceptance copy of Offer Letter, the original copy of the medical report enclosing clinical documents and two passport size photos for your kind perusal.

Thanking you,

Yours faithfully,

25/08/25

Dr. Utkarsh Mukkannawar
Mob: 9822077507

CE

May be posted in Civil Engineering Department, after due observance of formalities as per T&C of engagement, under intimation to GAD Please.

10/9/2025
Secretary.

Date: 10th September 2025

To,

The Secretary,

Deendayal Port Authority,

Gandhidham, Kutch

Subject: Duty Report for the Port of Manager (Environment & Safety) on contractual basis at DPA – reg.

Sir,

I Ms. Neha Chandrashekhar Dekate, have been selected and offered the position of Manager (Environment & Safety) on contractual basis under professional functionaries' category vide letter no. GA/PS/4292 (PF)/2025/1349 with effective from 12th August'2025.

As per clause no. 19, "I have to report for medical examination before the Chief Medical Officer, DPA at Gopalpuri Hospital..... "

Accordingly, I hereby submit and enclose my medical examination report as clinically healthy and "FIT to Join".

Further, I hereby submit my duty report today i,e. 10th September 2025 (FN) along with duly signed acceptance copy of Offer letter, the original copy of the medical report enclosing clinical documents and two passport size photos for your kind perusal.

Thanking you,

Yours faithfully,

Neha Stte

Ms. Neha Dekate

Mob: 9096069665

CG/Sr AS

May be posted in Environment Cell of Civil Engineering Department, subject to observance of due formalities as per terms & conditions of engagement in DPA on contract basis, Above.

3/9/2025
Secretary

To,

The Secretary

Administrative Building

Deendayal Port Authority

Date: 03/09/2025

SUBJECT: Duty Report for Contractual Engagement as Manager – Environment & Safety in Deendayal Port Authority (DPA)

Ref : DPA letter GA/PS/4292(PF)/2025/1348 dated 12/08/2025

Sir,

With reference to the above referred letter dated 12/08/2025 I am hereby pleased to submit my Duty Report and I confirm to join the organization with effect from today i.e.03/09/2025.

Thanking You

Yours Faithfully

Rajeshwari Sharma

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