DEENDAYAL PORT AUTHORITY
(Erstwhile: DEENDAYAL PORT TRUST)

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EG/WK/5202 (D)/Part (CRZ)/ 141 Dated: 09/01/2026

To,
The Director (Environment) &
Member Secretary, GCZMA,
Forest & Environment Department,
Govt. of Gujarat,
Block No.14, 8th floor, New Sachivalaya,
Gandhinagar - 382 010.

Sub: CRZ Clearance for "Creation of water front facilities (Oil Jetties 8, 9, 10 & 11) and development of land of area 554 acres for associated facilities for storage at Old Kandla, Gandhidham, Kutch, Gujarat by M/s Deendayal Port Authority" - **Submission of six-monthly Compliances of the stipulated conditions in CRZ Recommendations req.**

Ref.: (1) Letter No. ENV-10-2018-24-T Cell dated 30/7/2020 of Director (Environment) & Additional Secretary, Forest & Environment Department, GoG.
(2) DPT letter no. EG/WK/5202 (D)/ Part (CRZ 2)/28 dated 29/06/2021
(3) DPT letter no. EG/WK/5202 (D)/ Part (CRZ 2)/142 dated 08/02/2022
(4) DPA letter no. EG/WK/5202 (D)/ Part (CRZ 2)/128 dated 30/06/2022
(5) DPA letter no. EG/WK/5202 (D)/ Part (CRZ 2)/296 dated 05/05/2023
(6) DPA letter no. EG/WK/5202 (D)/ Part (CRZ 2)/363 dated 18/09/2023
(7) DPA letter no. EG/WK/5202 (D)/ Part (CRZ 2)/44 dated 27/03/2024
(8) DPA letter no. EG/WK/5202 (D)/ Part (CRZ 2)/115 dated 12/08/2024
(9) DPA letter no. EG/WK/5202 (D)/ Part (CRZ 2)/21 dated 03/02/2025
(10) DPA letter no. EG/WK/5202 (D)/ Part (CRZ 2)/23 dated 18/06/2025

Sir,

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

In this connection, it is to state that, the Gujarat Coastal Zone Management Authority vide above referred letter dated 30/7/2020 had recommended the subject project of Deendayal Port Authority. Subsequently, the MoEF&CC, GoI had accorded the Environmental & CRZ Clearance vide letter dated 20/10/2020 for the subject project. Subsequently, DPA vide above cited letters had submitted compliance report of the stipulated conditions in CRZ recommendations to GCZMA.

Now, as directed under Specific Condition No. 26 mentioned in the CRZ Clearance letter dated 30/7/2020 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 of the stipulated conditions for period April 2025 to September 2025 along with necessary annexures, for kind information & record please **(Annexure I).**

Further, as per the MoEF&CC, Notification 5.0.5845 (E) dated 26.11.2018, in which it is mentioned that, "***In the said notification, in paragraph 10, in subparagraph (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 in ID **gczma.crz@gmail.com** & **direnv@gujarat.gov.in** .

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

Yours Faithfully,

XEN (EMC)
Deendayal Port Authority

Copy to: -

Shri Amardeep Raju, MoEF&CC,GoI
Scientist E, Ministry of Environment, Forest and Climate Change,
& Member Secretary (EAC-Infra.1),
Indira Paryavaran Bhavan,
3rd Floor, Vayu Wing, Jor Bagh Road, Aliganj,
New Delhi-110003.
Email ID: ad.raju@nic.in

Annexure - I

Annexure 1

Compliance Report (For the period of April 2025 to September 2025)

Subject: Point-wise Compliance of conditions stipulated in CRZ Recommendations for project "Creation of water front facilities (oil jetties 8,9,10 and 11) and development of land (1432 acres – revised area 554 acres) for associated facilities for storage at old Kandla, Tal: Gandhidham Dist. Kutch, Gujarat by Deendayal Port Authority (Erstwhile Deendayal Port Trust)" -reg.

Ref No: - CRZ recommendation issued by GCZMA vide Letter No- ENV-10-2018-24- T Cell dated 30.07.2020

S. No	CRZ Conditions	Compliance Status
	SPECIFIC CONDITIONS	
1.	The DPA shall strictly adhere to the provisions of the CRZ Notification, 2011 issued by the Ministry of Environment, Forests and Climate Change, Government of India	It is assured that, the provisions of the CRZ Notification, 2011 shall be strictly adhere to by the DPA.
2.	Necessary permissions from different departments/ agencies under different laws/ acts shall be obtained before commencing any activity (including the construction)	The Consent to Establish (CTE) from the GPCB had already been obtained vide CTE No. 94118 granted by the GPCB vide letter no. PC/CCA-KUTCH 1524/GPCB ID 56985 dated 23/7/2018 with a validity period 3/4/2023. DPA also obtained validity extension vide GPCB order no. PC/CCA-KUTCH 1524/GPCB ID 56985 dated 30/09/2023 valid up to 19/11/2030. Further, Construction activity of Oil Jetty 08 is completed, accordingly DPA had obtained the CCA (AWH – 136469) from the GPCB vide letter PC/CCA-KUTCH-1524/GPCB ID 56985 dated 20/08/2024 for the same. A copy submitted along with compliance report submitted on 03/02/2025.
3.	The DPA shall ensure that the all the provisions of CRZ Notification 2011 shall be complied with and storage facilities in CRZ areas shall be in compliance with Annexure-ll of the above said Notification	It is assured that all the provisions of CRZ Notification, 2011 will be complied with and only storage of permissible cargo as per CRZ Notification, 2011, Annexure II will be allowed to store in storage facilities to be Developed.
4.	There shall not be any blockage of creek due to laying of pipeline. And free flow of water shall be maintained.	The construction activity Construction of Oil Jetty No. 8 completed and partial development of embankment for road network along with reclamation of Land has been undertaken. However, for remaining works to be undertaken (Construction of OJ 9 , 10 & 11 and development of Land), it is assured that no activity other than those permissible in Coastal Regulation Notification shall be carried out in the CRZ area.
5.	There shall not be any mangrove destruction/ damage due to proposed activities and adequate buffer zone of 70 metres shall be maintained from mangrove areas	It is assured that all the proposed activities shall be carried out strictly as per the EC & CRZ Clearance accorded by the MoEF&CC, GoI dated 20/11/2020.
6.	The DPA shall effectively implement the Mangrove Development, Protection & Management plan for control of indirect impact on mangrove habitat	As per the directions of the GCZMA and MoEF&CC, GoI, DPA had already undertaken Mangrove Plantation in an area of 1600 Ha. till date since the year 2005. A statement showing details of mangrove plantation at various locations with cost incurred has been submitted along with earlier compliance reports Further, DPA has assigned the work to for the

		"Mangrove Plantation in an area of 50 Ha for the Deendayal Port Authority to GUIDE, bhuj vide work order dated 10/06/2024. A copy of final report has been submitted along with earlier compliance reports. It is also relevant to submit here that, as per the direction of the Gujarat Coastal Zone Management Authority, DPA had already prepared & submitted a report on mangrove conservation and management plan formulated by Gujarat Institute of Desert Ecology during the study period of Jan-April, 2015 (Report already submitted along with 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 for the year 2021 to 2022 has been submitted along with the compliance report submitted with 5/5/2023 Further DPA has assigned work to M/s GUIDE, Bhuj vide work order dated 10/06/2024 for "Monitoring of Mangrove Plantation carried out by DPA" for the Period of 10/06/2024 to 09/06/2025. A copy of final report submitted by GUIDE,Bhuj is attached herewith as **Annexure A**
7.	The DPA shall have to make a provision that mangrove areas get proper flushing water and free flow of water shall not be obstructed	The construction activity Construction of Oil Jetty No. 8 completed and partial development of embankment for road network along with reclamation of Land has been undertaken. However, for remaining works to be undertaken (Construction of OJ 9 , 10 & 11 and development of Land), it is assured that no activity other than those permissible in Coastal Regulation Notification shall be carried out in the CRZ area.
8.	The DPA shall have to dispose of the dredged material at the designated dredged material disposal point based on scientific study and approved by the MOEF&CC, GOI	No dredging activity has been started yet. However, it is assured that dredging activity will be carried out strictly as per the requirement of the condition and the same shall be disposed at designated dumping Ground (25° 51' 00" N & 70°10' 00" E).
9.	The DPA shall have to maintain the record for generation and disposal of capital dredging and maintenance dredging	No dredging activity has been started yet. However, it is assured that necessary record will be maintained as per the requirement of the condition.
10.	No dredging, reclamation or any other project related activities shall be carried out in the CRZ area categorized as CRZ I (i) (A) and it shall have to be ensured that the mangrove habitat and other ecologically important and significant areas, if any, in the region are not affected due to any of the project activities.	It is assured that all the project related activities will be strictly carried out as per the EC & CRZ Clearance accorded by the MoEF&CC, GoI dated 20/11/2020.
11.	The DPA shall ensure that construction activities like dredging etc. shall be carried out in confined manner to reduce the impact on marine environment.	No dredging activities have been started yet. However, it is assured that construction activities like dredging will be carried out as per the requirement of the condition.
12.	The DPA shall ensure that the dredging shall not be carried out during the fish breeding season.	No dredging activities have been started yet. Point Noted for Compliance.

13.	Construction waste including debris and dredged material shall be disposed safely in the designed areas as approved by MoEF&CC, GoI and it shall be ensured that there shall be no impact on flora and fauna	DPA had already issued general circular vide dated 3/9/2019 regarding Construction and Demolition Waste Management for strict implementation in DPA. **Copy submitted along with the compliance report submitted with 05/05/2023**
14.	No effluent or sewage shall be discharged into the sea / creek or in the CRZ area and shall be treated to conform the norms prescribed by the Gujarat Pollution Control Board and would be reused / recycled as per the approval of the Board.	It is assured that No effluent or sewage will be discharged into the Sea/creek or in the CRZ area. Further, Generated waste water from the oil jetty no. 8 will be treated in septic tank/soak pit. However, after completion of entire project facility (Oil Jetties 8 to 11 & associated area for storage), possibility may be explored to treat the waste water generation (about 16 KLD) through existing STP of DPA
15.	All the recommendations and suggestions given by the Cholamandalam MS Risk Services Limited in their Environment Impact Assessment report shall be implemented strictly by DPA	The compliance of the recommendations and suggestions is given by the EIA Consultant, M/s SV Enviro, Vizag in A Copy of EIA Report submitted along with compliance report submitted on 03/02/2025.
16.	The DPA shall exercise extra precautions to ensure the navigation safety and mitigation of the risk associated with the project activities especially due to collision, sinking or accidents of the vessels and would deploy the latest communication and navigation aids for this purpose. The proposed facilities shall also be covered under the VTMS being developed by the GMB	In this regard, it is to state that, Deendayal Port Authority had already contributed Rs. 41.25 crores for installing and operating the VTMS in the Gulf of Kachchh.
17.	The cost of the external agency that may be appointed by this department for supervision / monitoring of the project activities during construction/ operational phases shall be paid by DPA	Point Noted.
18.	The DPA shall contribute financially for any common study or project that may be proposed by this Department for environmental management / conservation / improvement for the Gulf Kutch	Point noted for compliance.
19.	The piling activities debris and any other type of waste shall not be discharged into the sea or creek or in the CRZ areas. The debris shall be removed from the site immediately after the piling activities are over.	DPA has included clause in the tender for the Contractor to undertake precautions for safeguarding the environment during the course of the construction work.
20.	The camps shall be located outside the CRZ area and the 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 labours.	DPA has included clause in the tender for the Contractor to undertake precautions for safeguarding the environment during the course of the construction work.
21.	The DPA shall prepare and regularly update their Local Oil Spill Contingency and Disaster Management Plan in consonance with the National Oil Spill and Disaster Contingency Plan	Point Noted for compliance. DPA is already having Local Oil Spill contingency plan and updated DMP. Copies of the same already communicated along with compliance report submitted on 03/02/2025.
22.	The DPA 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 for compliance.
23.	The groundwater shall not be tapped to meet with the water requirements in any case	Water requirements will be met through procurement from GWSSB or private tankers. It is hereby assured that no groundwater shall be

		tapped.
24.	DPA shall take up greenbelt development activities in consultation with the Gujarat institute of Desert Ecology / Forest Department / Gujarat Ecology Commission	DPA has already developed Green belt in and around the Port area. Further, DPA assigned work for Green belt development in an area of about 32 hectares to the Forest Department, Govt. of Gujarat during August, 2019 at the cost of Rs. 352.32 lakhs. The work is completed. Further, DPA also undertook massive green belt development in and around the Port area and at Gandhidham area. Further, DPA also assigned the work of ***"Greenbelt Development in Deendayal Port Authority and its surrounding areas Charcoal Site (Phase I)"*** vide Work Order dated 31/05/2022 at the cost of Rs. 33.22 lakhs . The work is completed. The final report is submitted along with the compliance submitted on 18/09/2023. 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 work is completed and final report submitted along with compliance report submitted on 03/02/2025. 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 submitted by GUIDE, Bhuj is attached herewith as **Annexure B**.
25.	The DPA 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	As per the CSR Guidelines issued by the Ministry of Ports, Shipping & Waterways, Government of India, from time to time, DPA had undertaken CSR activities since the year 2011-12. Already CSR works are being attended by DPA. The details of CSR activities undertaken/to be undertaken by DPA are placed in **Annexure C**.
26.	A six-monthly report on compliance of the conditions mentioned in this letter shall have to be furnished by DPA on a regular basis to this Department and MoEF&CC, GoI.	DPA has been regularly submitting the six-monthly report on compliance of the conditions mentioned in the CRZ Recommendation letter dated 30/7/2020 to the CRZ Authority and to the MoEF&CC, GoI. Last compliance submitted submitted along with compliance report submitted on 03/02/2025.
27.	The DPA shall ensure that the numbers of the Vessels and machinery deployed during marine construction, which are a source of low level organic and PHC pollution will be optimized to minimize risks of accidents involving these vessels.	Point Noted for compliance.

28.	The noise level during transport and construction of marine facilities shall be kept minimum.	DPA appointed NABL Accredited laboratory for regular Monitoring of environmental parameters since the year 2016 in continuation of this DPA appointed M/s Gujarat Environment Management Institute (GEMI), Gandhinagar (NABL Accredited laboratory) for regular Monitoring of environmental parameters vide work order dated 15/02/2023. The work is in progress & DPA is submitting the monitoring data regularly to all the concerned authorities along with compliance reports submitted. The latest Environmental Monitoring Reports are attached herewith as **Annexure D**
29.	The DPA shall regularly conduct the surveys to identify changes in the channel bathymetry to minimize navigation hazards. Proper navigational aids and guidance should be provided to ships navigating the channel and there should be a properly structured vessels traffic management Strategy to avoid accidents.	Point noted for compliance. Further, it is to state that, Deendayal Port Authority had already contributed Rs. 41.25 crores for installing and operating the VTMS in the Gulf of Kachchh.
30.	The DPA shall carry out separate study for further erosion and deposition pattern in the area after dredging through a reputed agency and shall follow the suggestions of the study done by reputed agency, for maintenance dredging, the recommendations/ suggestions of the reputed agency shall be follow by the DPA.	No dredging activity has been started yet. However, it is assured that necessary will be conducted as per the requirement of the condition.
31.	Any other condition that may be stipulated by this Department and MoEF&CC, GoI from time to time for environmental protection / management purpose shall also have to be complied with by DPA.	Point noted.

Annexure - A

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.

Gujarat Institute of Desert Ecology

Institute Seal

Authorized Signatory

DIRECTOR
Gujarat Institute of Desert Ecology
Bhuj - Kachchh.

Project Team

Project Coordinator: Dr. V. Vijay Kumar, Director

Project Personnel

Principal Investigator

Dr. B. Balaji Prasath, Senior Scientist

Co-Investigator

Dr. Kapilkumar Ingle, Project Scientist-II

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.

Contents

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.

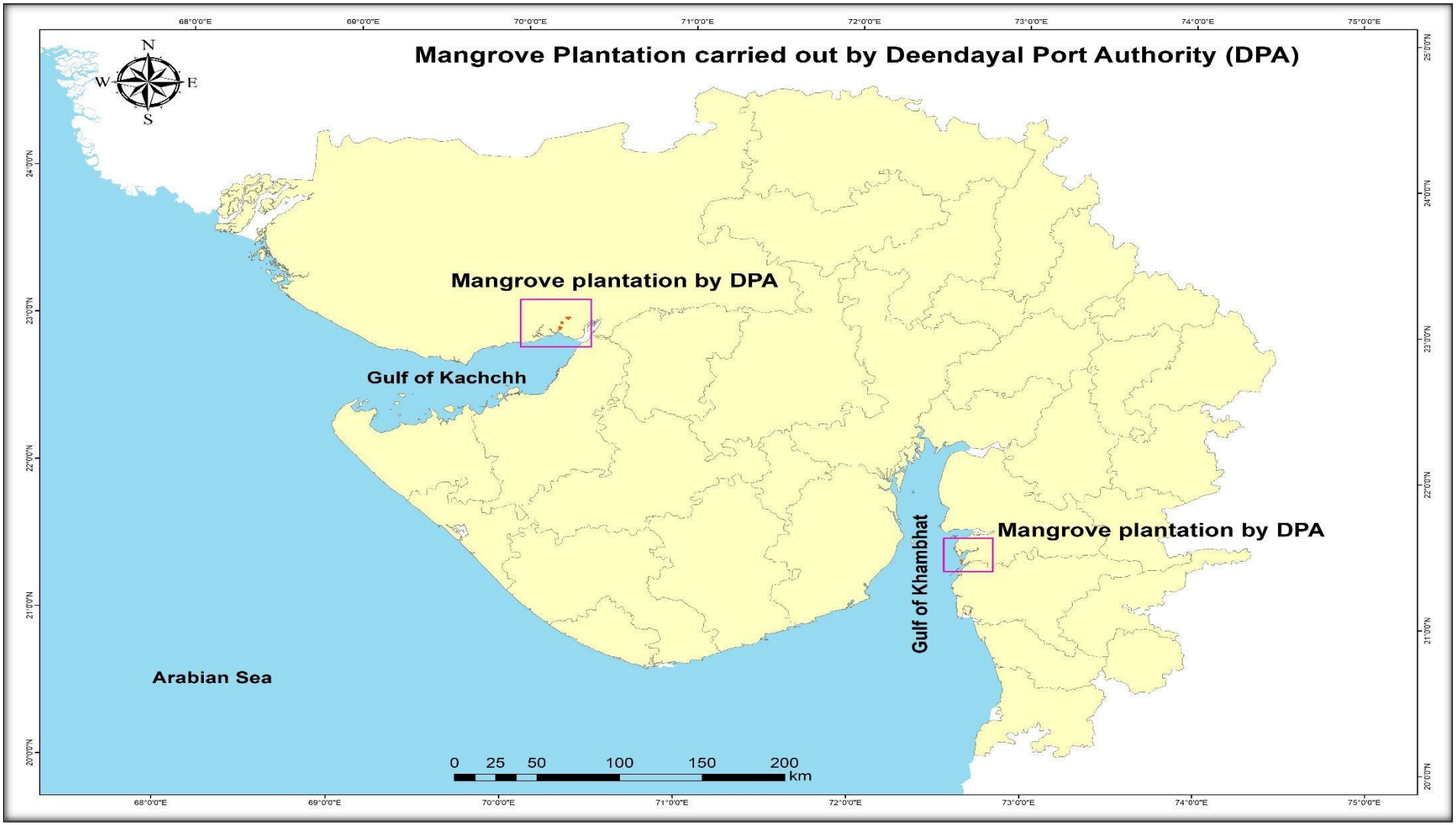

Figure 1: Mangrove plantation carried out by DPA at Sat Saida Bet and Nakti creek in Kachchh district and Kantiyajal in Bharuch district

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).

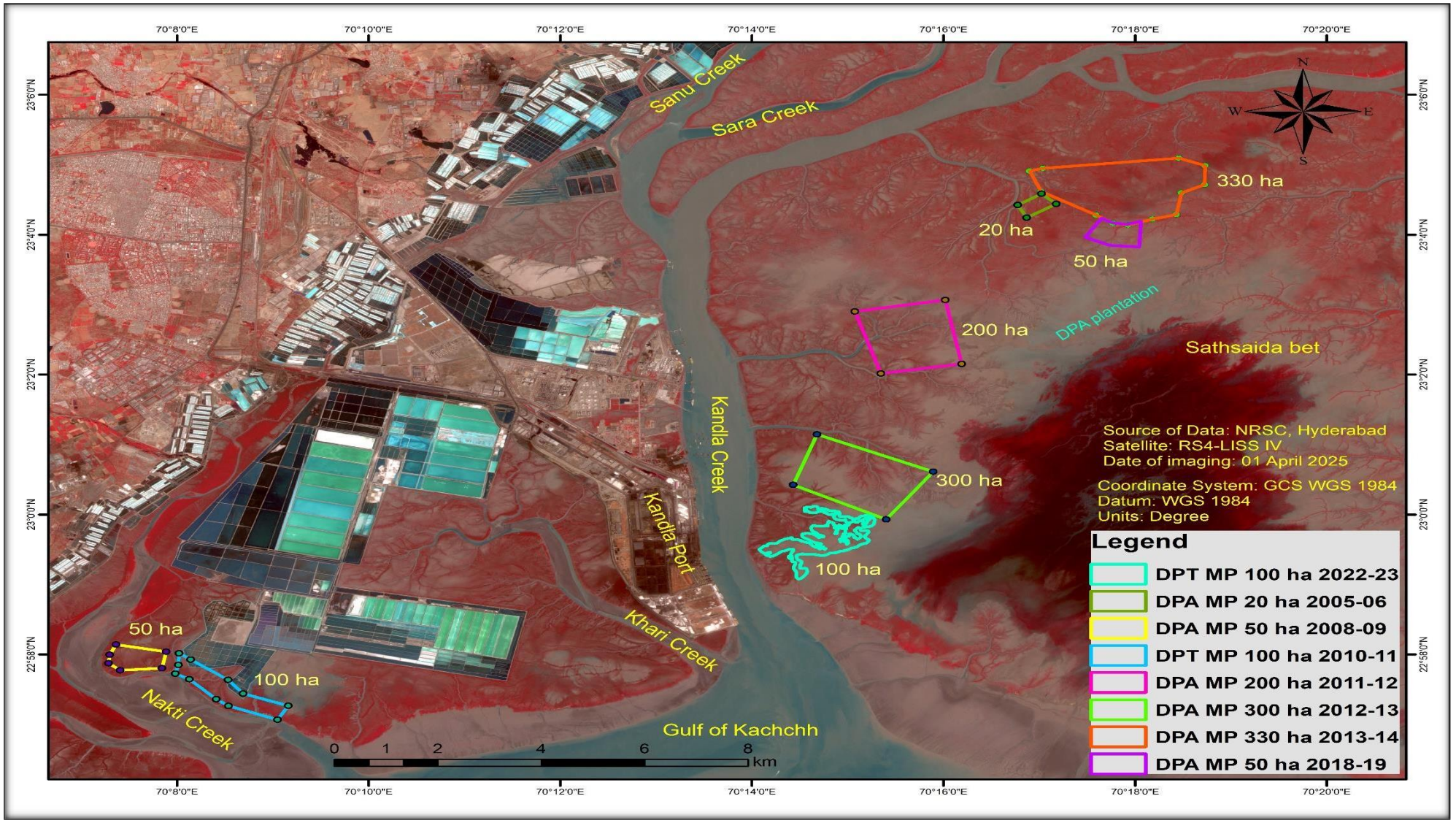

Figure 2: Location of Mangrove Plantation sites at Sat Saida Bet and Natki Creek in Kandla district

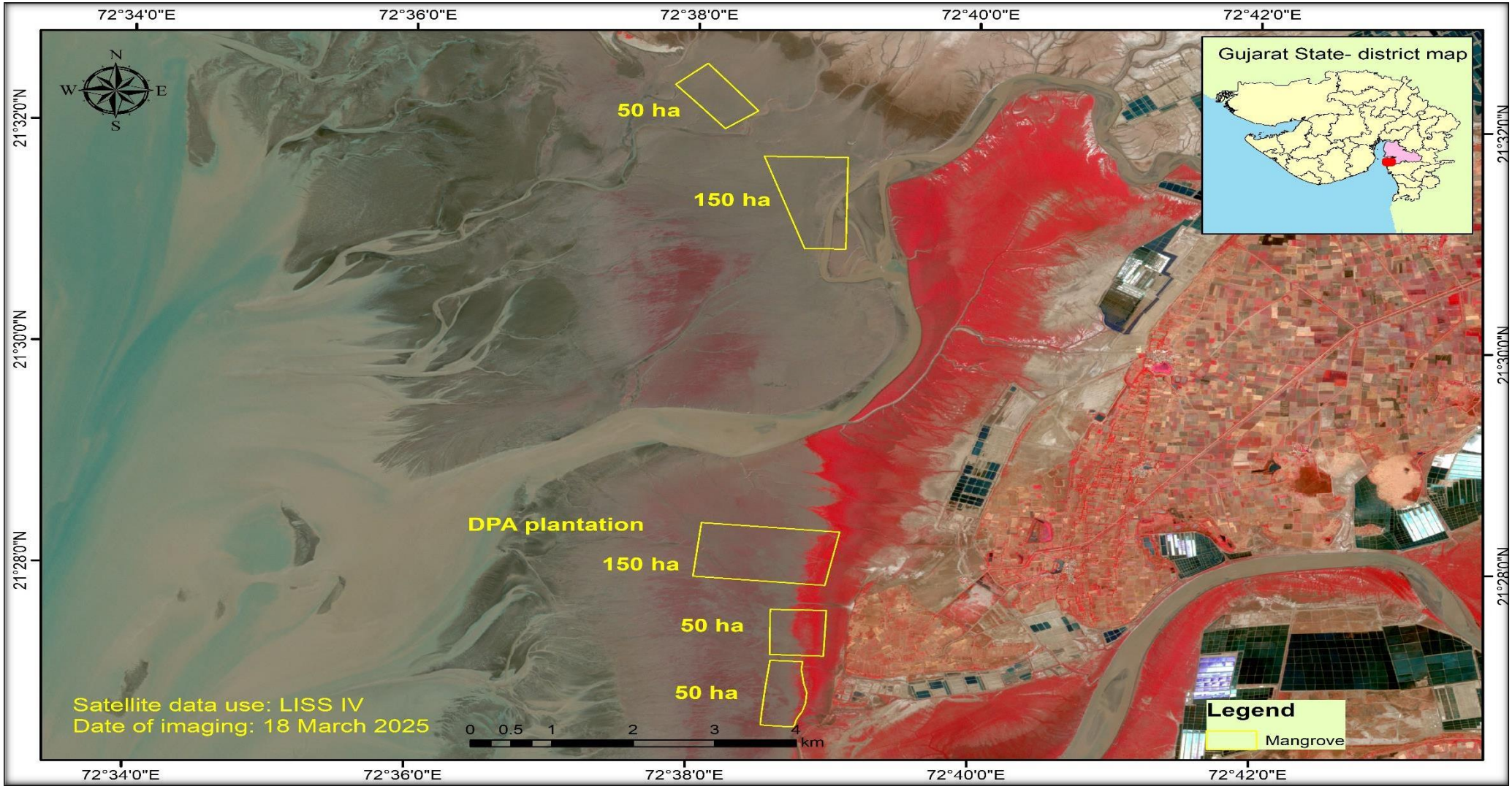

Figure 3: Location of Mangrove Plantation sites at Kantiyajal in Bharuch district

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.

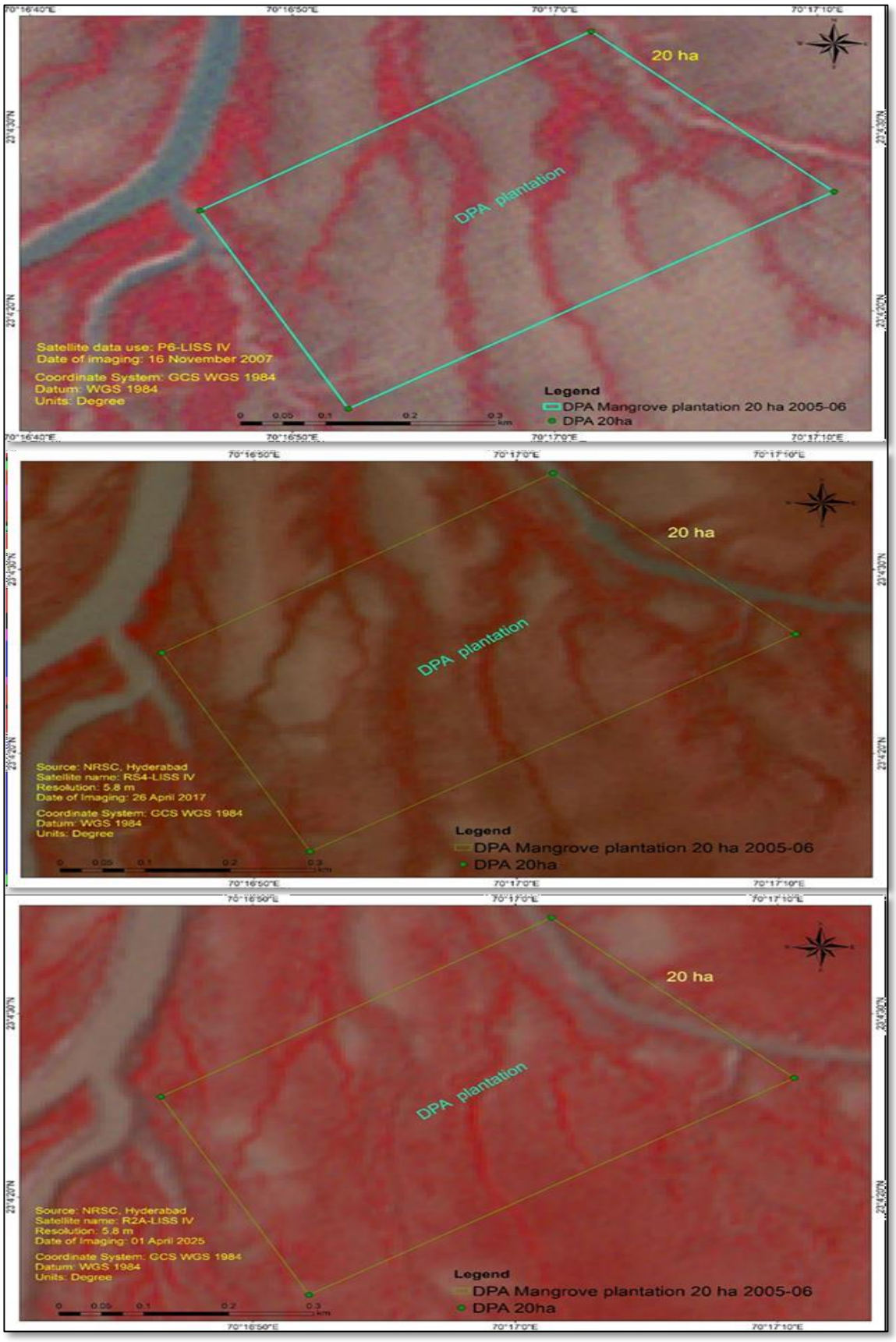

Figure 4: Satellite imageries of the 20 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

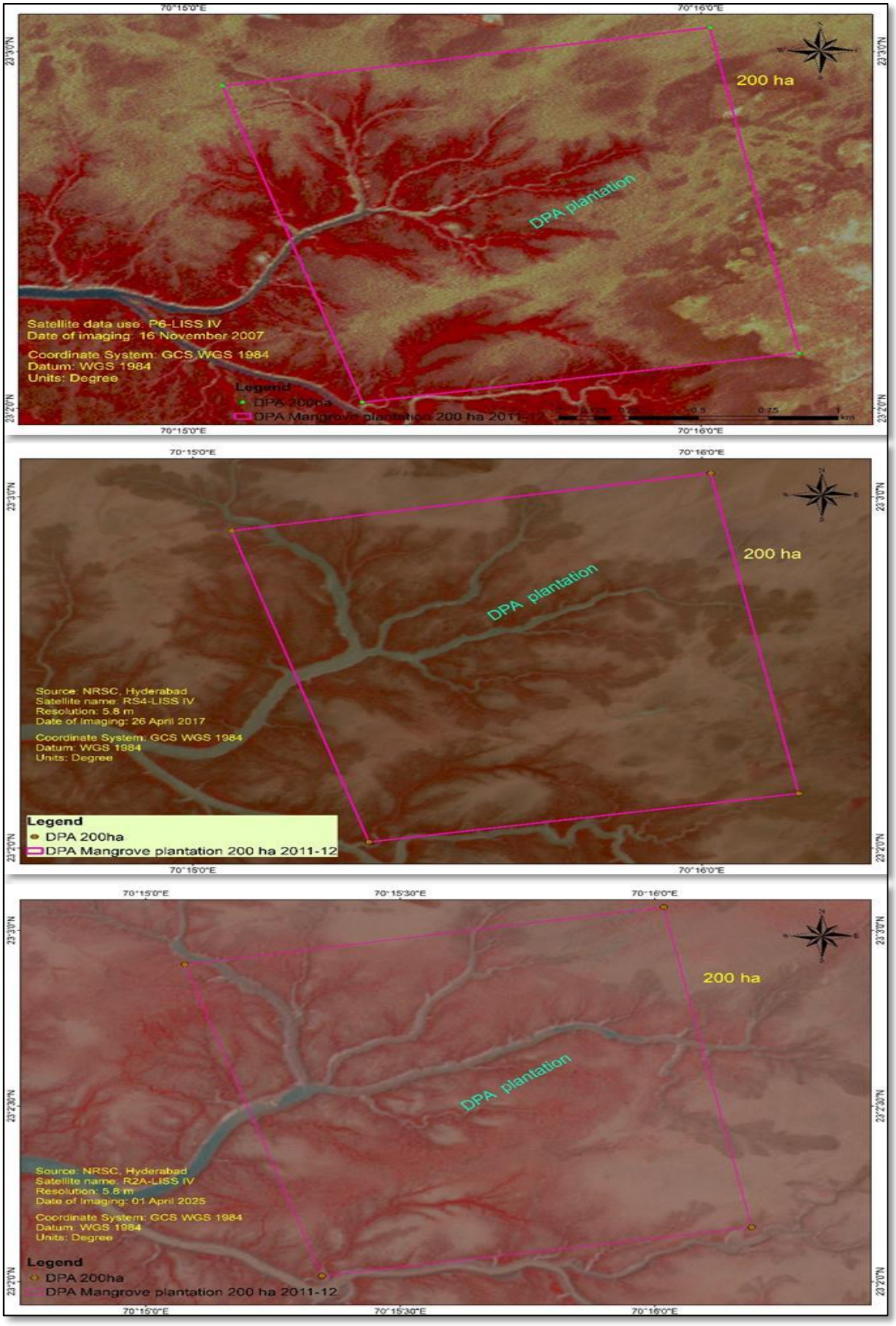

Figure 5: Satellite imageries of the 200 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

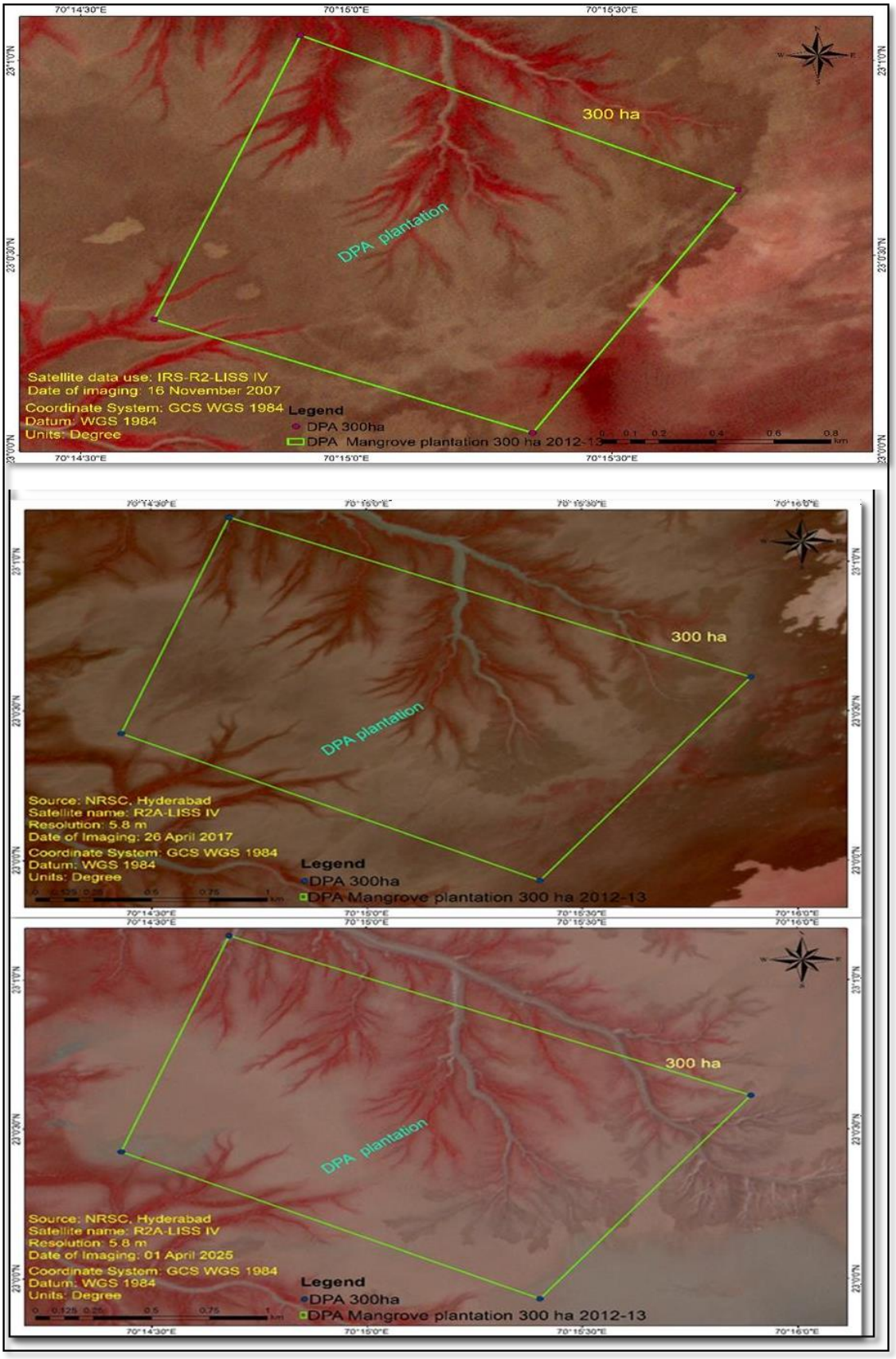

Figure 6: Satellite imageries of the 300 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

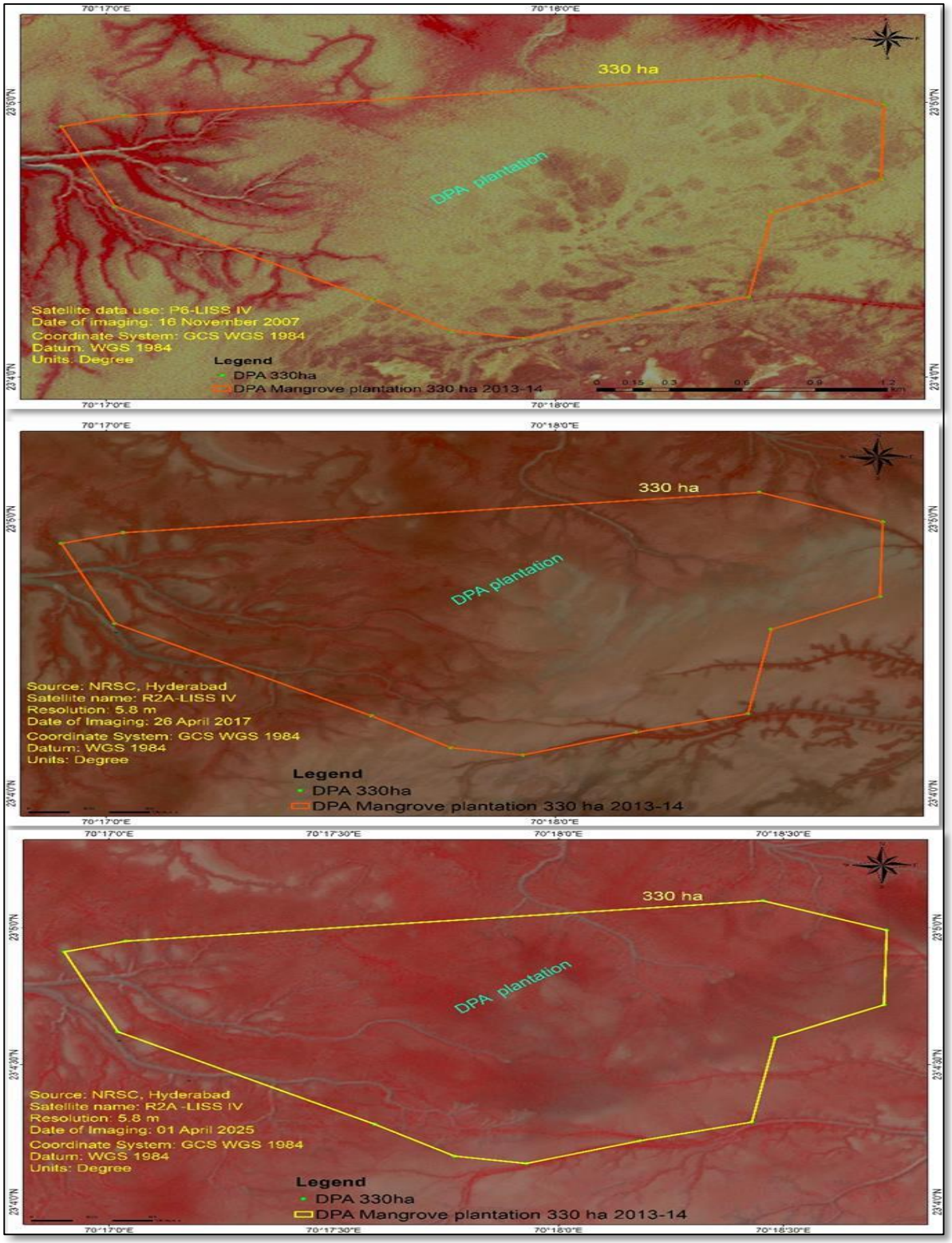

Figure 7: Satellite imageries of the 330 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

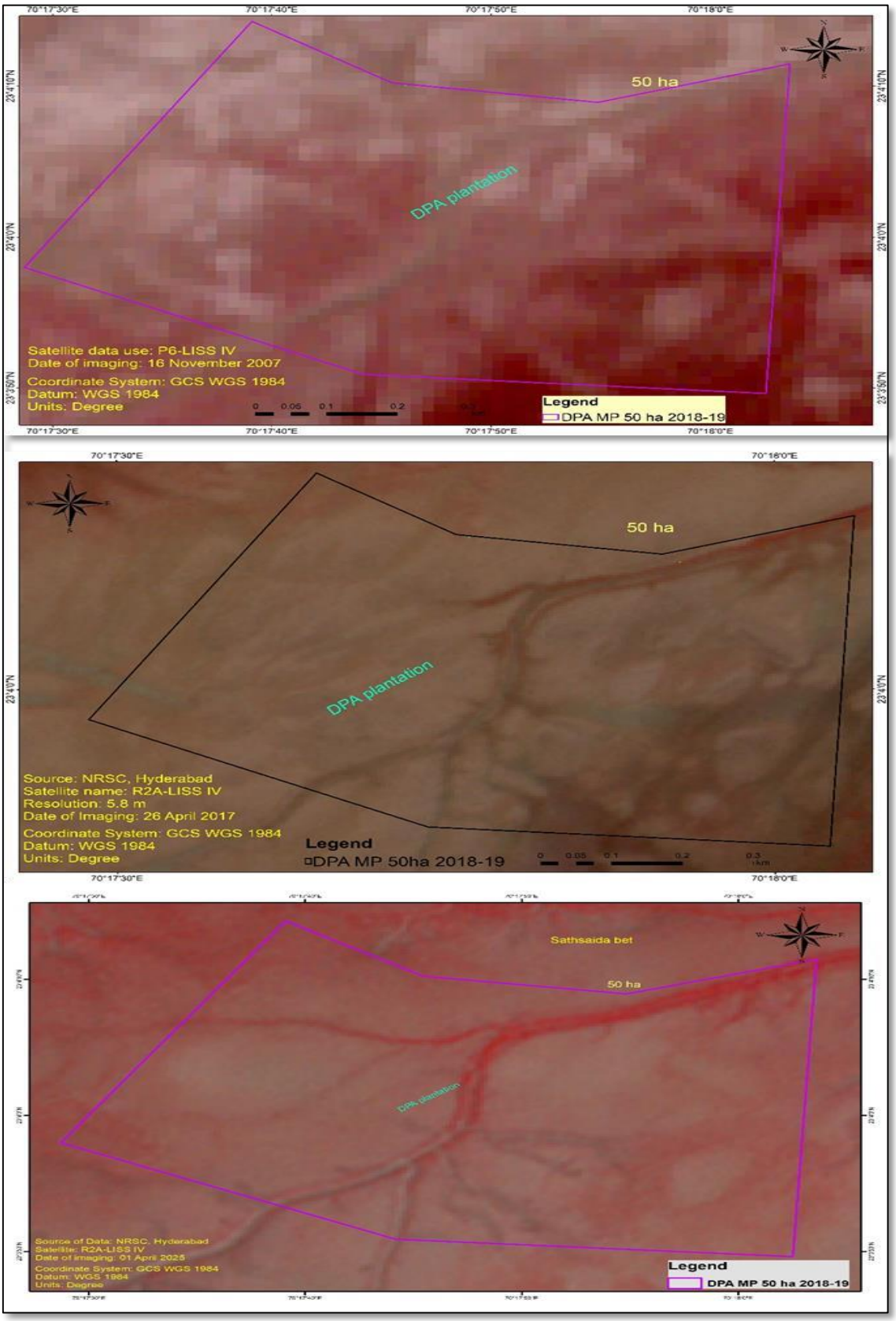

Figure 8: Satellite imageries of the 50 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

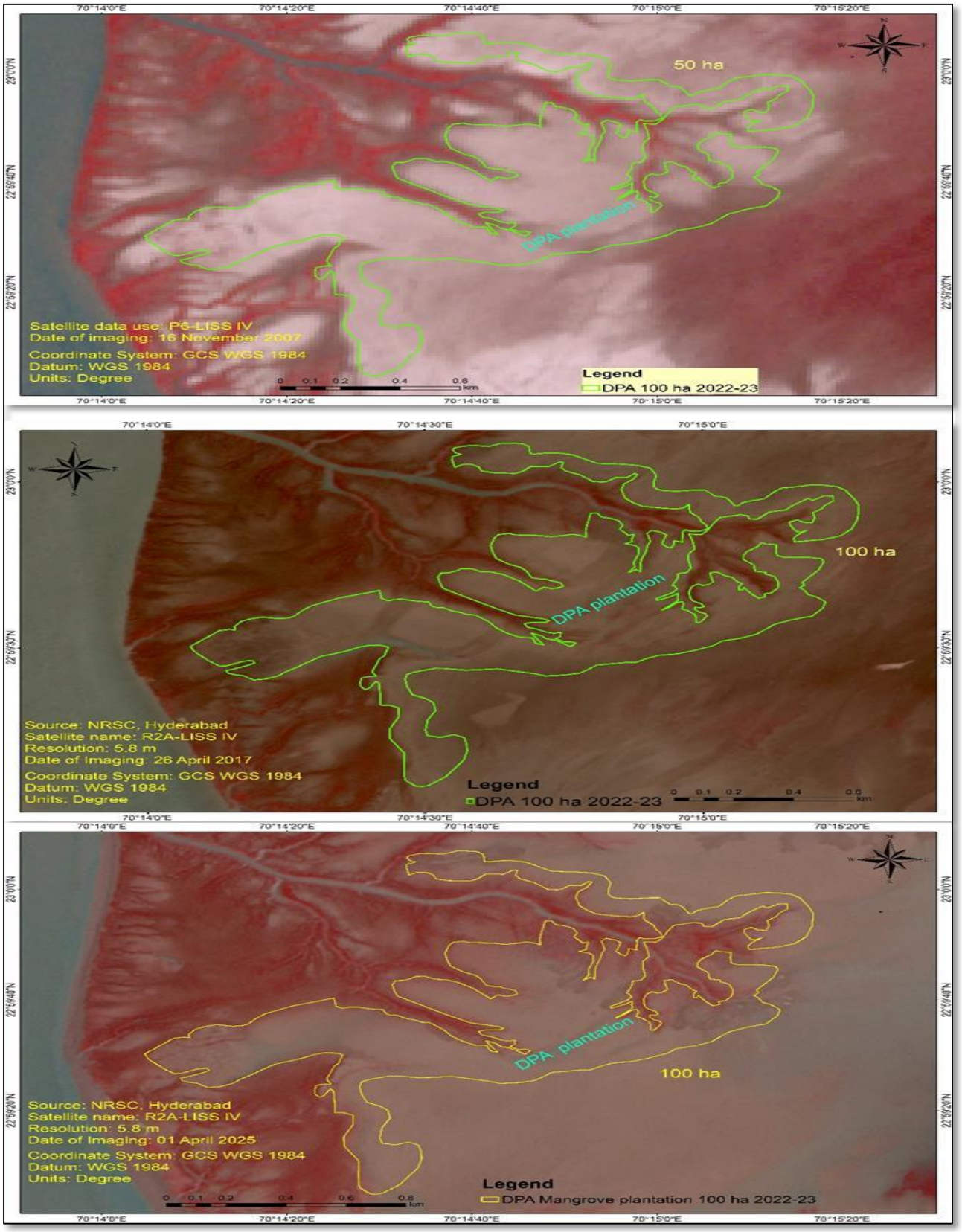

Figure 9: Satellite imageries of the 100 Ha plantation site at Sat Saida Bet (2007, 2017, and 2025)

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.

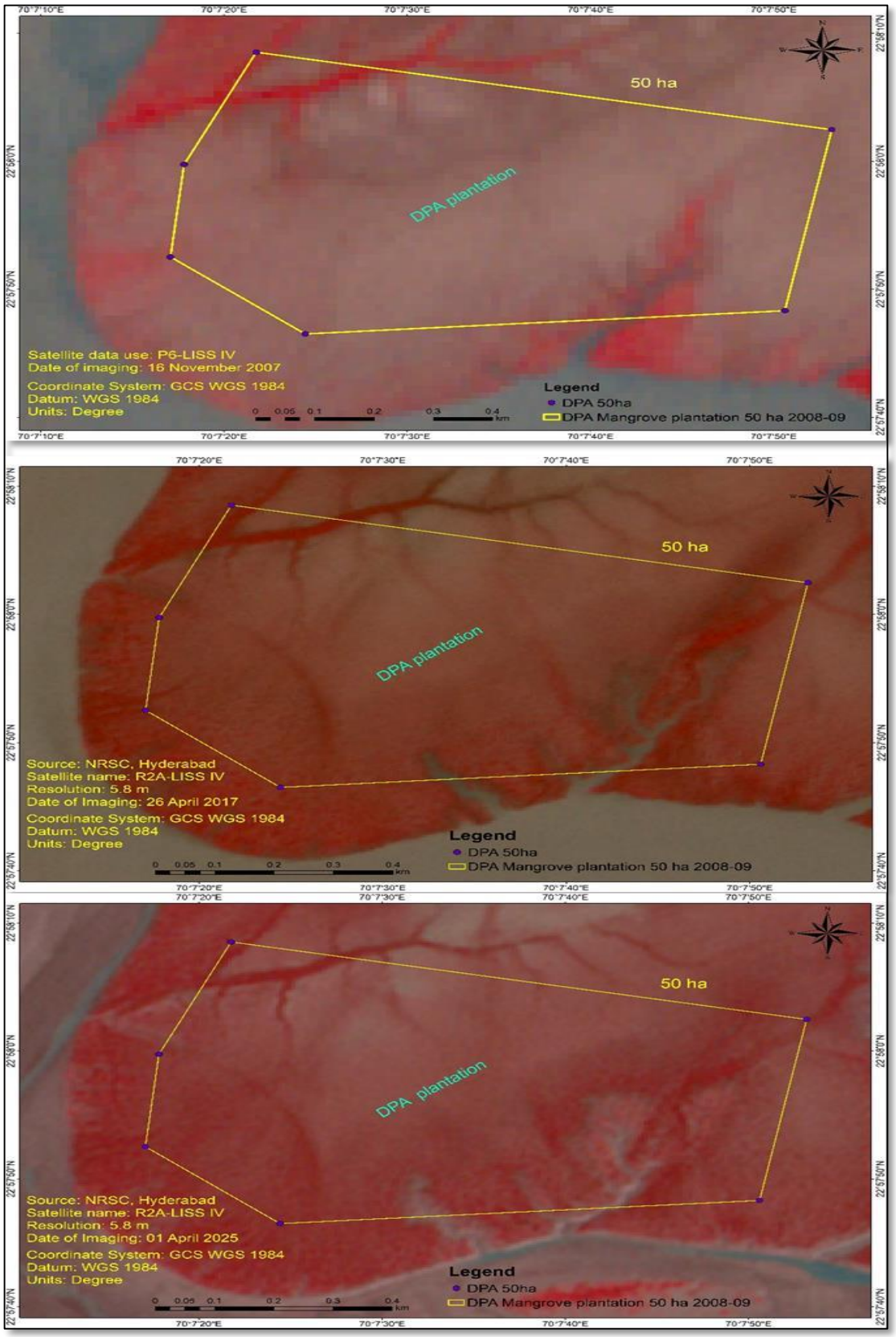

Figure 10: Satellite imageries of the 50 Ha plantation site at Nakti Creek (2007, 2017, and 2025)

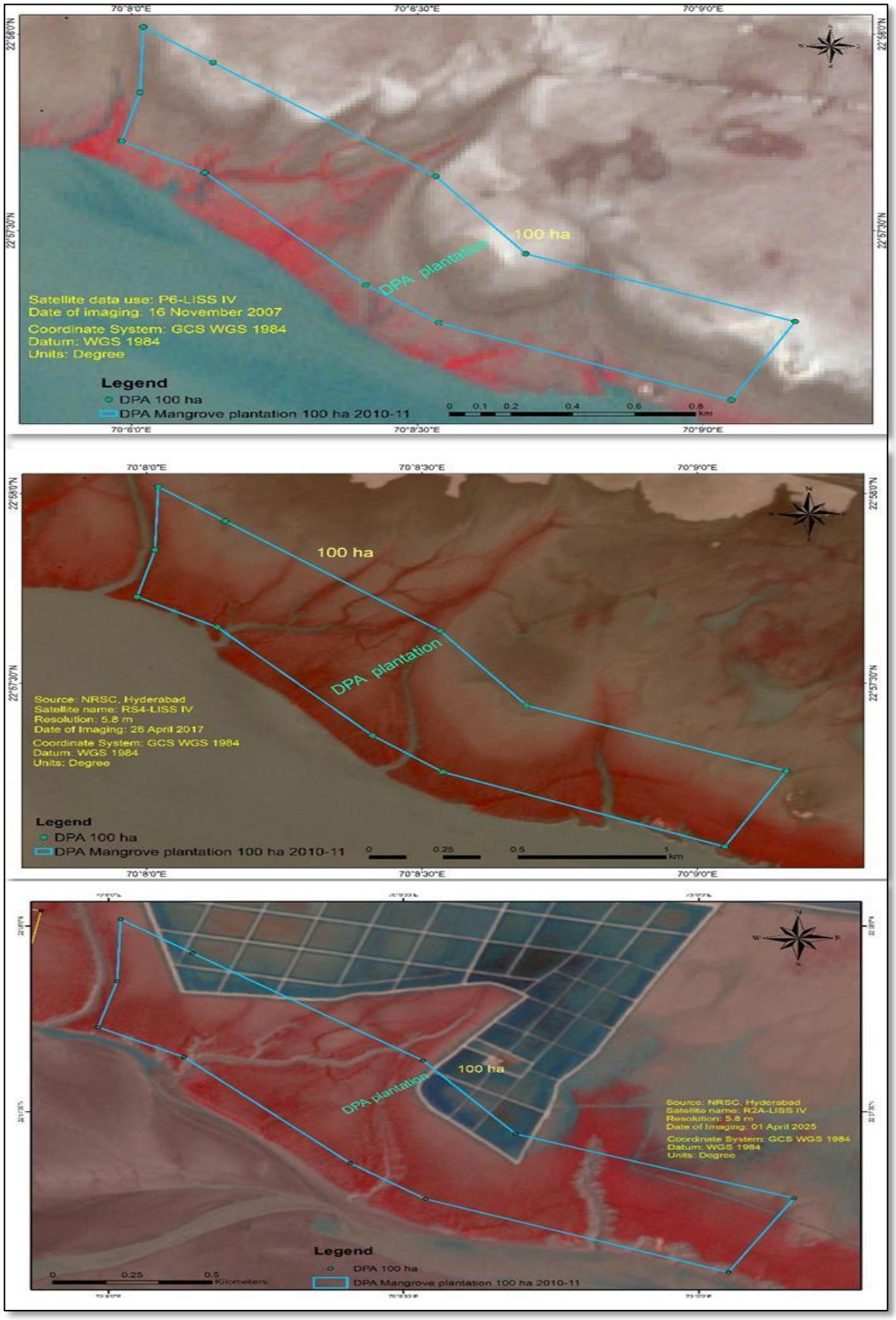

Figure 11: Satellite imageries of the 100 Ha plantation site at Nakti Creek (2007, 2017, and 2025)

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.

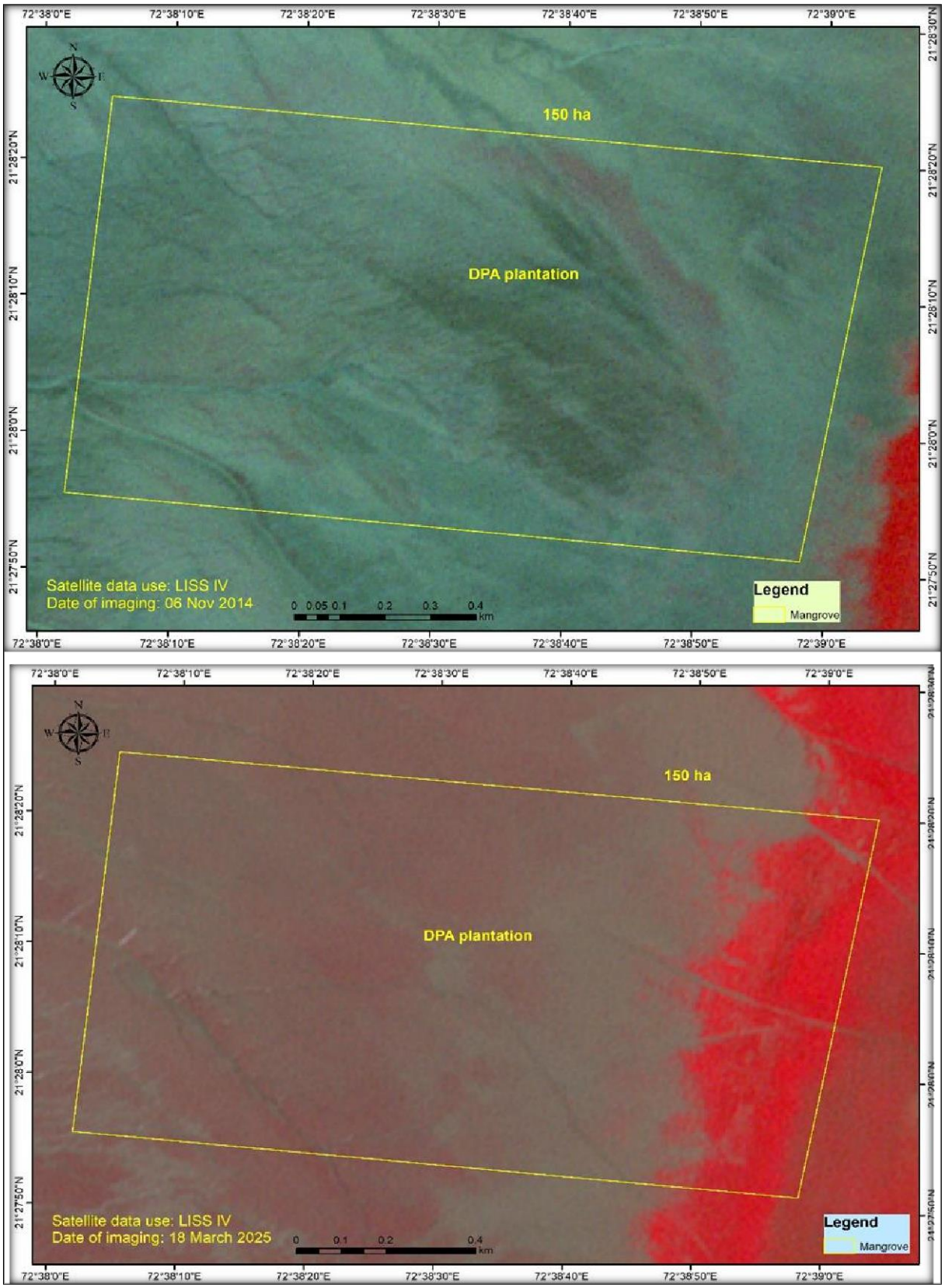

Figure 12: Satellite imageries of the 150 Ha block-1 plantation site at Kantiyajal (2014 and 2025)

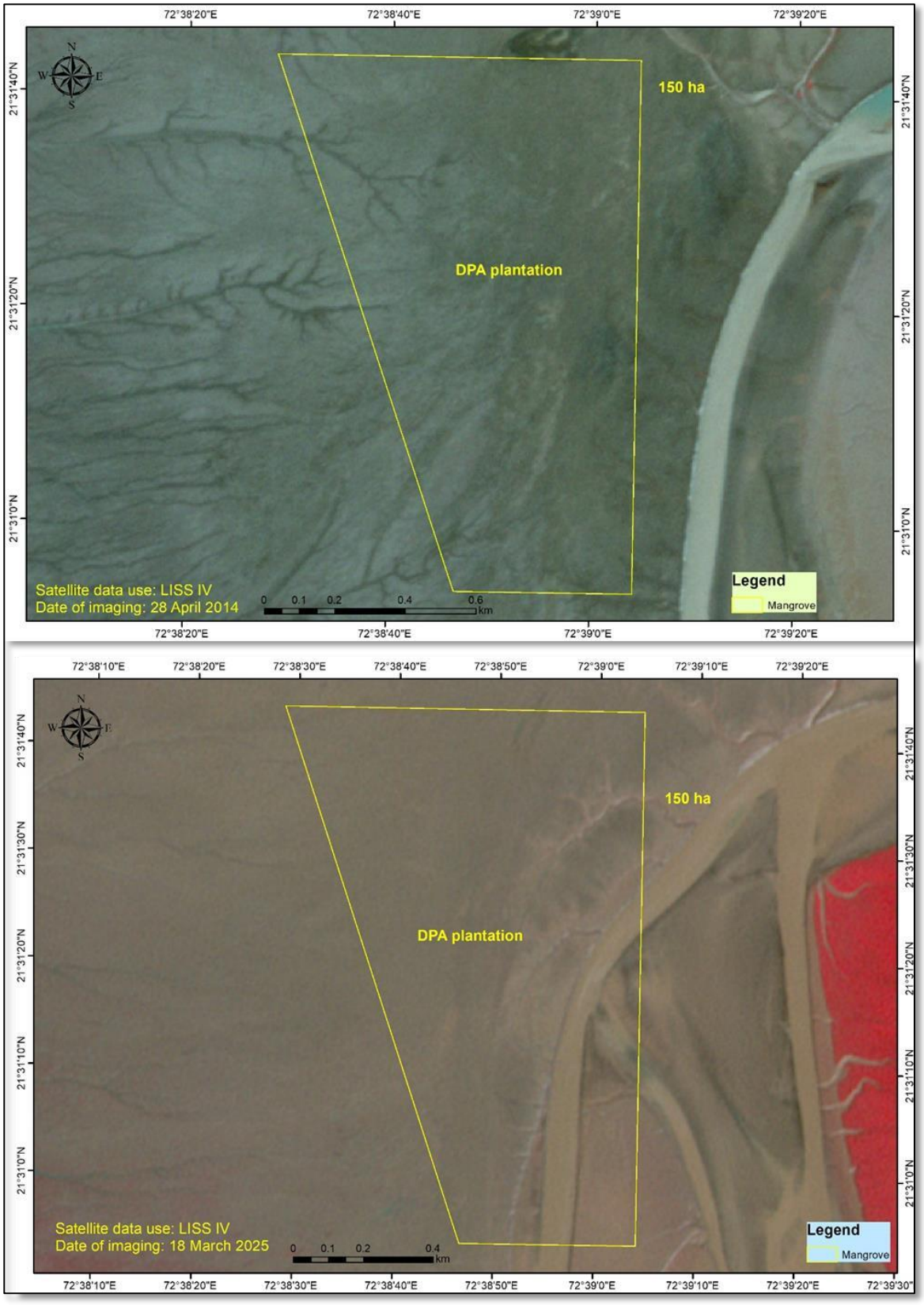

Figure 13: Satellite imageries of the 150 Ha block-2 plantation site at Kantiyajal (2014 and 2025)

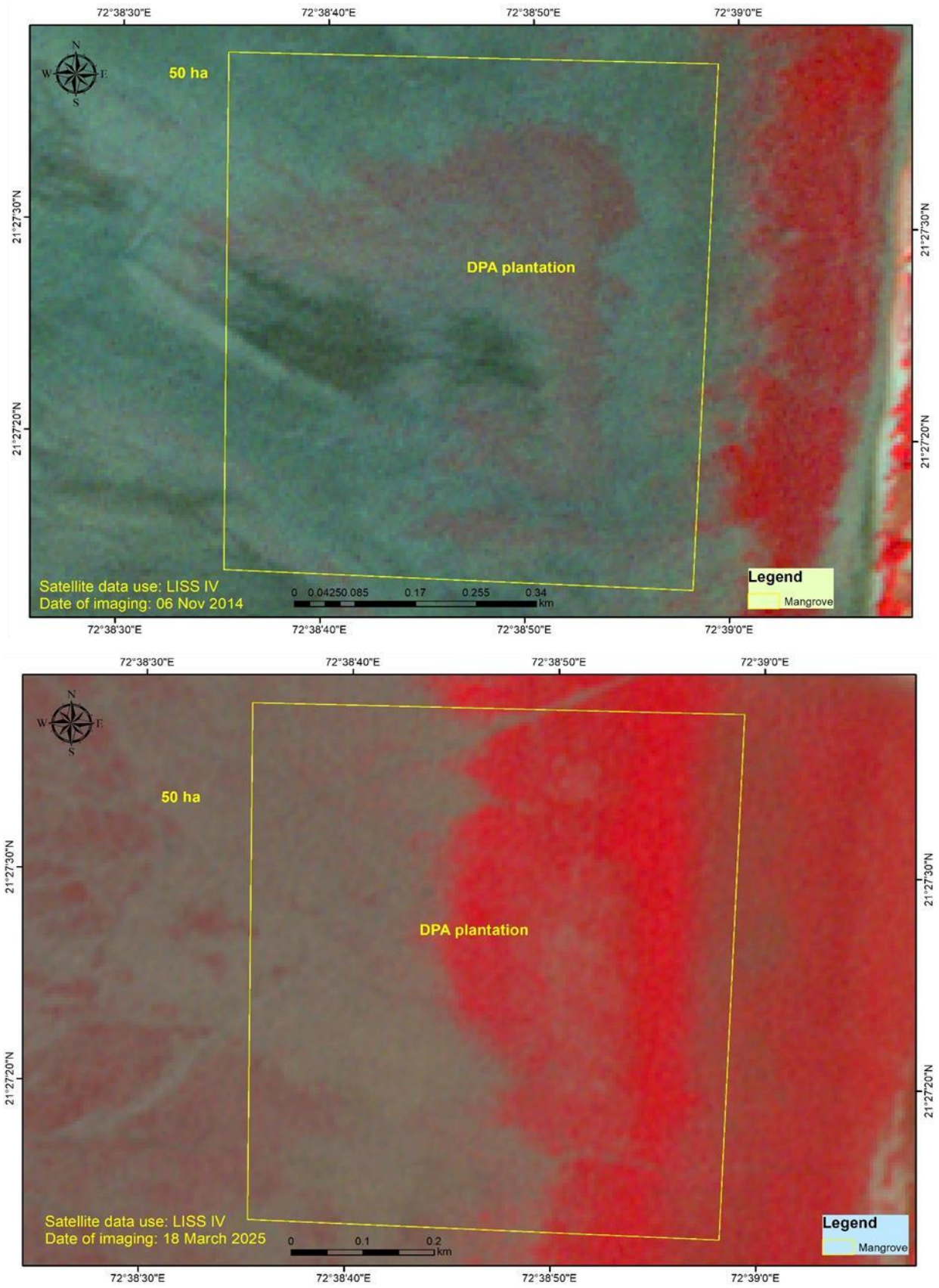

Figure 14: Satellite imageries of the 50 Ha block-3 plantation site at Kantiyajal (2014 and 2025)

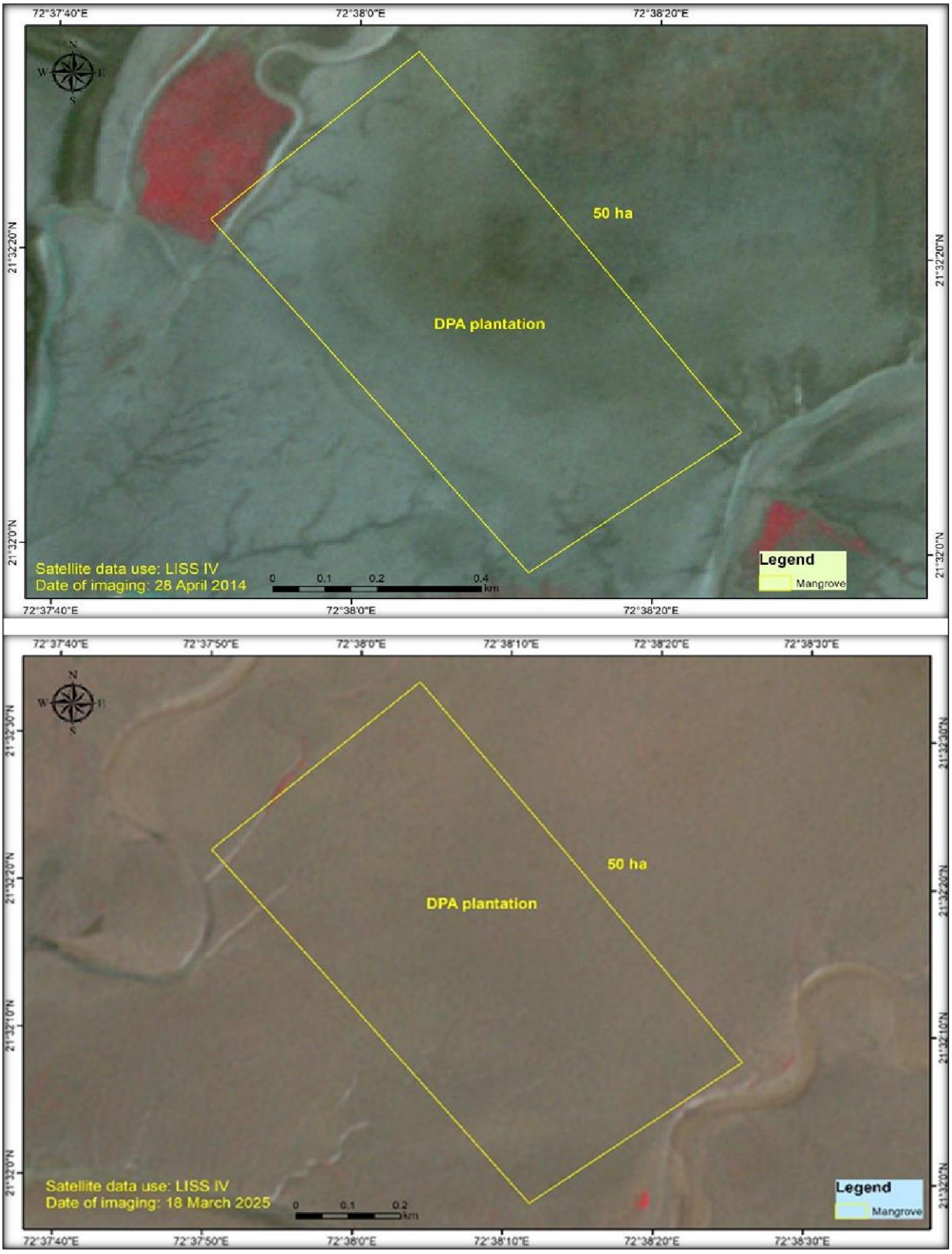

Figure 15: Satellite imageries of the 100 (50-1) Ha block-4 plantation site at Kantiyajal (2014 and 2025)

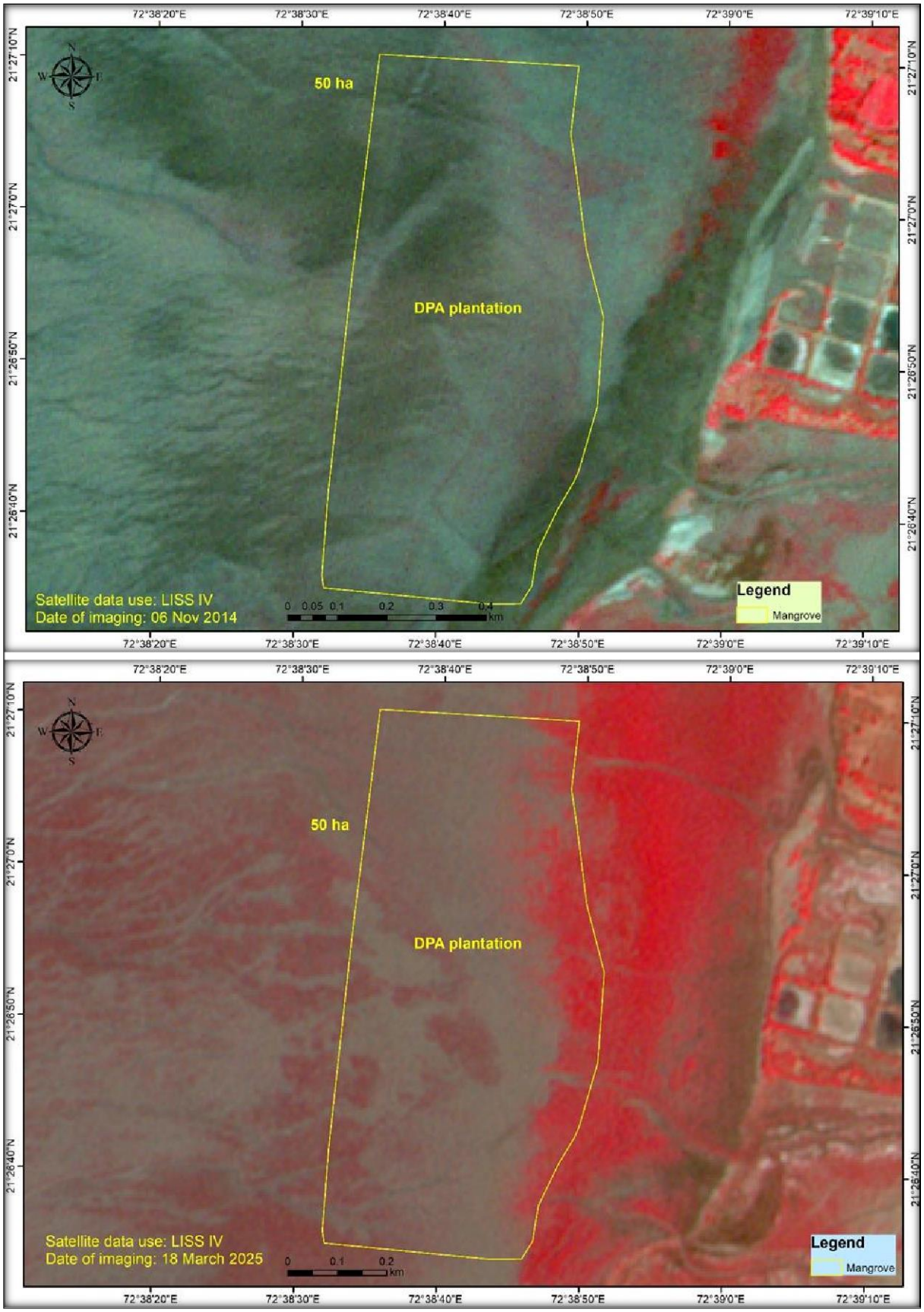

Figure 16: Satellite imageries of the 100 (50-2) Ha block-5 plantation site at Kantiyajal (2014 and 2025)

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

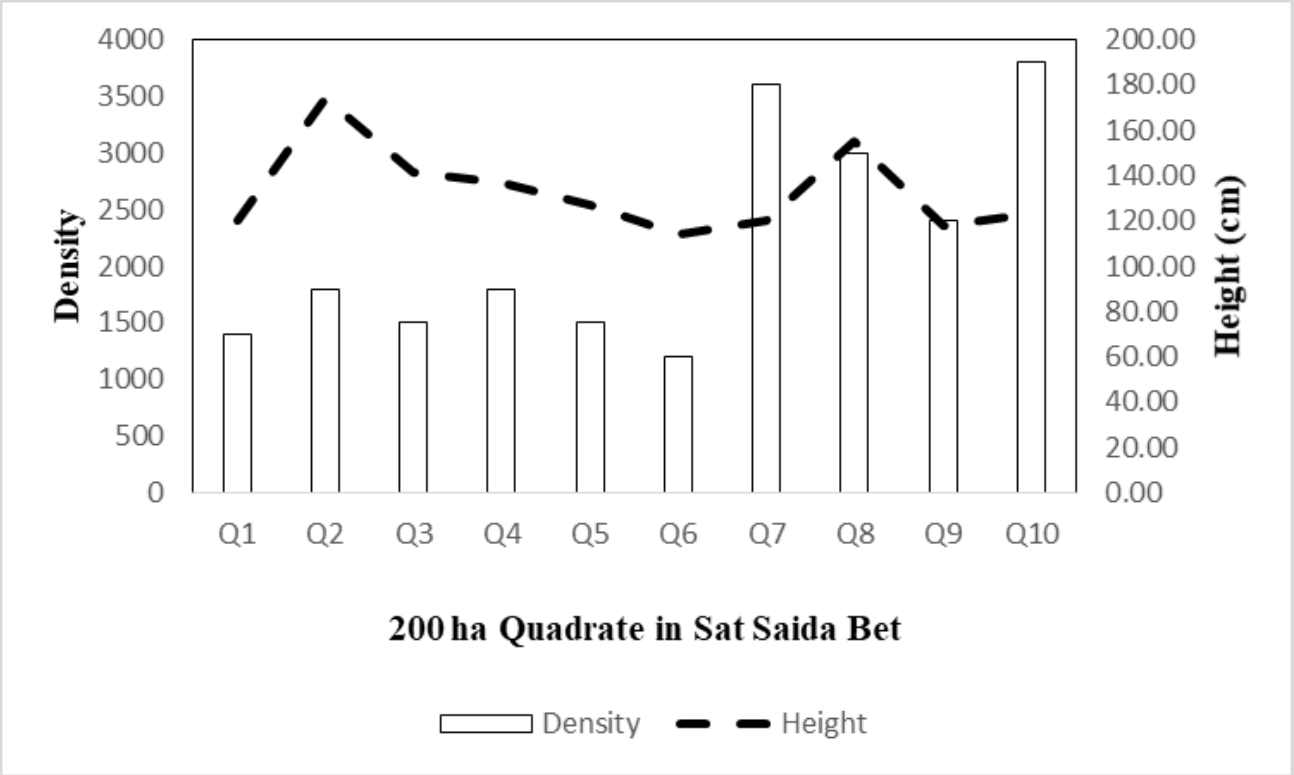

Fig.17 Details of density (No) and height of mangroves in 200 ha plantation area in 2011-2012 at Sat Saida Bet.

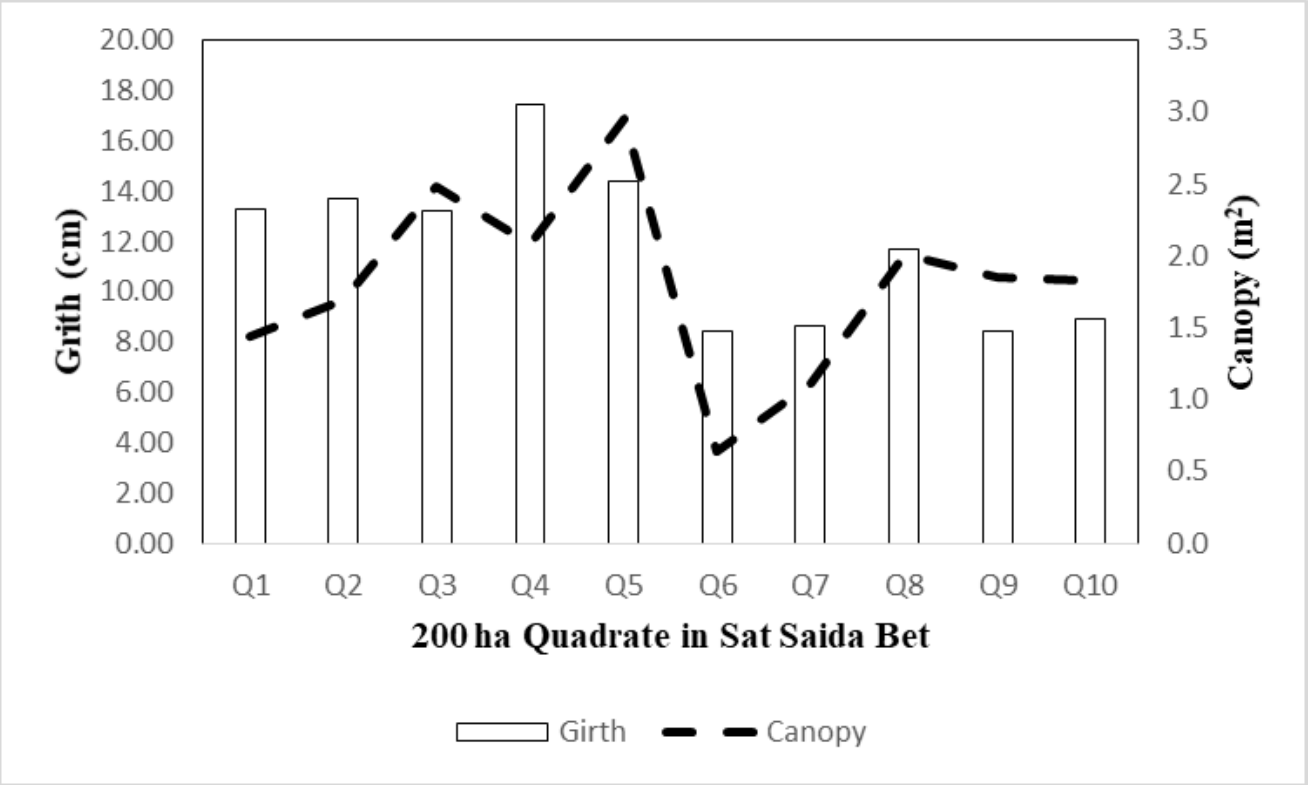

Fig. 18 Details of Canopy and Basal Girth of mangroves in 200 ha plantation area in 2011-2012 at Sat Saida Bet.

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

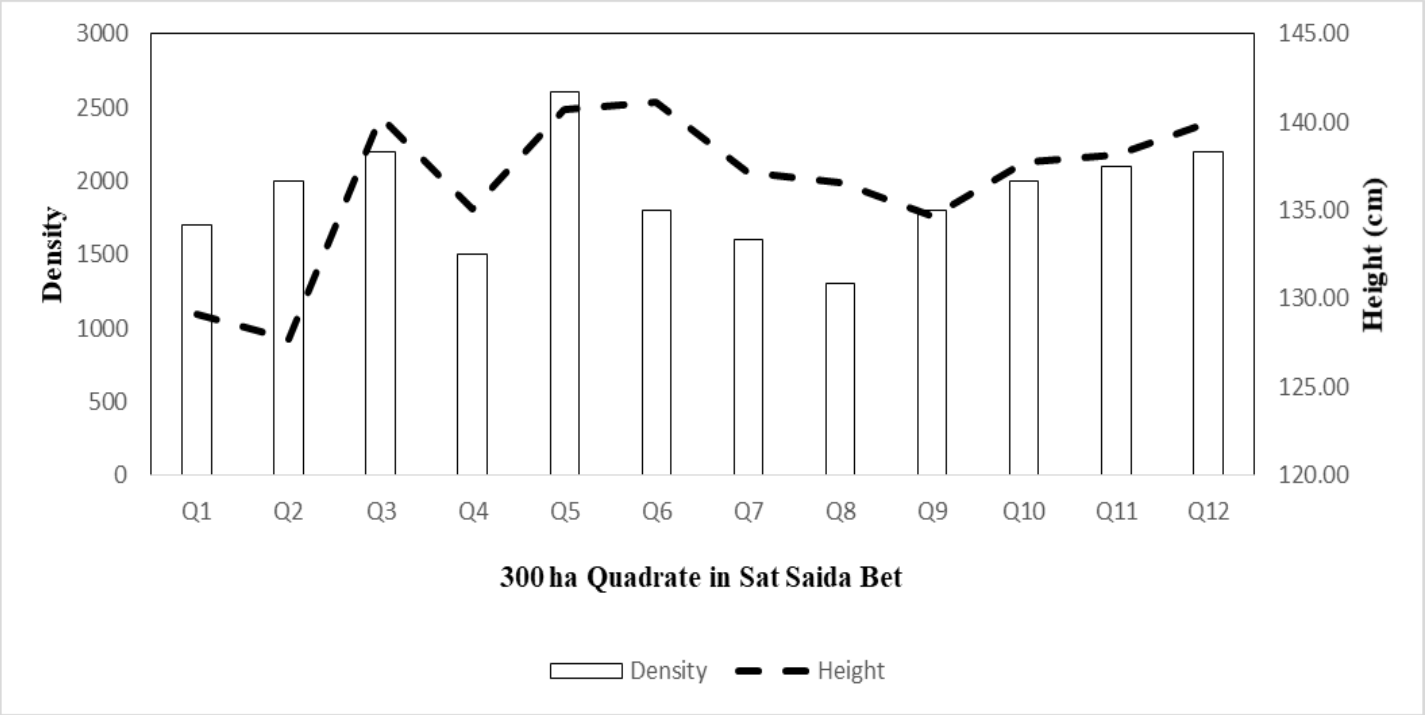

Fig.19 Details of density (No) and height of mangroves in 300 ha plantation area in 2012-2013 at Sat Saida Bet.

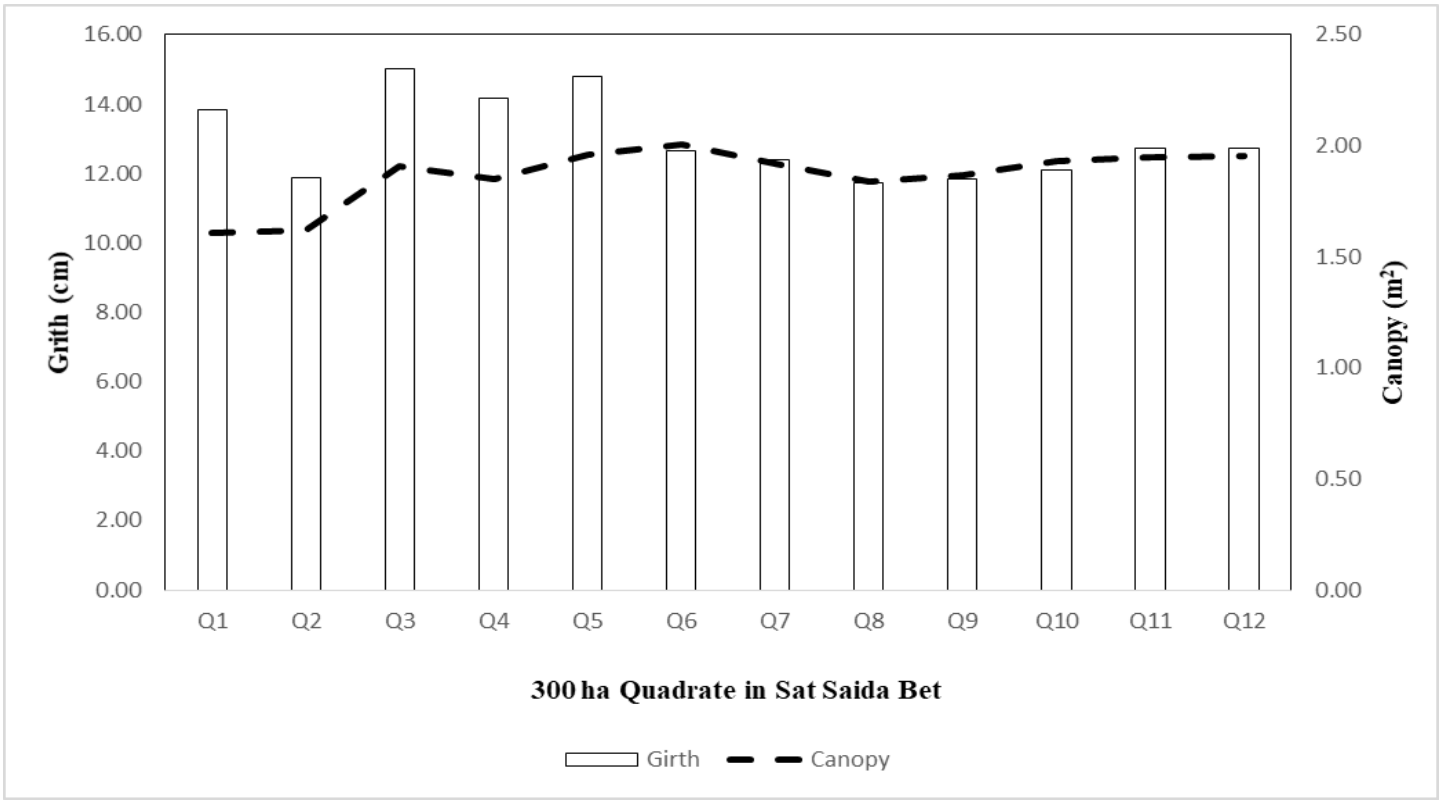

Fig.20 Details of Canopy and Basal Girth of mangroves in 300 ha plantation area in 2012-2013 at Sat Saida Bet.

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

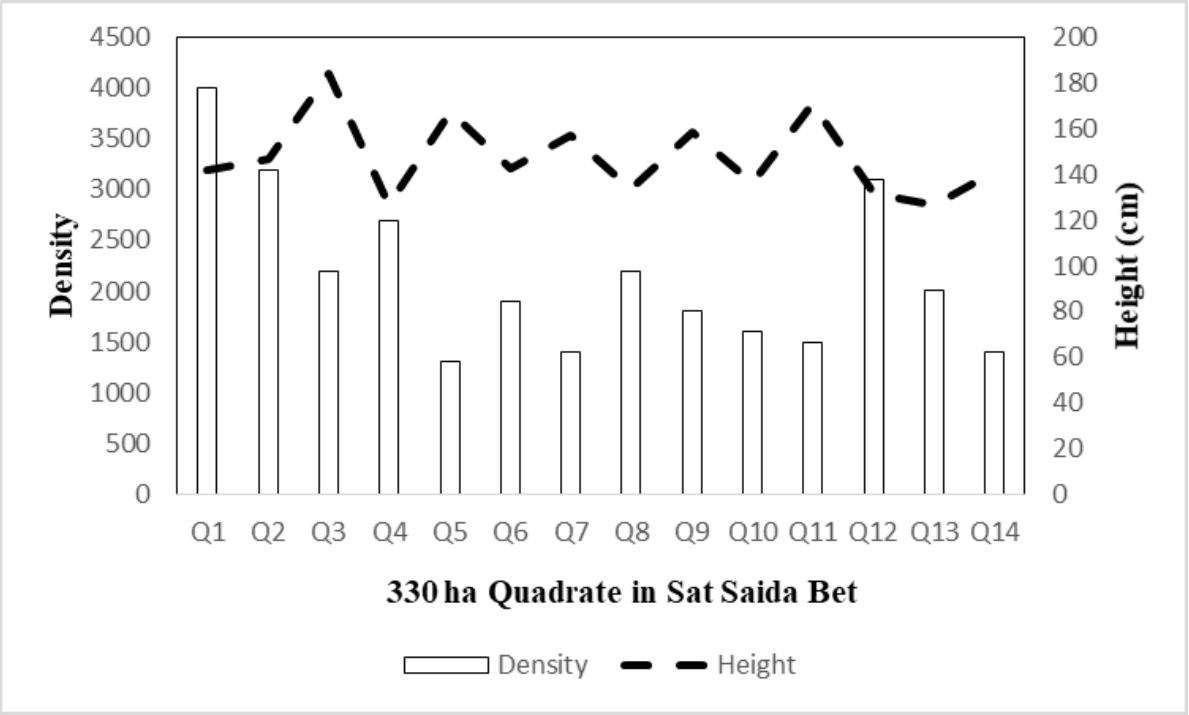

Fig. 21 Details of density (No) and height of mangroves in 330 ha plantation area in 2013-2014 at Sat Saida Bet

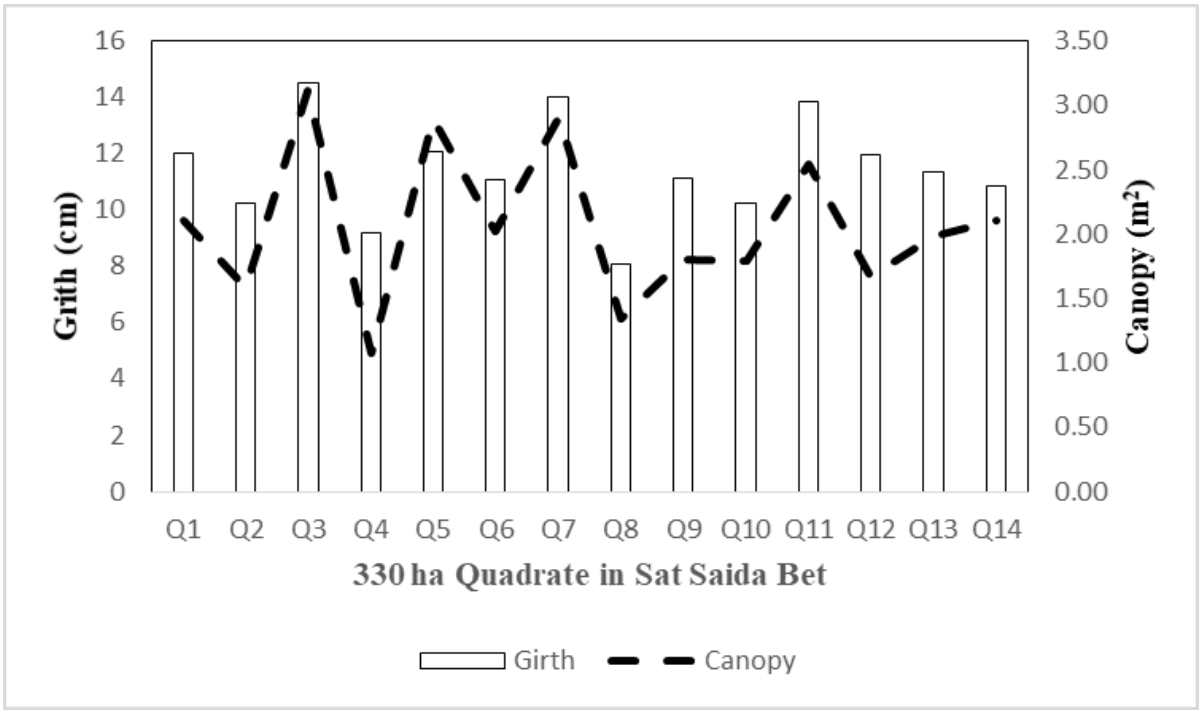

Fig. 22 Details of Canopy and Basal Girth of mangroves in 330 ha plantation area in 2013-2014 at Sat Saida Bet.

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

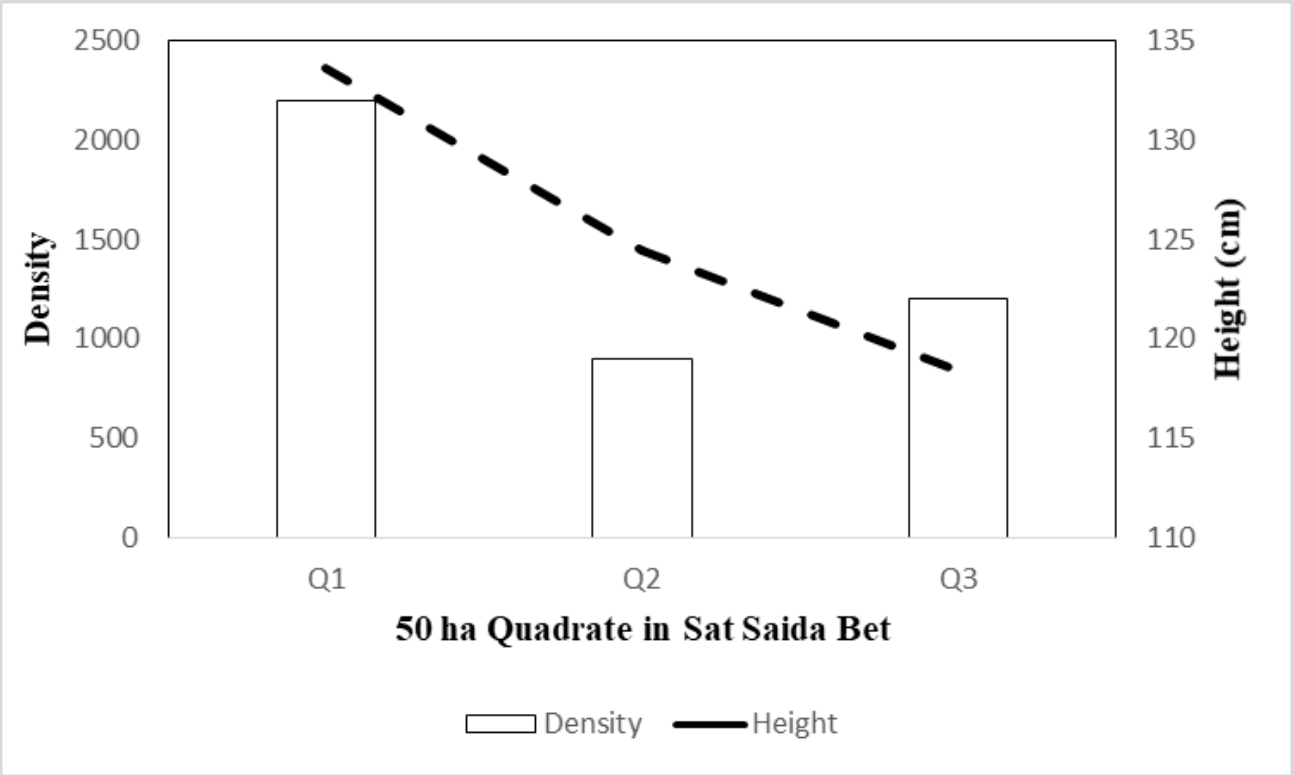

Fig.23 Details of density (No) and height of mangroves in 50 ha plantation area in 2018-2019 at Sat Saida Bet.

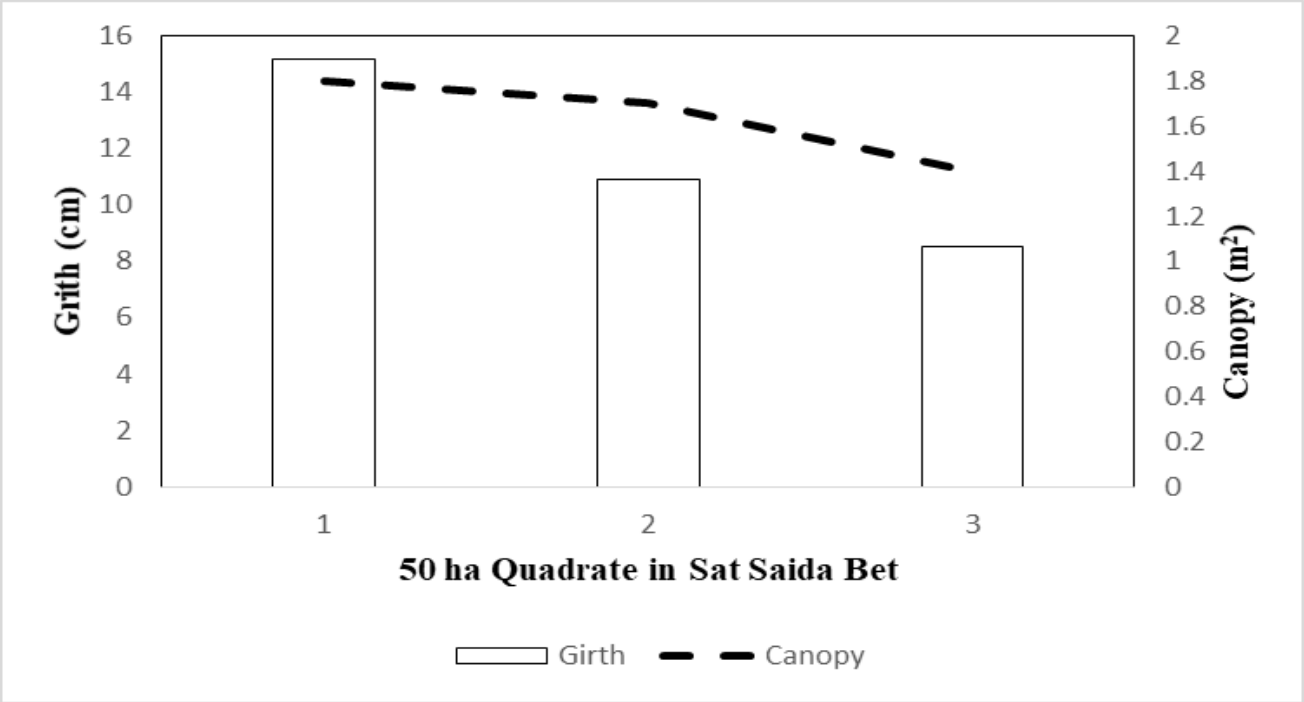

Fig. 24 Details of Canopy and Basal Girth of mangroves in 50 ha plantation area in 2018-2019 at Sat Saida Bet.

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

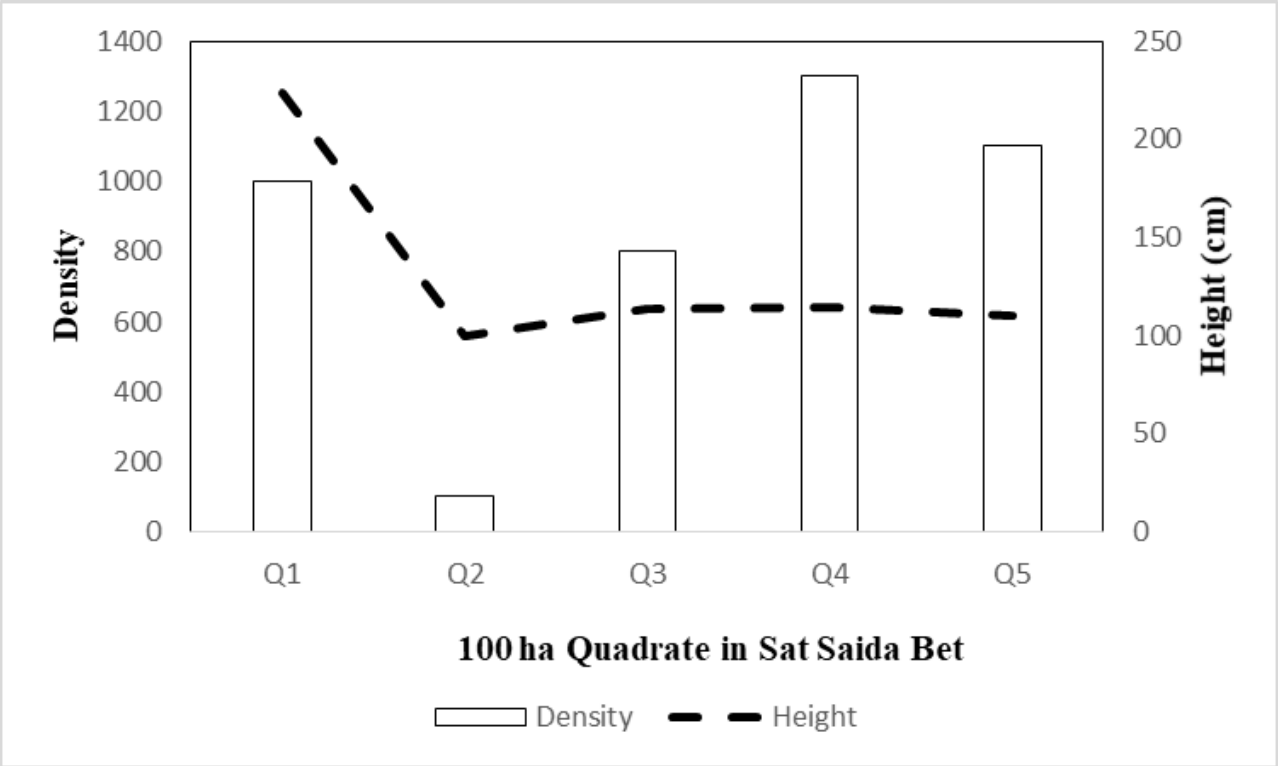

Fig. 25 Details of density (No) and height of mangroves in 100 ha plantation area in 2022-2023 at Sat Saida Bet

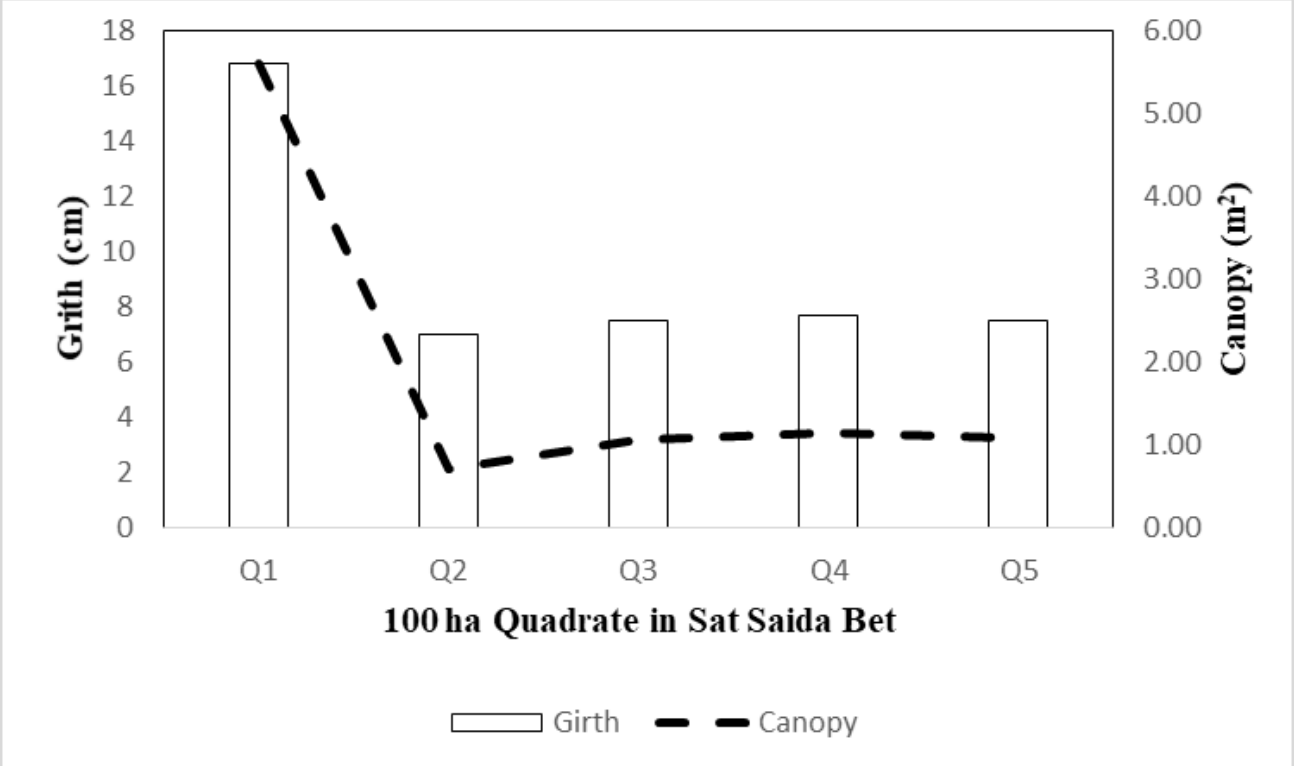

Fig. 26 Details of Canopy and Basal Girth of mangroves in 100 ha plantation area in 2022-2023 at Sat Saida Bet.

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

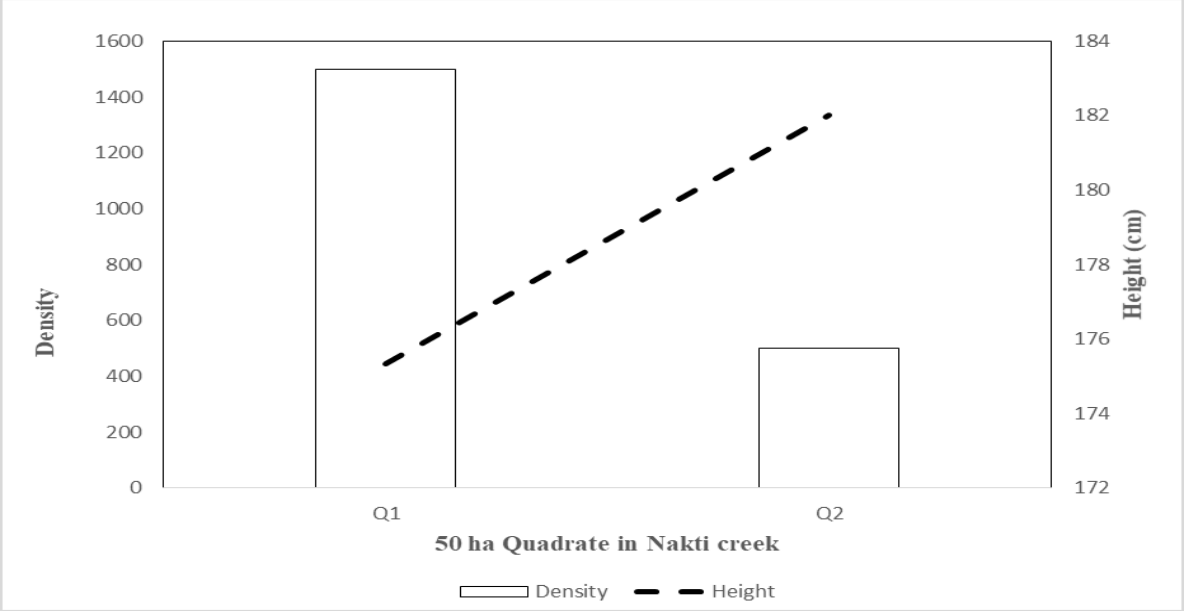

Fig. 27 Details of density (No) and height of mangroves in 50 ha plantation area in 2008-2009 at Nakti Creek.

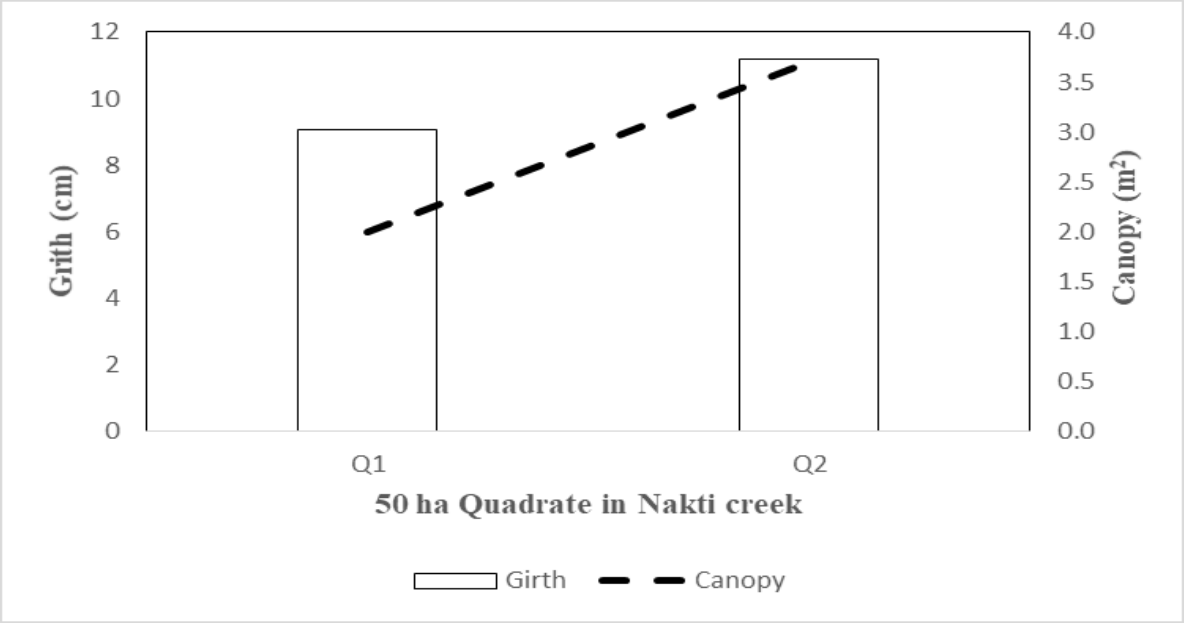

Fig. 28 Details of Canopy and Basal Girth of mangroves in 50 ha plantation area in 2008-2009 at Nakti Creek.

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

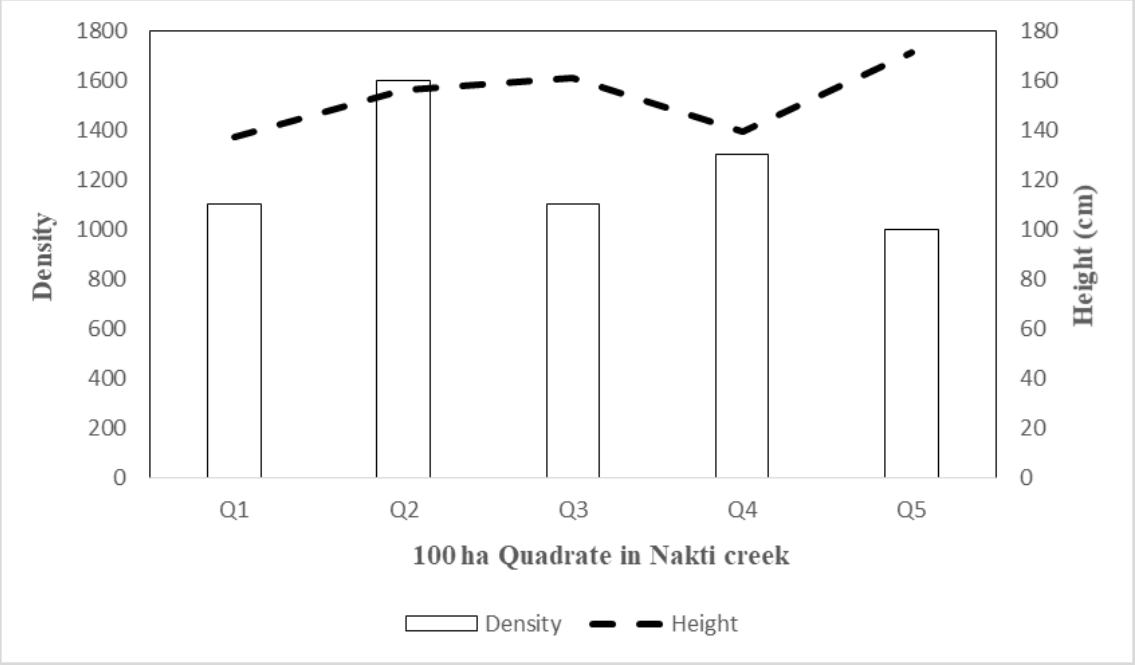

Fig.29 Details of density (No) and height of mangroves in 100 ha plantation area in 2010-2011 at Nakti Creek

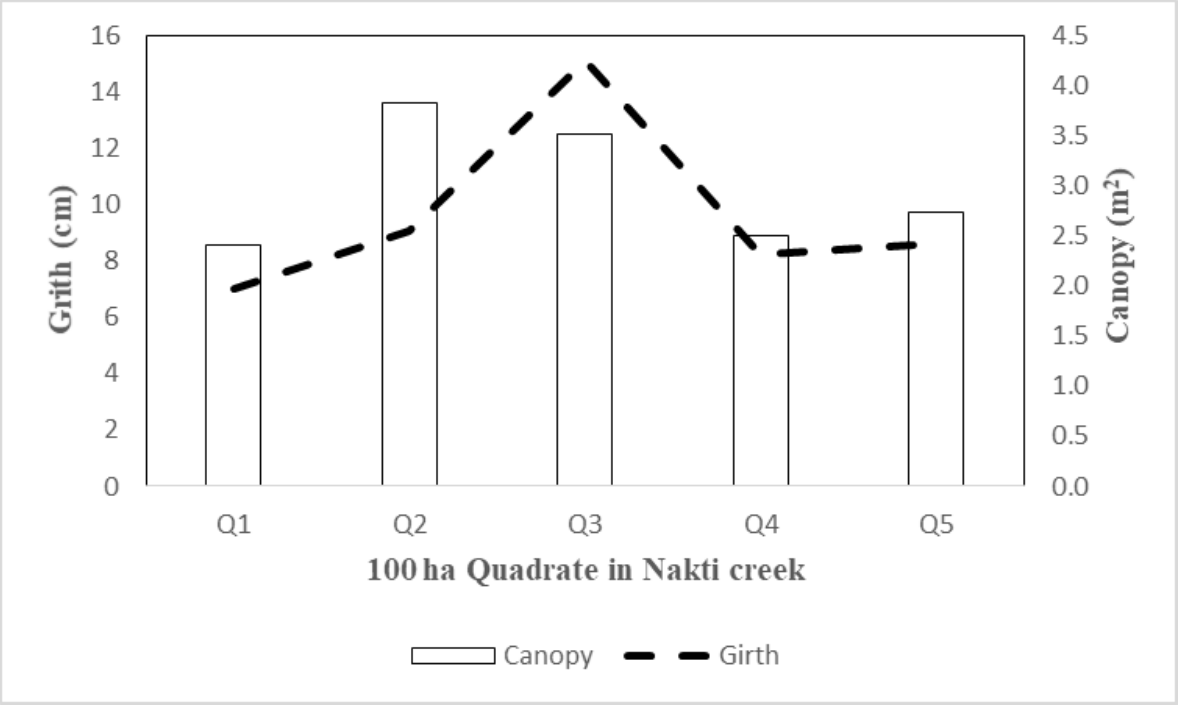

Fig.30 Details of Canopy and Basal Girth of mangroves in 100 ha plantation area in 2010-2011 at Nakti Creek.

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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.

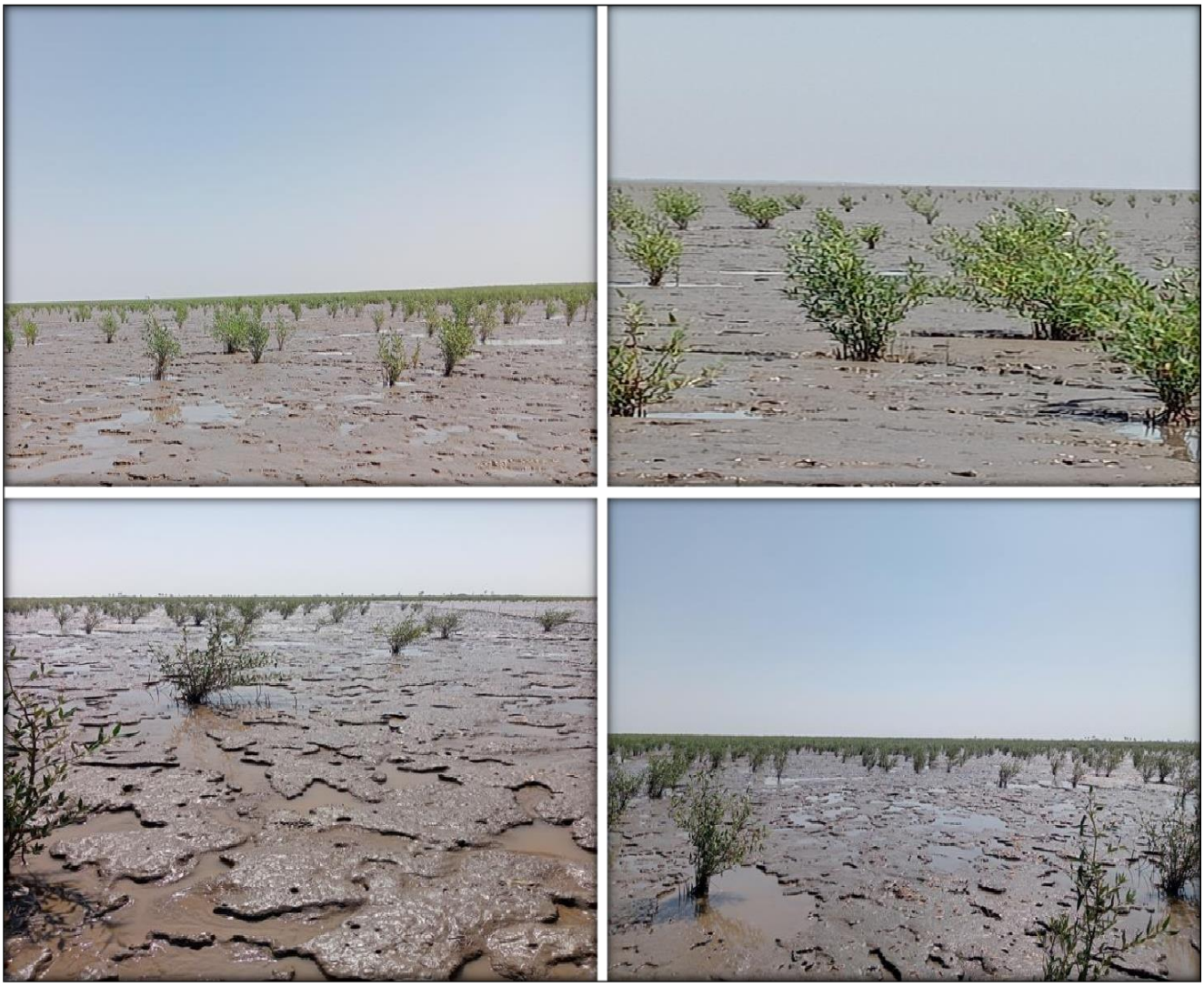

Plate 9: Mangrove plantation 150 Ha at Kantiyajal site Block- 1 during a visit in 2025

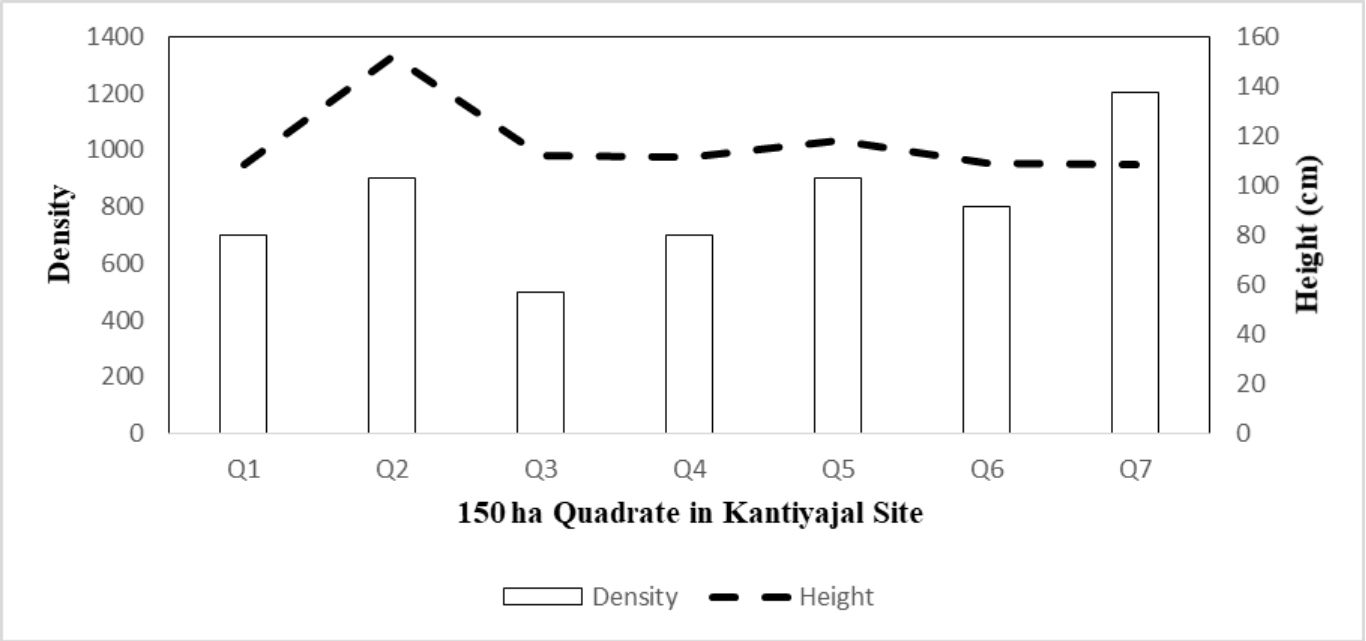

Fig.31 Details of density (No) and height of mangroves in 150 ha plantation area in 2015-2016 at Kantiyajal site

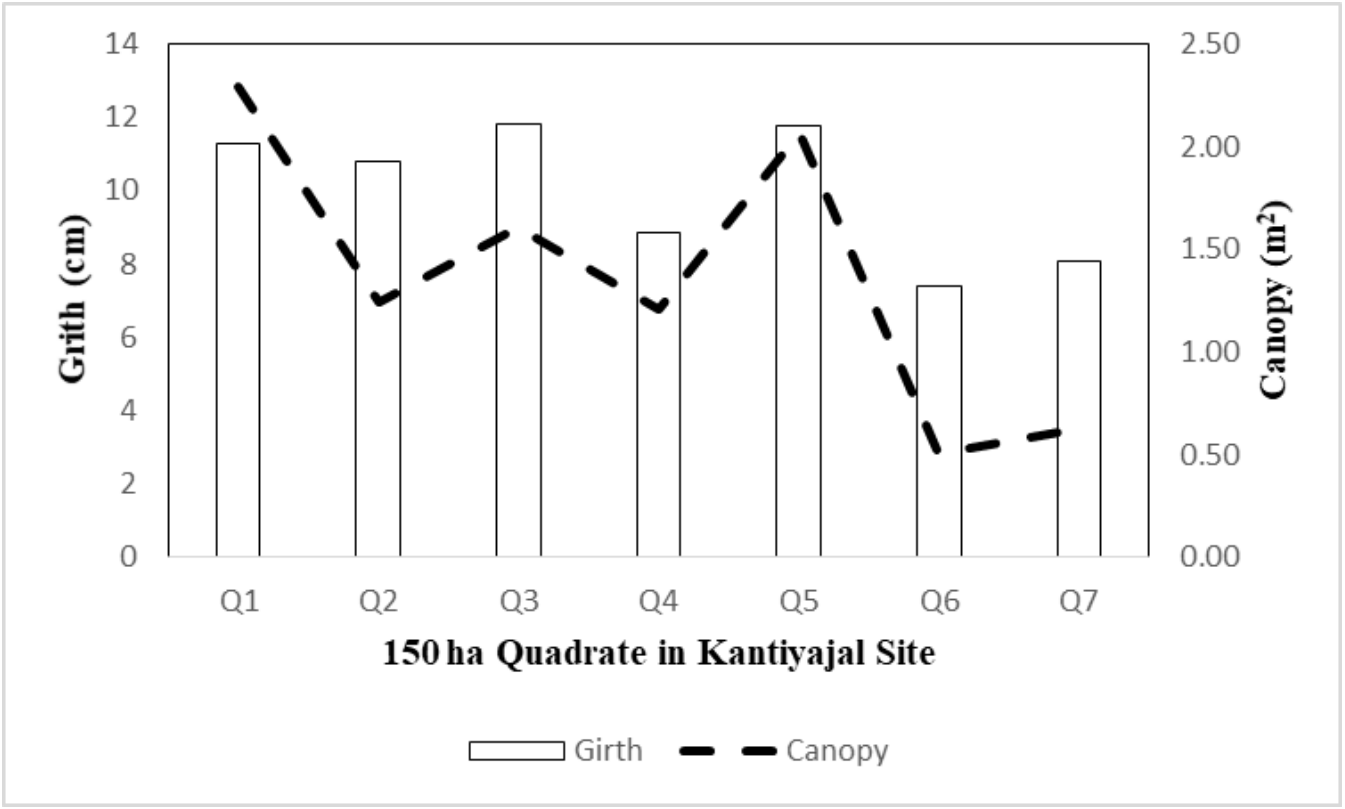

Fig.32 Details of Canopy and Basal Girth of mangroves in 150 ha plantation area in 2015-2016 at Kantiyajal site

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

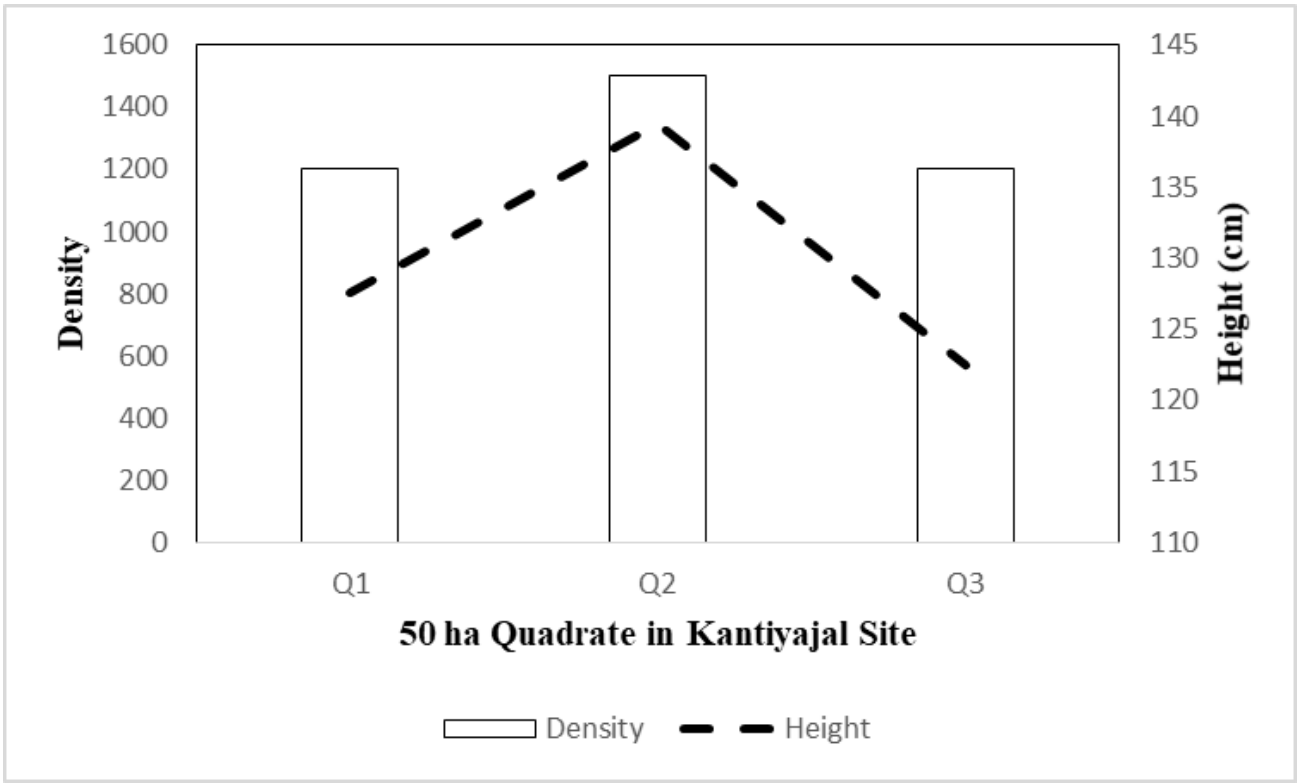

Fig.33 Details of density (No) and height of mangroves in 50 ha plantation area in 2018-2019 at Kantiyajal site

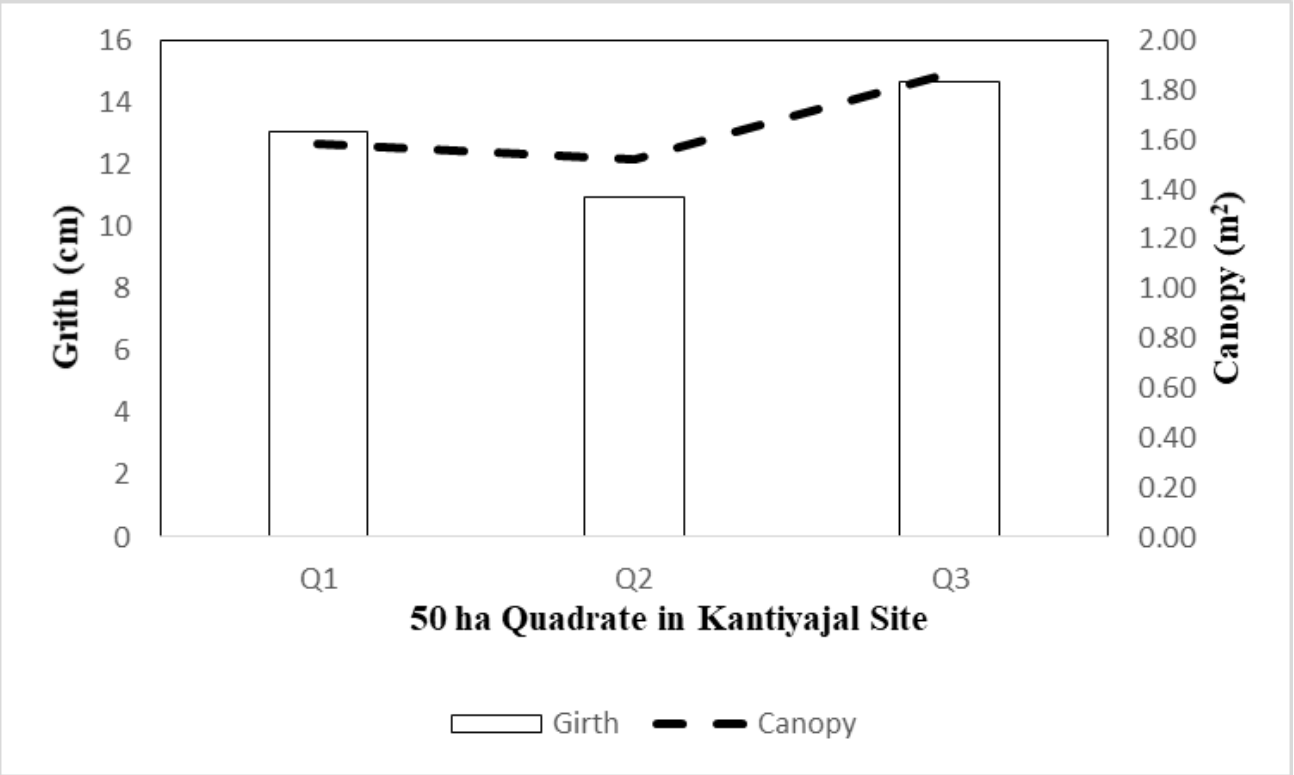

Fig.34 Details of Canopy and Basal Girth of mangroves in 50 ha plantation area in 2018-2019 at Kantiyajal site

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

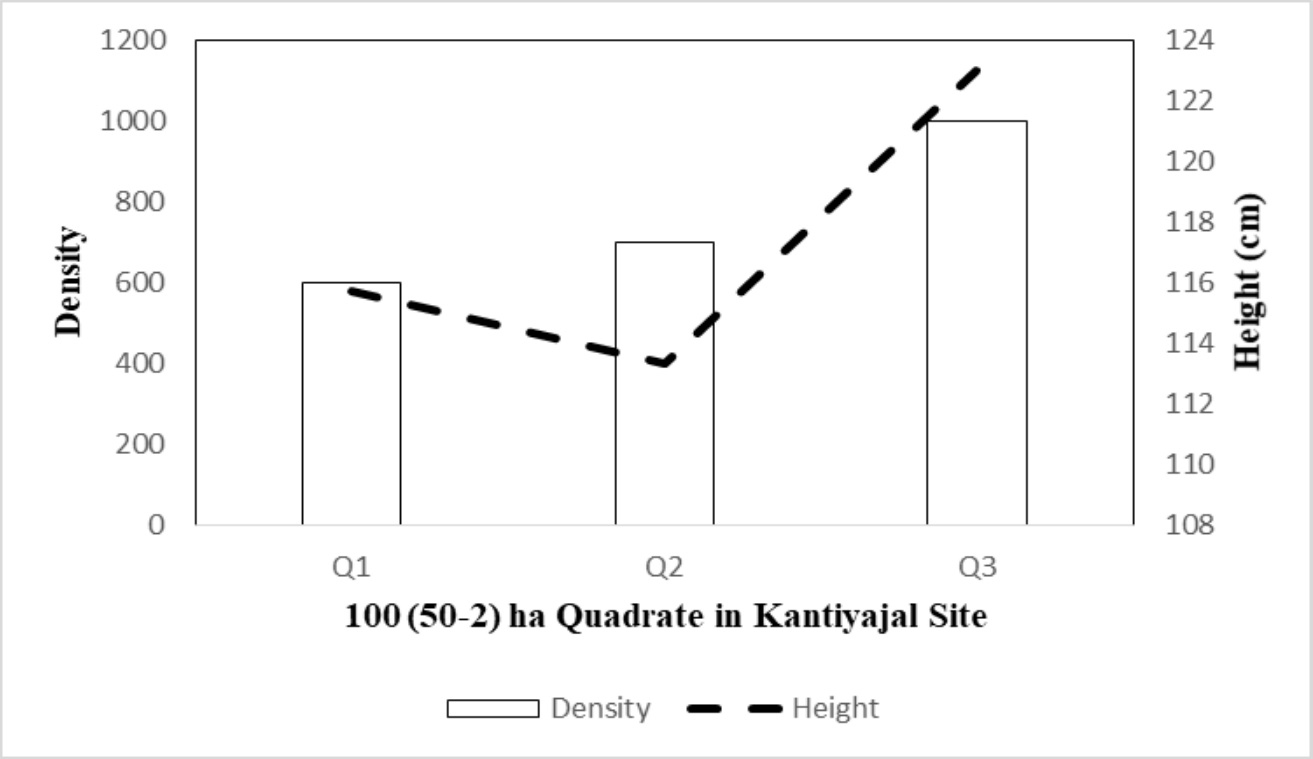

Fig.35 Details of density (No) and height of Mangrove 100 (50-2) Ha plantation area in 2021-2022 at Kantiyajal site

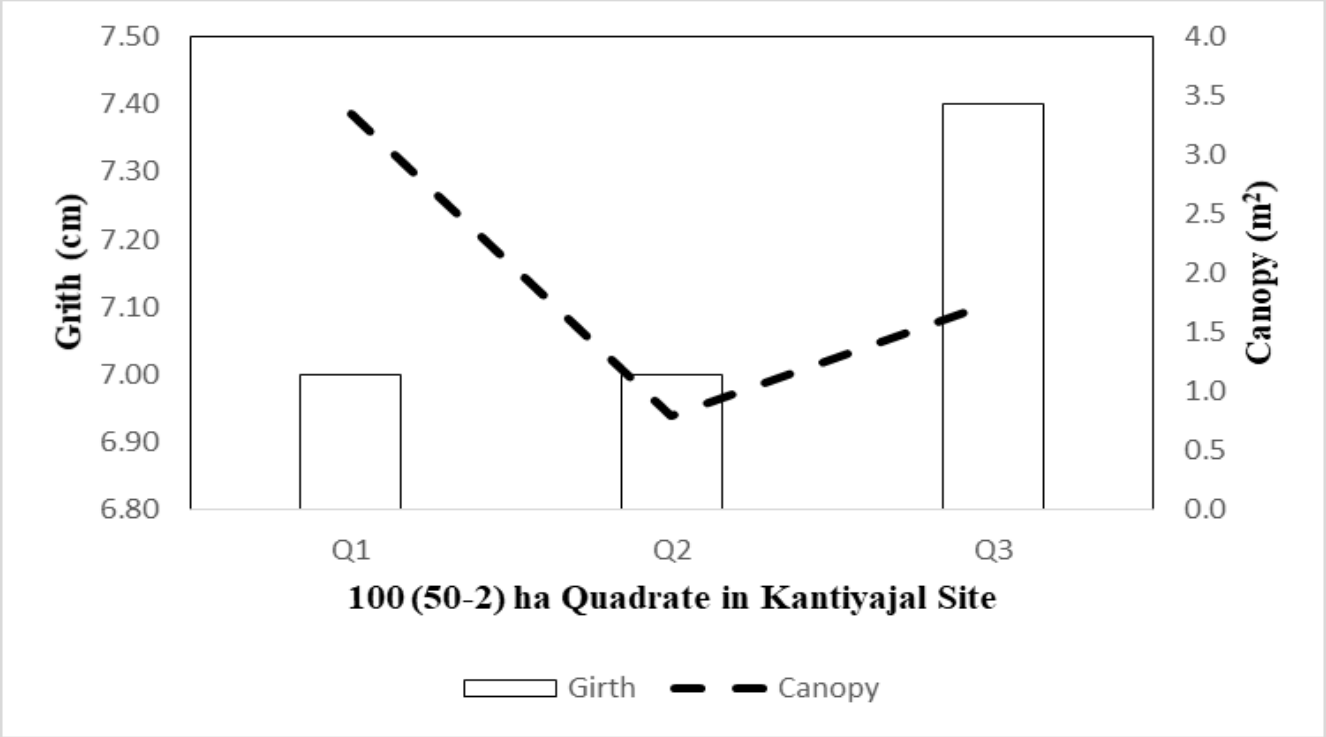

Fig.36 Details of Canopy and Basal Girth of Mangrove 100 (50-2) Ha plantation area in 2021-2022 at Kantiyajal site

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).

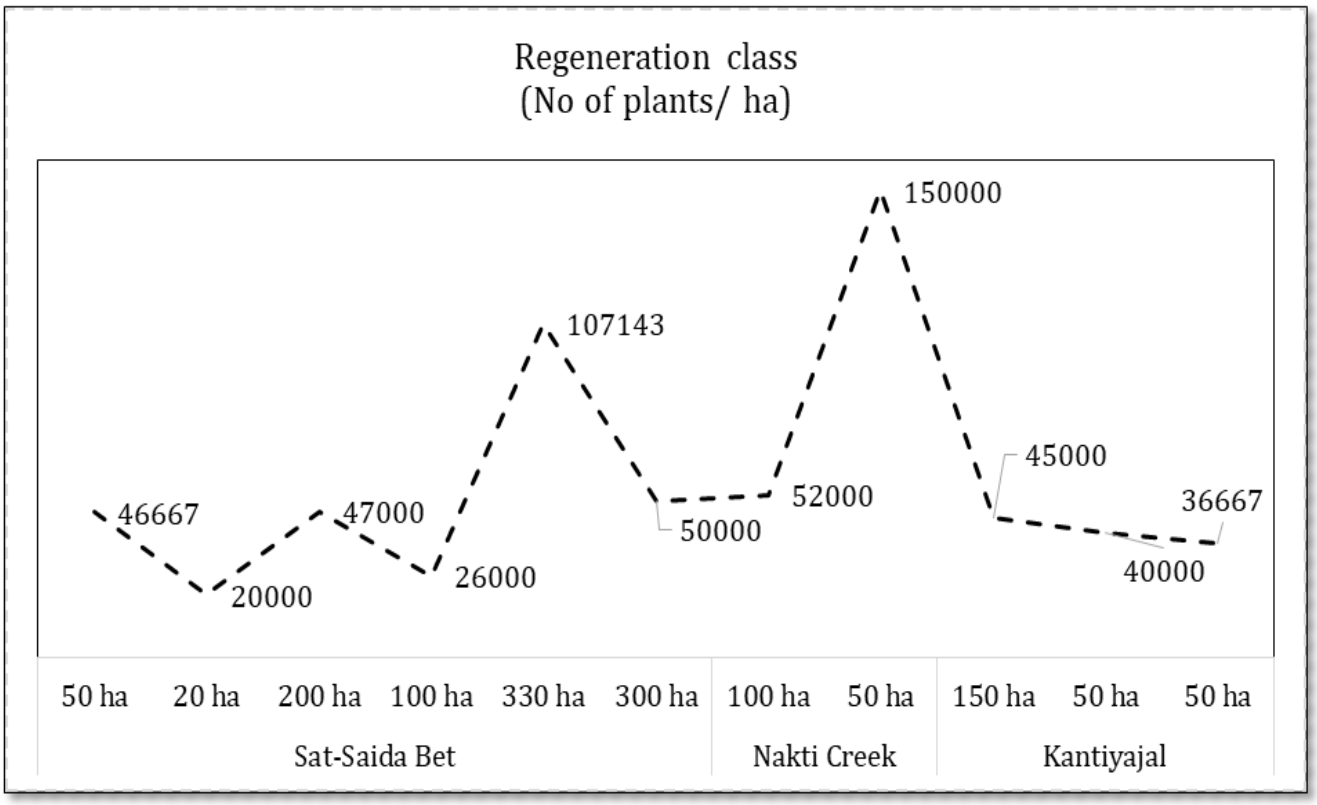

Fig. 37: Regeneration class mangroves in surveyed areas of plantations

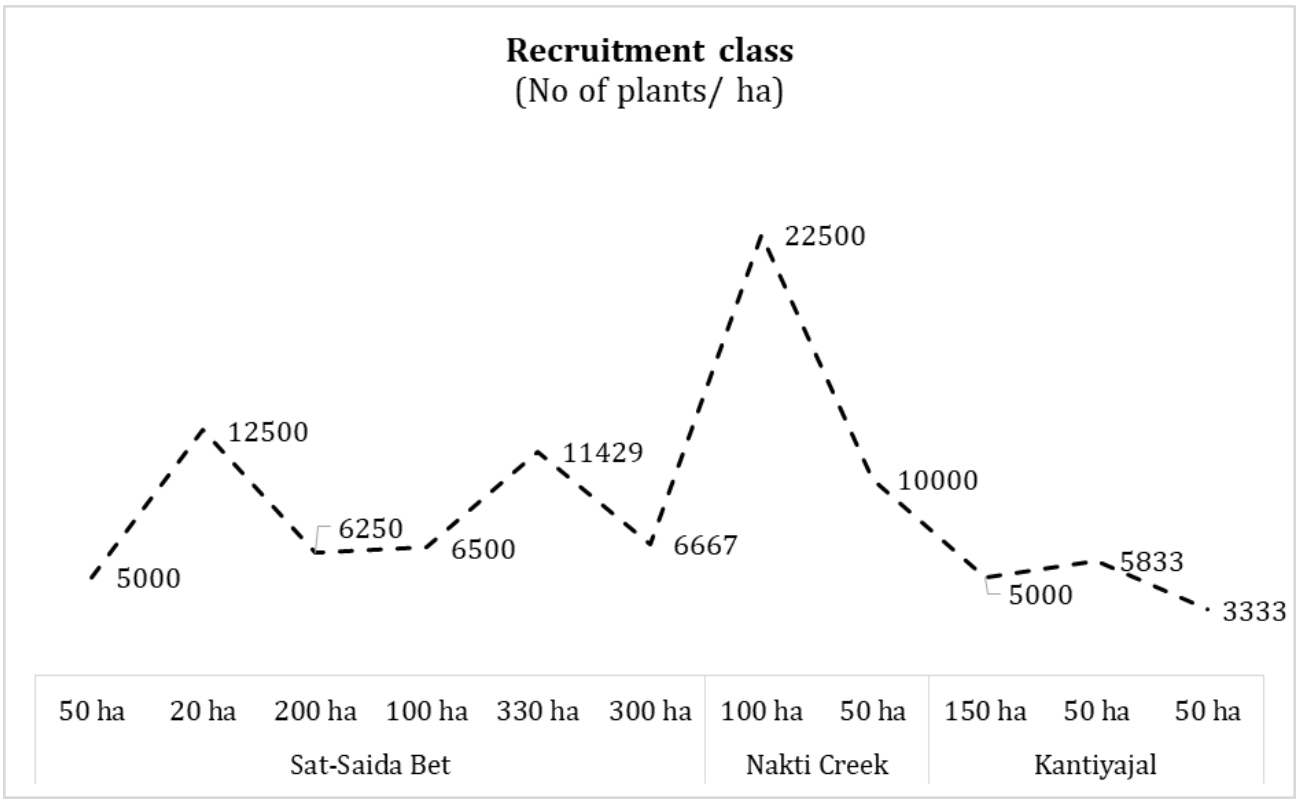

Fig. 38: Recruitment class mangroves in surveyed areas of plantations

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	56.14
	20	0.93	1.23	22.88	
	30	0.78	1.27	29.72	
TC-4	10	1.01	1.25	12.63	77.64
	20	0.98	1.30	25.48	
	30	1.08	1.22	39.53	
TC-5	10	0.75	1.18	8.85	61.3
	20	0.72	1.25	18.00	
	30	0.87	1.32	34.45	
TC-6	10	0.38	1.32	5.02	45.1
	20	0.69	1.30	17.94	
	30	0.60	1.23	22.14	
TC-7	10	0.62	1.37	8.49	49.59
	20	0.59	1.32	15.58	
	30	0.63	1.35	25.52	
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).

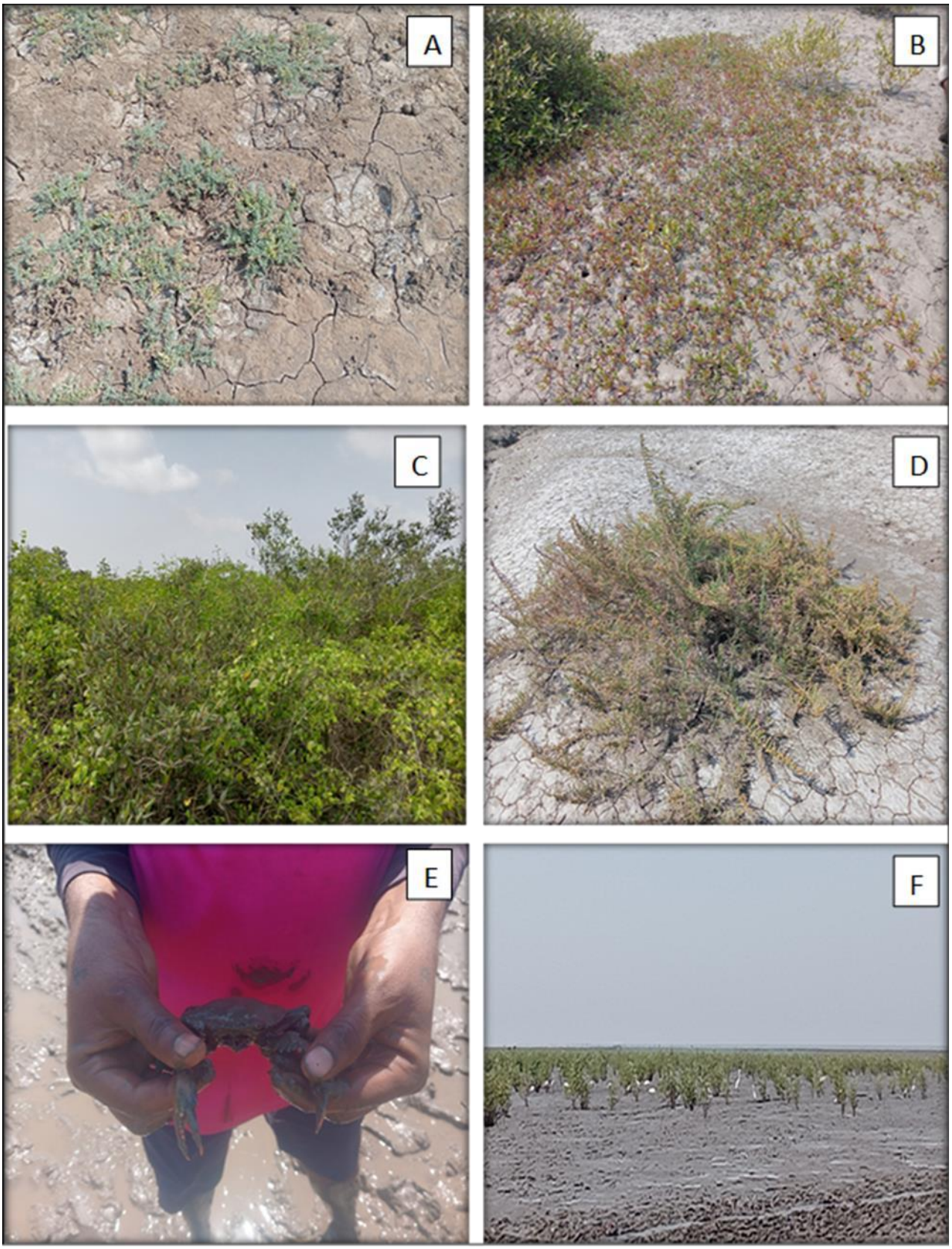

Plate 14. Mangrove associated Halophytes and fauna diversity in plantation site during a visit in 2025

[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.

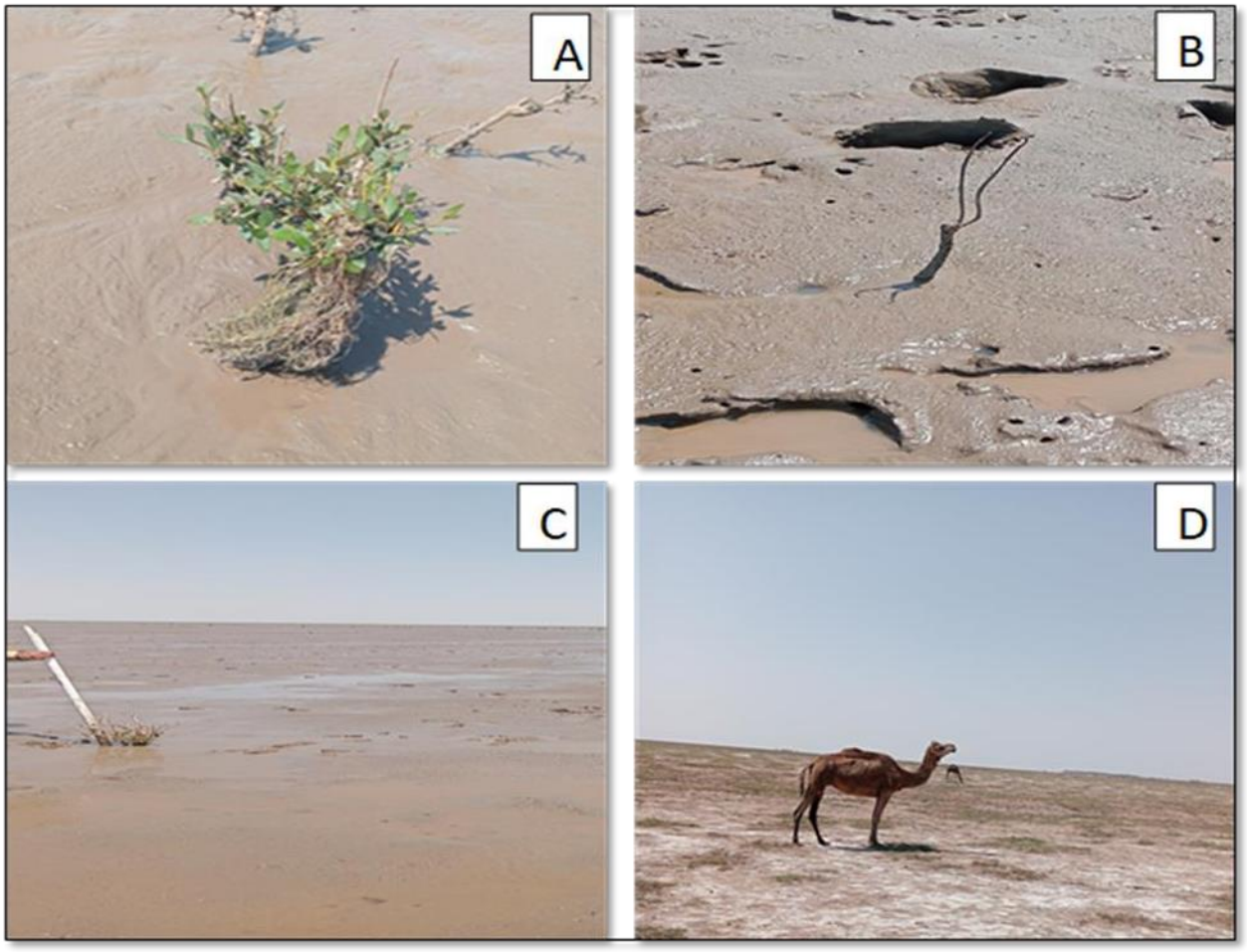

Plate 15. Mangrove Stress factors observed in plantation site during a visit in 2025.

[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 - B

Inception Report

On

Greenbelt Development in Deendayal Port Authority (DPA) and its surrounding areas (Phase-III) along with two years maintenance

Submitted to

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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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Content

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 Road 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) and management of the plantation sites.
3. Identify suitable plant species as per site scenario for the greenbelt plantation and plantation of plant saplings (5000 plants-suitable to the area & 200 plants at Gopalpuri-fruit bearing/medicinal/air purifying) including maintenance of the same for 1st year, along with maintenance, management and monitoring of plantation including drip/tanker water supply for a further period of 2 years.
4. Adopting plantation technique and soil/manure amendments.
5. Regular monitoring (survival and growth) of the plantation.

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 Gopalpuri-200 plants & 2nd Road 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

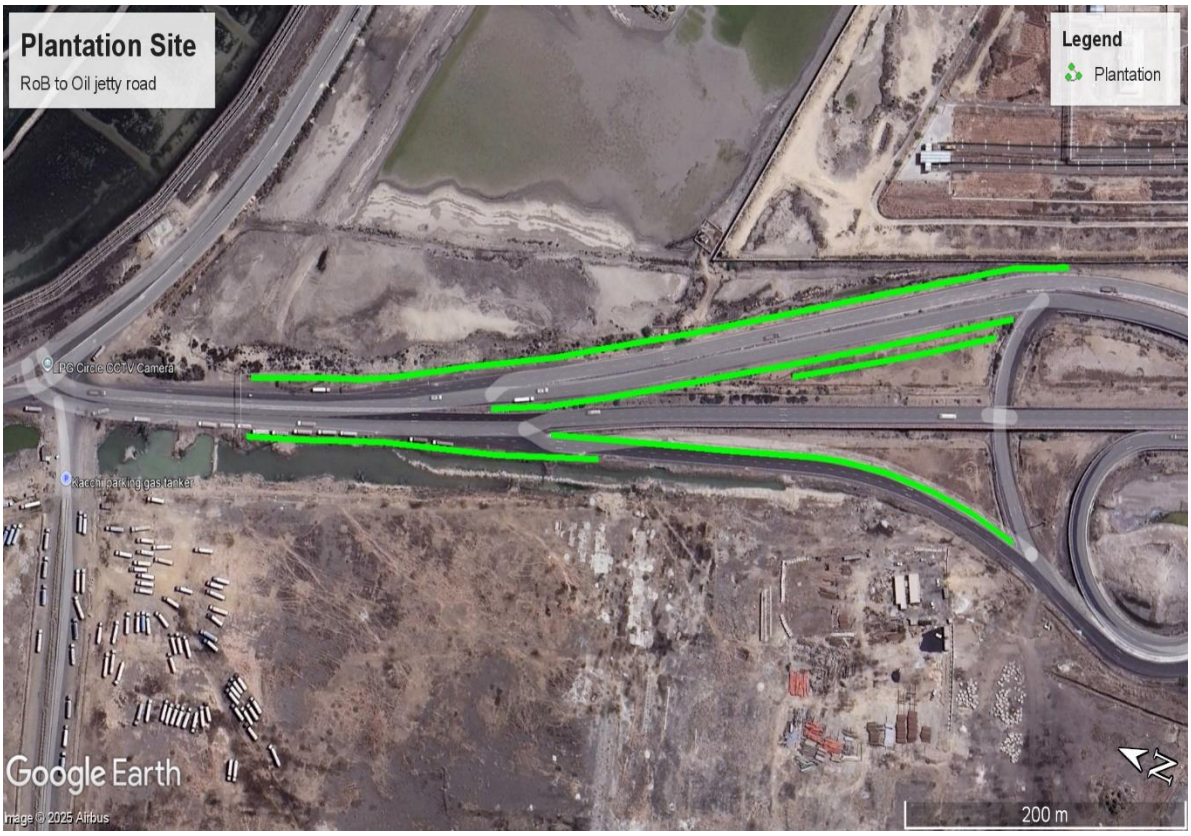

Fig. Map of Plantation Area RoB to Oil Jetty Road

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 - C

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 - D

Environmental Monitoring Report (EMR)
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"

(Monitoring Period: September-October 2025)

Document Ref No.: GEMI/DPA/782(2)(6)/2025/63

Submitted to:

Deendayal Port Authority (DPA), Kandla

Gujarat Environment Management Institute (GEMI)

(An Autonomous Institute of Government of Gujarat)

GEMI Bhavan, 246-247, GIDC Electronic Estate, Sector-25, Gandhinagar-382025

"AN ISO 9001:2015, ISO 14001:2015 AND ISO 45001:2018 Certified Institute"

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 Report (September-October 2025)"* is prepared.

- **Name of the Report:** *Environment Monitoring Report (September-October 2025)*
- **Date of Issue:** 17/12/2025
- **Version:** 1.0
- **Report Ref.:** GEMI/DPA/782(2)(6)/2025/63

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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 EMP

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.sd

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 16th September - 15th October 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 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, sulfate, 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** as follows:

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:

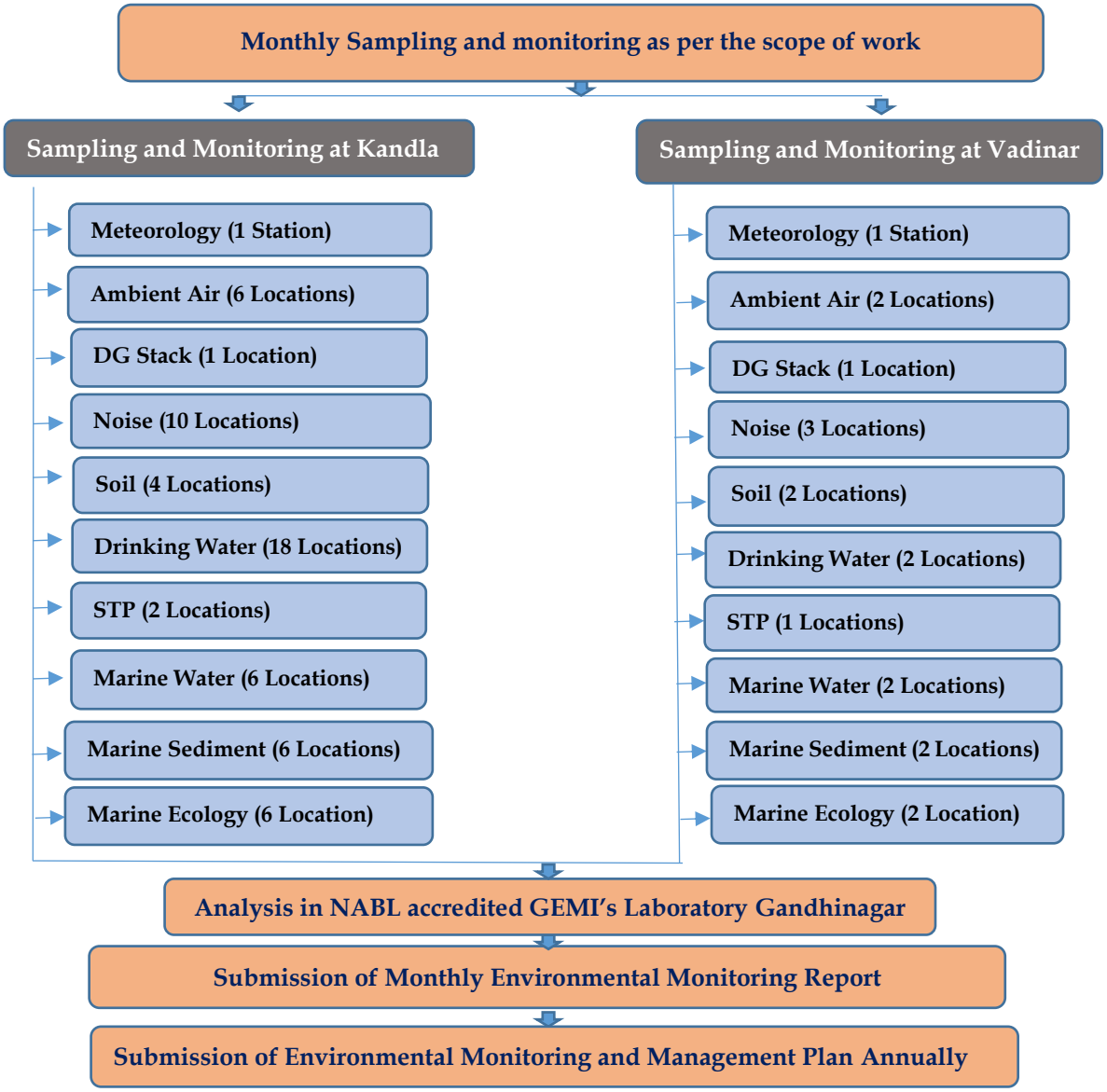


Figure 1: Methodology flow chart

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		

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

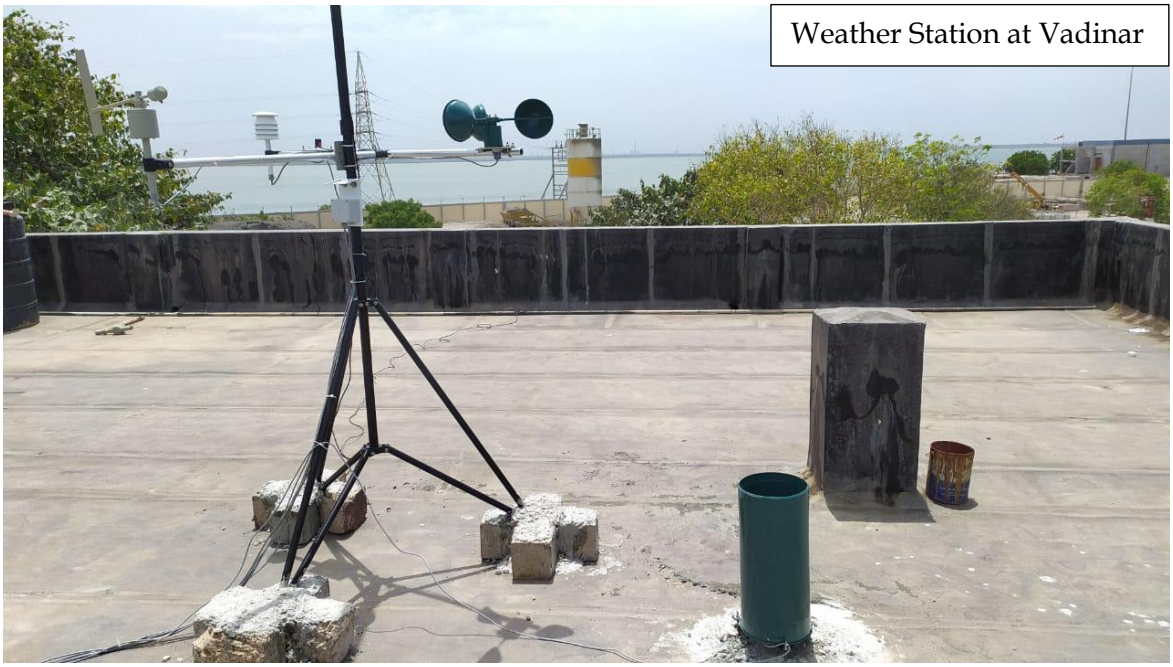


Figure 2: Photographs of Automatic Weather Monitoring Station at Kandla and Vadinar

3.2 Results and discussion

The summary of hourly climatological observations recorded at Kandla and Vadinar during the monitoring period, 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 Period	**Wind Speed (Km/h)**			**Temperature (°C)**			**Relative humidity (%)**			**Solar Radiation (W/m²)**	**Wind Direction (°)**	**Rainfall (mm)**
Stat.	**Mean**	**Max.**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**			
September-October 2025	2.59	50	0.6	30.24	39.2	24.5	67.09	89.4	31.5	75.35	North	0.08
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)**
Stat.	**Mean**	**Max.**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max.**	**Min**			
September-October 2025	3.28	52	0.6	29.53	38	23.5	68.85	85.6	52.1	70.32	NNW	0.05

3.3 Data Interpretation and Conclusion

- **Temperature**

a. **Kandla:** The ambient temperature for the monitoring period varies between the range of 24.5– 39.2°C for Kandla, with average temperature of 30.24°C.
b. **Vadinar:** The ambient temperature for the monitoring period varies between the range of 23.5-38°C for Vadinar, with average temperature of 29.53°C.

- **Relative Humidity**

a. **Kandla**: The Relative Humidity recorded between the range of 31.5–89.4, with average Humidity of 67.09%.
b. **Vadinar:** During the study period, the Relative Humidity varies between 52.1-85.6%, with average Humidity of 68.85%.

- **Rainfall**

a. **Kandla:** 0.08 mm/hr rainfall was observed at Kandla.
b. **Vadinar:** 0.05 mm/hr rainfall was observed at Vadinar.

- **Wind Speed**

Wind speed and Direction play a significant role in transporting the pollutants and thus decides the air quality.

a. **Kandla:** Wind speed recorded ranges between 0.6–50 Km/hr.
b. **Vadinar:** During the monitoring period, the Wind speed recorded ranges between 0.6-52 Km/hr.

- **Solar Radiation:**

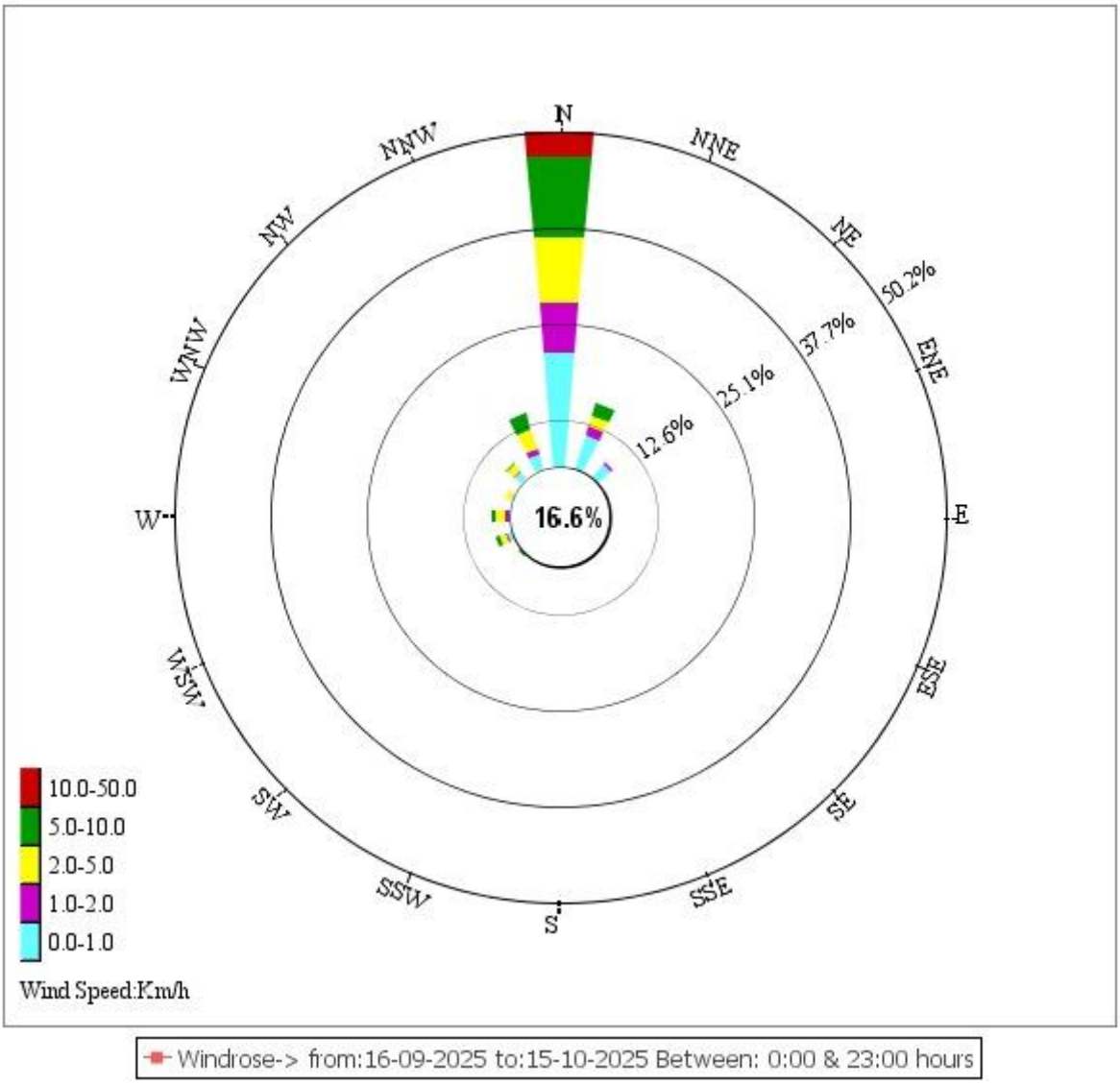
a. **Kandla:** The average Solar Radiation for the monitoring period was recorded as 75.35 W/m^2.
b. **Vadinar:** The average Solar Radiation was recorded as 70.32 W/m^2.

- **Wind rose diagram -**

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

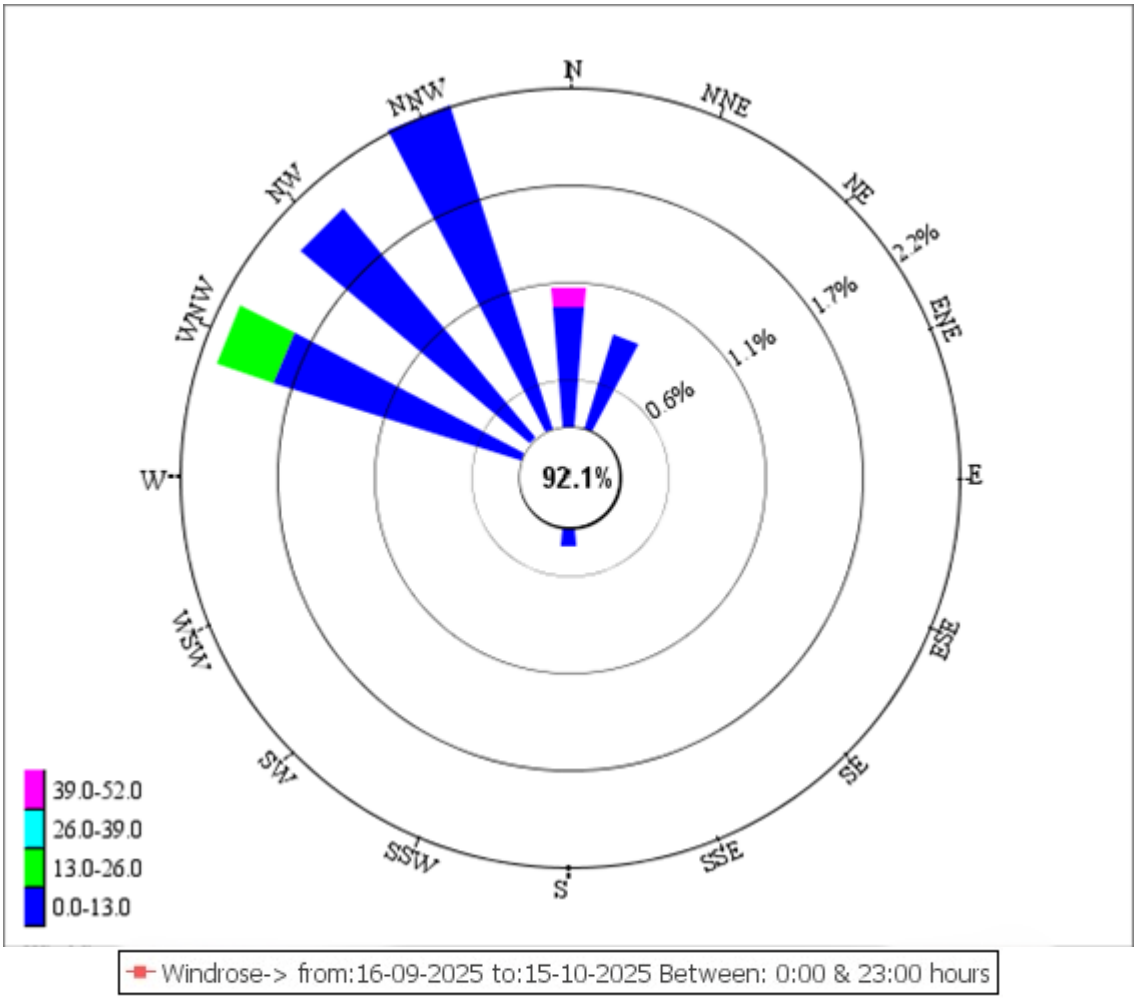
This Wind Rose Diagram reveals that at Kandla and Vadinar, during the monitoring period, the prevailing winds predominantly blow from the North at Kandla. At Vadinar, the winds were observed to blow from North North West Direction.

Wind Rose Plot **M/s Deendayal Port Authority** **Site: Kandla Port (Environment Laboratory)**	**Display: Wind Direction** **Wind Speed (Km/hr)**



Modeler: Envirotech Instruments Pvt. Ltd. Delhi.

Wind Rose Plot **M/s Deendayal Port Authority** **Site: Vadinar Port (Canteen Area)**	**Display: Wind Direction** **Wind Speed (Km/hr)**



Modeler: Envirotech Instruments Pvt. Ltd. Delhi.

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. Ambient air quality has been monitored from 16th September to 15th October 2025.

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	Bansal Canteen	23.027197N 70.195451E	Vehicular activity and dust emission
4.		A-4	Sewa Sadan-3	23.009945N 70.221745 E	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 two ambient air monitoring locations have been changed: Location A-3, previously at Kandla Port Colony, has now been shifted to Bansal Canteen, and Location A-4, earlier at Marine Bhavan, is now relocated to Sew Sadan-3. 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

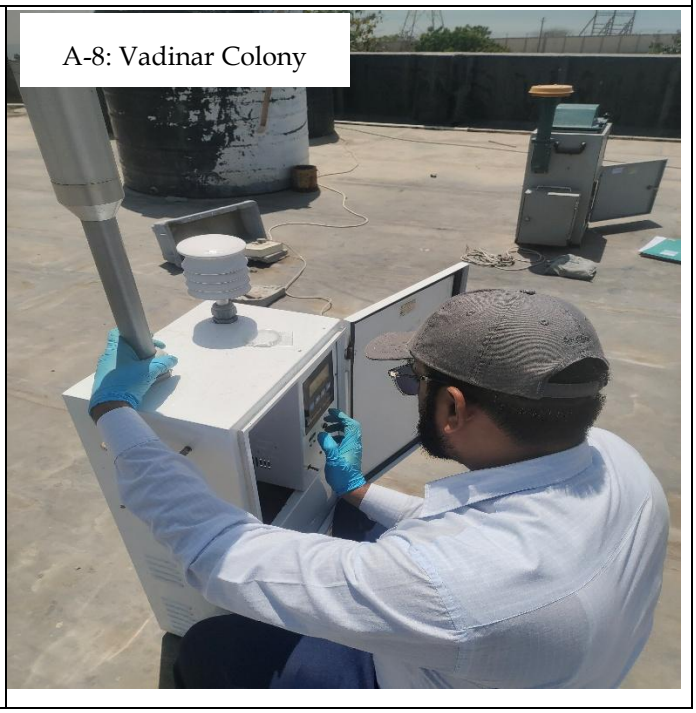
A-2: Oil Jetty No. 7

A-3: Bansal Canteen

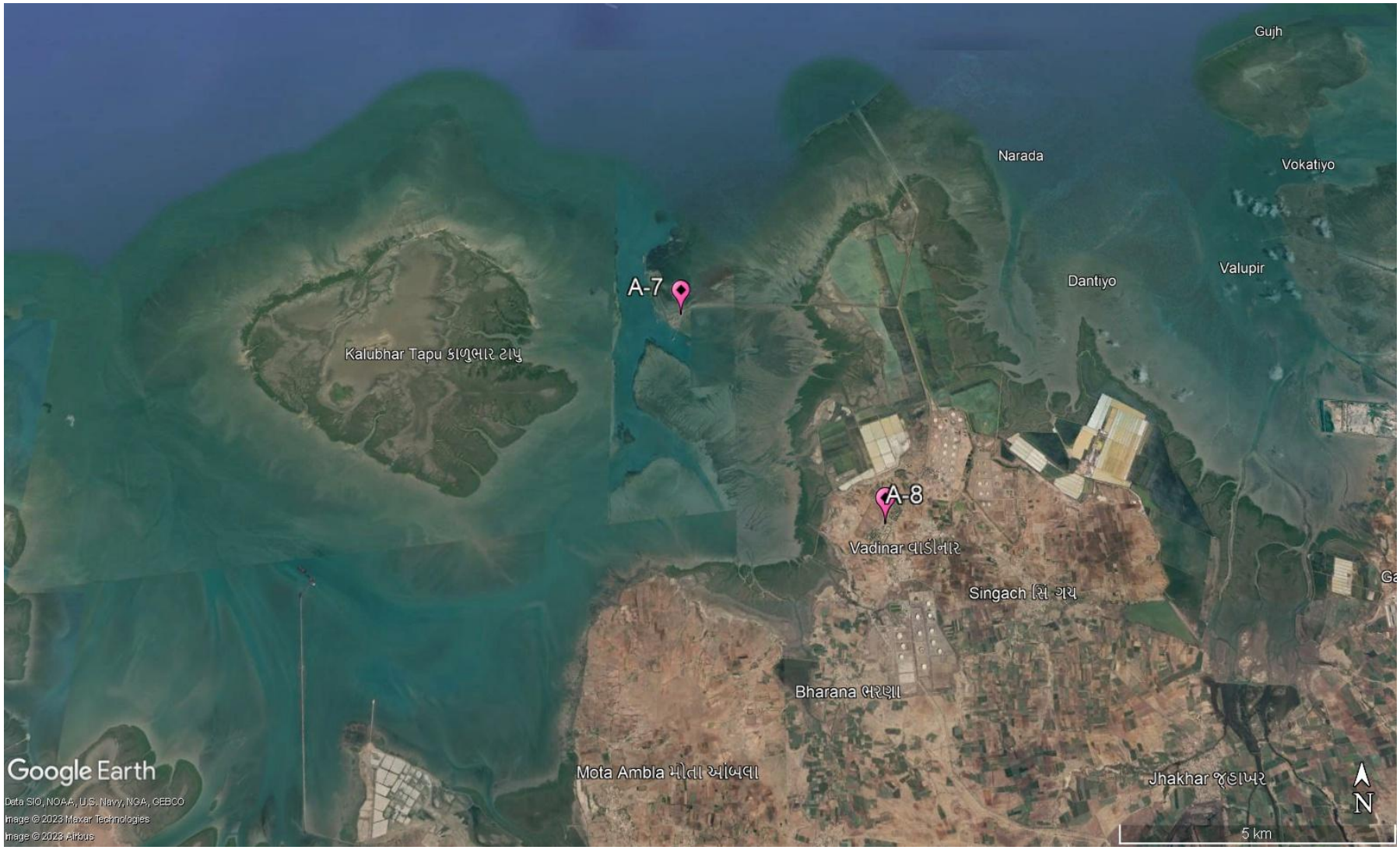
A-4: Sewa Sadan-3

A-5: Coal Storage Area

A-6: Gopalpuri Hospital

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

Map 4: Locations for Ambient Air Monitoring at Kandla



Map 5: Locations for Ambient Air Monitoring at Vadinar

Frequency

The sampling for Particulate matter i.e. PM_{10} and $PM_{2.5}$ and the gaseous components like SO_x, NO_x, CO as well as the Total VOCs were monitored twice in 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 monthly basis.

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

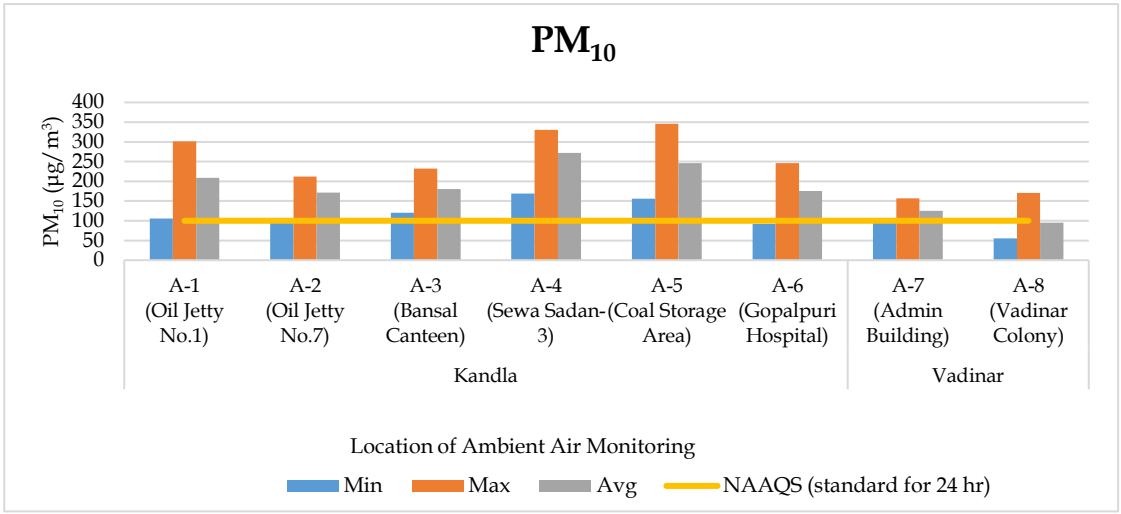
Station Code & Name	Unit of Average Concentration	Average Pollutant Concentration					
	Pollutants	**PM_{10} (µg/m³)**	**$PM_{2.5}$ (µg/m³)**	**SO_2 (µg/m³)**	**NO_X (µg/m³)**	**VOC (µg/m³)**	**CO (mg/m³)**
	Duration	**(24 hr)**				**(2 hr)**	**(1 hr)**
	NAAQS by CPCB / **Monitoring days**	**100**	**60**	**80**	**80**	**-**	**2**
A-1: Oil Jetty No.1,	16-09-2025	217.38	17.01	7.21	42.31	0.14	0.81
	18-09-2025	105.45	19.25	6.81	50.21	0.09	0.81
	22-09-2025	301.24	53.21	7.45	60.25	0.14	0.76
	24-09-2025	126.13	20.31	6.23	23.65	0.22	0.79

Station Code & Name	Unit of Average Concentration	Average Pollutant Concentration					
	Pollutants	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	SO_2 (µg/m³)	NO_X (µg/m³)	VOC (µg/m³)	CO (mg/m³)
	Duration	(24 hr)				(2 hr)	(1 hr)
	NAAQS by CPCB / Monitoring days	100	60	80	80	-	2
Kandla	29-09-2025	200.15	15.24	7.11	54.62	0.12	0.80
	06-10-2025	223.42	33.20	7.10	32.36	0.19	0.80
	08-10-2025	250.13	27.51	6.54	29.51	0.15	0.81
	13-10-2025	245.16	40.26	8.11	42.13	0.23	0.78
	Minimum	**105.45**	**15.24**	**6.23**	**23.65**	**0.09**	**0.76**
	Maximum	**301.24**	**53.21**	**8.11**	**60.25**	**0.23**	**0.81**
	Average	**208.63**	**28.25**	**7.07**	**41.88**	**0.16**	**0.80**
	Std. Deviation	**64.87**	**13.27**	**0.57**	**12.79**	**0.05**	**0.02**
A-2: Oil Jetty No.7, Kandla	16-09-2025	101.32	20.36	<5	16.43	0.14	0.82
	18-09-2025	164.53	25.64	6.23	15.42	0.18	0.81
	22-09-2025	142.24	32.61	<5	14.66	0.19	0.79
	24-09-2025	152.43	42.15	<5	20.31	0.15	0.77
	29-09-2025	202.13	29.35	7.23	16.25	0.1	0.79
	06-10-2025	212.34	35.62	<5	10.23	0.07	0.82
	08-10-2025	196.22	31.25	<5	<6	0.13	0.80
	13-10-2025	200.13	29.46	12.23	<6	0.21	0.79
	Minimum	**101.32**	**20.36**	**6.23**	**10.23**	**0.07**	**0.77**
	Maximum	**212.34**	**42.15**	**12.23**	**20.31**	**0.21**	**0.82**
	Average	**171.42**	**30.81**	**8.56**	**15.55**	**0.15**	**0.80**
	Std. Deviation	**38.23**	**6.49**	**3.21**	**3.26**	**0.05**	**0.02**
A-3: Bansal Canteen , Kandla	16-09-2025	120.32	31.25	10.24	9.24	0.2	0.78
	18-09-2025	132.42	23.26	9.21	10.26	0.21	0.80
	22-09-2025	164.10	31.54	10.25	<6	0.09	0.81
	24-09-2025	184.25	28.65	9.43	12.45	0.12	0.81
	29-09-2025	232.23	46.21	<5	15.42	0.16	0.80
	06-10-2025	210.36	29.54	8.56	18.21	0.13	0.75
	08-10-2025	203.25	30.42	7.45	16.43	0.15	0.69
	13-10-2025	195.43	39.52	11.44	<6	0.09	0.68
	Minimum	**120.32**	**23.26**	**7.45**	**9.24**	**0.09**	**0.68**
	Maximum	**232.23**	**46.21**	**11.44**	**18.21**	**0.21**	**0.81**
	Average	**180.30**	**32.55**	**9.51**	**13.67**	**0.14**	**0.77**
	Std. Deviation	**38.77**	**7.10**	**1.29**	**3.58**	**0.05**	**0.05**
A-4: Sewa Sadan - 3, Kandla	16-09-2025	214.29	19.95	<5	<6	0.17	0.81
	18-09-2025	216.58	19.92	<5	<6	0.2	0.80
	22-09-2025	168.93	28.55	<5	<6	0.19	0.83
	24-09-2025	308.67	37.66	7.75	20.13	0.15	0.78
	29-09-2025	317.46	49.09	7.45	<6	0.12	0.78
	06-10-2025	315.46	50.64	<5	<6	0.06	0.79
	08-10-2025	303.12	46.13	7.21	<6	0.09	0.79
	13-10-2025	330.21	52.64	<5	13.02	0.13	0.77
	Minimum	**168.93**	**19.92**	**7.21**	**13.02**	**0.06**	**0.77**
	Maximum	**330.21**	**52.64**	**7.75**	**20.13**	**0.20**	**0.83**

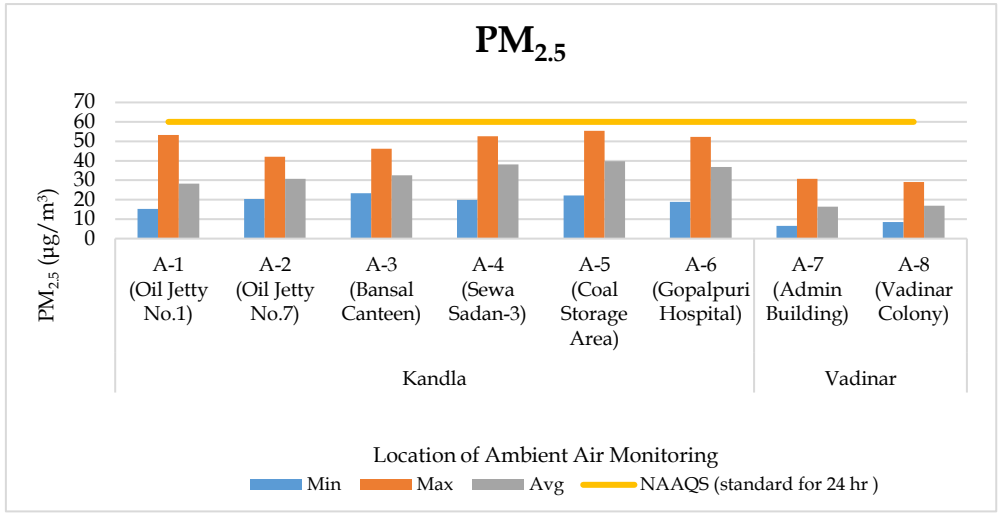
Station Code & Name	Unit of Average Concentration	Average Pollutant Concentration					
	Pollutants	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	SO_2 (µg/m³)	NO_X (µg/m³)	VOC (µg/m³)	CO (mg/m³)
	Duration	(24 hr)				(2 hr)	(1 hr)
	NAAQS by CPCB / Monitoring days	100	60	80	80	-	2
	Average	**271.84**	**38.07**	**7.47**	**16.58**	**0.14**	**0.79**
	Std. Deviation	**61.74**	**13.66**	**0.27**	**5.03**	**0.05**	**0.02**
A-5: Coal Storage Area, Kandla	16-09-2025	211.36	43.51	12.34	12.53	0.19	0.81
	18-09-2025	190.25	25.36	15.32	10.26	0.08	0.65
	22-09-2025	156.25	34.26	<5	24.65	0.21	0.72
	24-09-2025	256.33	22.25	22.41	28.61	0.08	0.71
	29-09-2025	312.21	42.35	<5	32.60	0.17	0.78
	06-10-2025	346.25	55.46	21.34	42.17	0.16	0.81
	08-10-2025	254.66	42.33	<5	31.26	0.19	0.81
	13-10-2025	244.12	52.65	11.23	20.46	0.05	0.79
	Minimum	**156.25**	**22.25**	**11.23**	**10.26**	**0.05**	**0.65**
	Maximum	**346.25**	**55.46**	**22.41**	**42.17**	**0.21**	**0.81**
	Average	**246.43**	**39.77**	**16.53**	**25.32**	**0.14**	**0.76**
	Std. Deviation	**62.08**	**11.86**	**5.12**	**10.67**	**0.06**	**0.06**
A-6: Gopalpuri Hospital, Kandla	16-09-2025	113.09	35.19	<5	18.12	0.1	0.61
	18-09-2025	103.79	24.79	<5	16.43	0.12	0.61
	22-09-2025	92.03	18.81	<5	25.63	0.15	0.60
	24-09-2025	191.84	45.74	7.88	32.65	0.18	0.60
	29-09-2025	234.86	52.31	9.07	29.51	0.06	0.60
	06-10-2025	200.12	23.10	7.92	22.36	0.12	0.62
	08-10-2025	222.31	42.56	8.21	31.44	0.1	0.61
	13-10-2025	246.14	51.44	9.01	35.61	0.13	0.59
	Minimum	**92.03**	**18.81**	**7.88**	**16.43**	**0.06**	**0.59**
	Maximum	**246.14**	**52.31**	**9.07**	**35.61**	**0.18**	**0.62**
	Average	**175.52**	**36.74**	**8.42**	**26.47**	**0.12**	**0.61**
	Std. Deviation	**62.77**	**13.23**	**0.58**	**7.01**	**0.04**	**0.01**
A-7: Admin Building, Vadinar	16-09-2025	137.98	6.52	<5	57.59	0.06	0.59
	18-09-2025	119.81	11.21	<5	32.69	0.17	0.63
	22-09-2025	106.48	15.24	<5	56.29	0.15	0.69
	24-09-2025	110.73	19.46	5.03	32.47	0.14	0.65
	29-09-2025	108.68	15.48	8.12	26.21	0.22	0.69
	06-10-2025	157.05	19.02	7.09	32.47	0.15	0.69
	08-10-2025	140.92	30.76	7.56	62.57	0.11	0.59
	13-10-2025	120.42	13.52	6.32	33.12	0.12	0.64
	Minimum	**106.48**	**6.52**	**5.03**	**26.21**	**0.06**	**0.59**
	Maximum	**157.05**	**30.76**	**8.12**	**62.57**	**0.22**	**0.69**
	Average	**125.26**	**16.40**	**6.82**	**41.68**	**0.14**	**0.65**
	Std. Deviation	**18.16**	**7.15**	**1.20**	**14.47**	**0.05**	**0.04**
A-8: Vadinar Colony,	16-09-2025	170.45	8.59	<5	35.86	0.23	0.67
	18-09-2025	95.73	17.06	<5	21.05	0.21	0.69
	22-09-2025	84.44	17.66	<5	28.68	0.12	0.65
	24-09-2025	71.15	17.86	<5	37.71	0.2	0.61

Station Code & Name	Unit of Average Concentration	Average Pollutant Concentration					
	Pollutants	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	SO_2 (µg/m³)	NO_X (µg/m³)	VOC (µg/m³)	CO (mg/m³)
	Duration	(24 hr)				(2 hr)	(1 hr)
	NAAQS by CPCB / Monitoring days	100	60	80	80	-	2
Vadinar	29-09-2025	55.70	14.14	7.29	45.32	0.16	0.71
	06-10-2025	78.47	14.93	7.00	39.56	0.15	0.71
	08-10-2025	109.34	29.16	7.30	43.72	0.14	0.57
	13-10-2025	97.45	15.42	7.12	22.25	0.18	0.72
	Minimum	**55.70**	**8.59**	**7.00**	**21.05**	**0.12**	**0.57**
	Maximum	**170.45**	**29.16**	**7.30**	**45.32**	**0.23**	**0.72**
	Average	**95.34**	**16.85**	**7.18**	**34.27**	**0.17**	**0.67**
	Std. Deviation	**34.65**	**5.79**	**0.14**	**9.29**	**0.04**	**0.05**

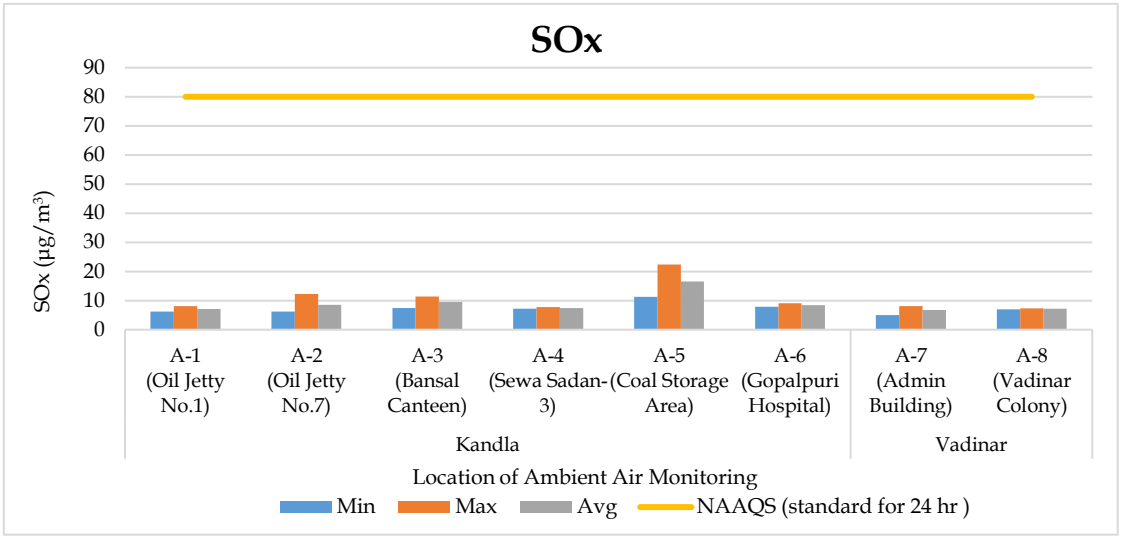
Graphs 1-6 shows spatial trend of ambient air parameter at all the eight-monitoring location (six at Kandla and 2 at Vadinar)



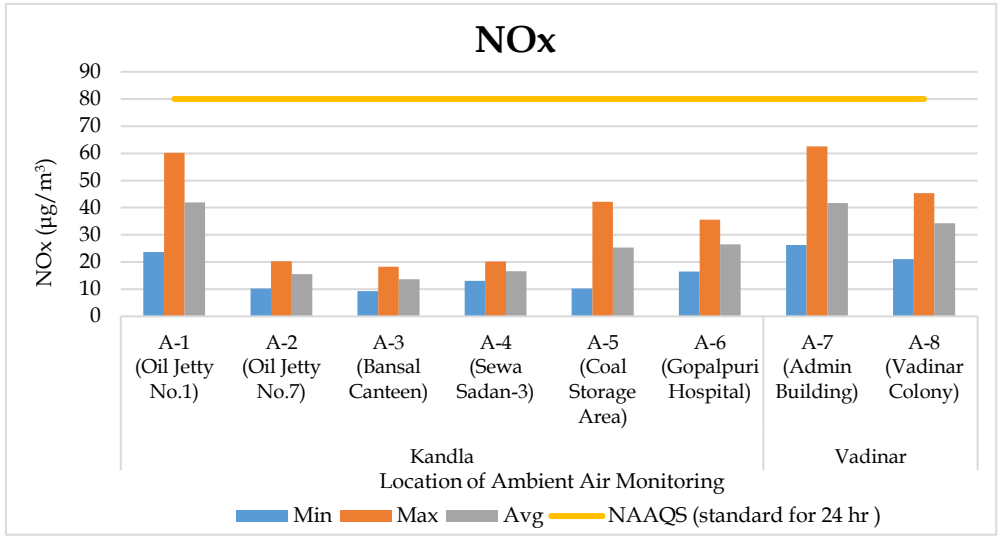
Graph 1: Spatial trend in Ambient PM_{10} Concentration



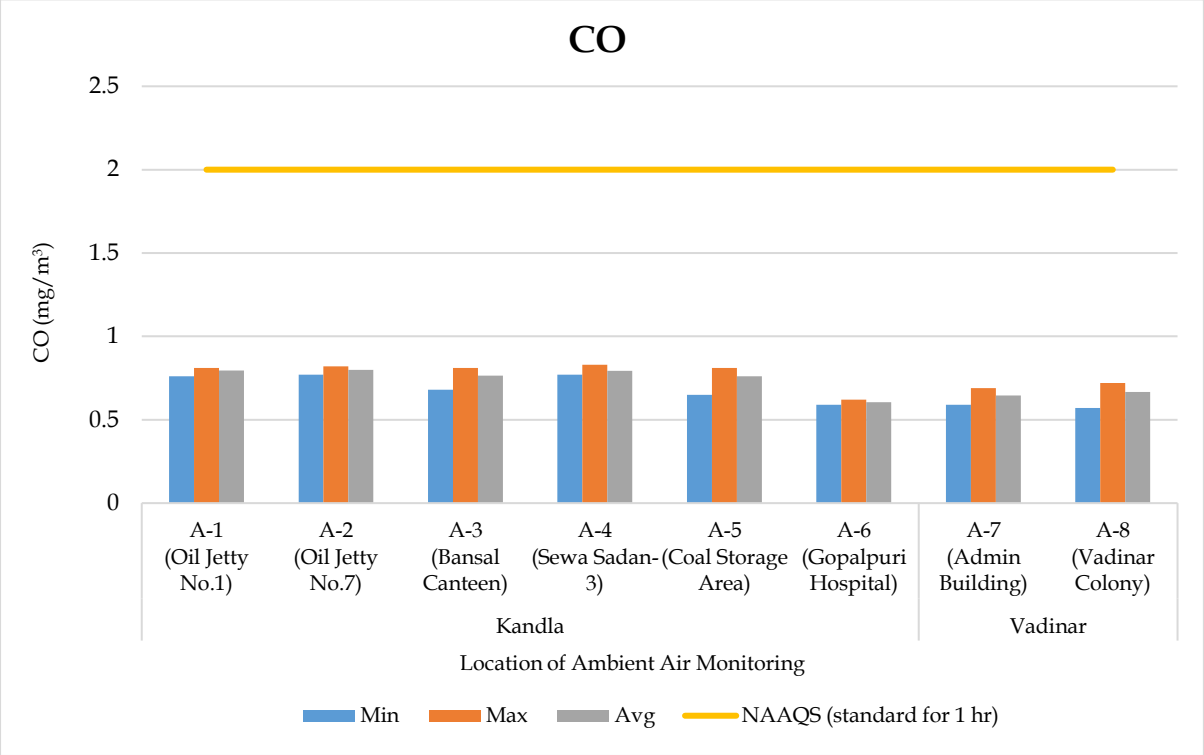
Graph 2: Spatial trend in Ambient $PM_{2.5}$ Concentration



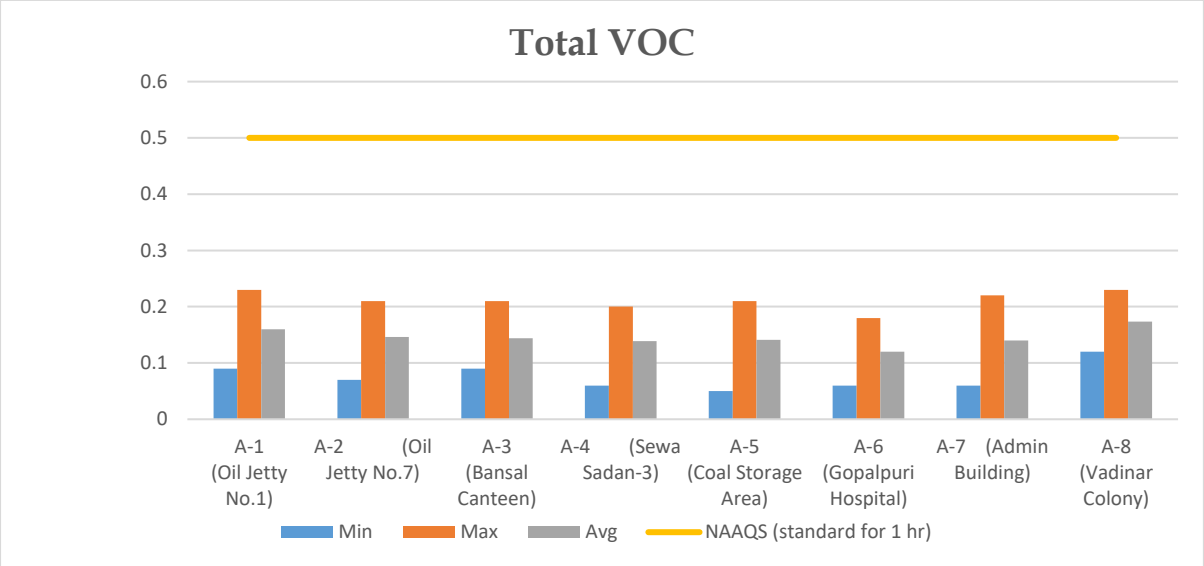
Graph 3: Spatial Trend in Ambient SOx Concentration



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

Benzene (µg/m³)								
Sr. No	Kandla						Vadinar		NAAQS standards (24 hr)
	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	
1	0	0	0	0	0	0	0	0	5 µg/m3

Table 8: Summarized results of Polycyclic Aromatic Hydrocarbons

Sr. No.	Components	Kandla						Vadinar	
		A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8
1	Napthalene	0.350	0.700	0.200	0.210	1.420	1.150	0.000	0.000
2	Acenaphthylene	0.070	0.010	0.150	0.850	0.390	0.480	0.070	0.000
3	Acenaphthene	0.020	0.060	0.380	0.080	0.610	0.000	0.000	0.000
4	Fluorene	0.450	0.320	0.210	0.260	0.200	0.00	0.000	0.000
5	Anthracene	0.350	0.380	0.320	0.540	0.310	0.120	0.110	0.000
6	Phenanthrene	0.080	0.085	0.090	0.090	0.000	0.220	0.080	0.000
7	Fluoranthene	0.700	0.720	0.540	0.210	0.580	0.350	0.000	0.000
8	Pyrene	0.090	0.540	0.320	0.650	0.690	0.250	0.090	0.000
9	Chrycene	0.810	1.250	0.580	0.490	0.710	1.150	0.180	0.110
10	Banz(a)anthracene	0.790	1.060	0.280	0.390	0.380	0.790	0.050	0.000
11	Benzo[k]fluoranthene	0.000	0.000	0.000	0.000	0.000	2.800	0.500	0.480
12	Benzo[b]fluoranthene	0.000	0.000	0.000	0.000	0.000	1.350	0.110	0.160
13	Benzopyrene	1.910	2.360	1.090	1.850	2.090	2.190	0.350	0.250
14	Indeno [1,2,3-cd] fluoranthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	Dibenz(ah)anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	Benzo[ghi]perylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 9: Summarized results of Non-methane VOC

Sr No	Kandla						Vadinar	
	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8
1	0	0	0	0	0	0	0	0

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).

- The concentration of PM_{10} at Kandla varies in the range of **92.03 to 346.25 µg/m³** with an average value of **209.02 µg/m³**. PM_{10} exceeded NAAQS of all the monitoring locations in Kandla. Whereas, at Vadinar, the concentration varies from **55.70 to 170.45 µg/m³**, with an average value of **110.30 µg/m³**.
- The elevated PM_{10} 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 PM_{10} levels in and around the Coal Storage Area and Marine.
- The **$PM_{2.5}$** concentrations at Kandla varies from **15.24 to 55.46 µg/m³** with average **34.36 µg/m³**. The **$PM_{2.5}$** concentration falls within the NAAQS limit for all locations of Kandla. Whereas, at Vadinar its concentration varies from **6.52 to 30.76 µg/m³** with average **16.63 µg/m³**. Also, due to construction and demolition all around the port contributing in increased particulate matter levels.
- The concentrations of **PM_{10}** at the Vadinar sampling locations are exceeding the limits prescribed by the National Ambient Air Quality Standards (NAAQS), primarily due to ongoing construction activities in the Vicinity.
- The concentration of **SO_x** varies from **6.23 to 22.41 µg/m³** with average concentration as **9.59 µg/m³** at Kandla and **5.03 to 8.12 µg/m³** with average as **7.00 µg/m³** at Vadinar. The average concentration of SO_x complies with the prescribed limit of NAAQS (80 µg/m³) for both the monitoring site.
- The concentration of **NO_x** varies from **9.24 to 60.25 µg/m³** with average **23.24 µg/m³** at Kandla and **21.05 to 62.37 µg/m³** with average **37.97 µg/m³** at Vadinar. The concentration of **NO_x** falls within the prescribed limit of NAAQS i.e. 80 µg/m³ at both the monitoring site of Kandla and Vadinar.
- The concentration of **CO** varies from 0.59 **to 0.83 µg/m³** with average **0.75 µg/**m³ at Kandla and **0.57 to 0.72 µg/m³** with average **0.66 µg/m³** at Vadinar. The concentration falls within the norm of 2 mg/m³ specified by NAAQS at both the monitoring sites
- The concentration of **Total VOCs** levels was recorded in range of **0.05 to 0.23 µg/m³** at Kandla and **in range of 0.06 to 0.23 µg/m³** at the location of Vadinar respectively. The main source of VOCs in the ambient air may be attributed to the burning of Gasoline and Natural gas in Vehicle exhaust and burning fossil fuels, and garbage that release VOCs into the atmosphere. During the monitoring period, the wind flows towards 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.
- **Benzene** was not detected on the location of Kandla & Vadinar.

- **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 Ambient air Monitoring location of Kandla recorded the **Non-methane VOC** (NM-VOC) concentration Value to be **0 µg/m³**. While at Vadinar, the concentration of NM-VOC falls is found to be **0 µg /m³** at both the location.

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 NAAQ
S 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. Apart from that, construction and demolition activities majorly contribute to particulate matter pollution.

4.4 Remedial Measures:

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.

- Store fine particulate cargo (e.g., coal, fertilizers) in covered sheds or domes.
- 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.
- Develop green belts using dust-tolerant species along port boundaries and roads.
- 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.
- 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-sulfur fuels (viz. Marine Gas Oil (MGO)/Liquefied Natural Gas (LNG), can significantly reduce sulfur 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.

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: Locations for DG Stack monitoring at Kandla

Map 7: Locations for DG Stack monitoring 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/Nm^3	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.

Frequency

Monitoring is required to be carried out once a month for both the locations of Kandla and Vadinar.

5.2 Result and Discussion

The sampling and monitoring of DG stack emission was carried out 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	Stack Monitoring Limits / Standards As per CPCB	DG- 1 (Kandla)	DG-2 (Vadinar)
1.	Suspended Particulate Matter (SPM) (mg/Nm^3)	150	75.21	40.36
2.	Sulphur Dioxide (SO_2) (PPM)	100	1.85	N.D.
3.	Oxides of Nitrogen (NO_x) (PPM)	50	30.45	18.54
4.	Carbon Monoxide (CO) (%)	1	0.29	0.07
5.	Carbon Dioxide (CO_2) (%)	-	1.45	1.87

5.3 Data Interpretation and Conclusion

The results of DG stack 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.

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

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 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			Standard	Night Time		
					Max.	Min.	Leq dB(A) Total		Max.	Min.	Leq dB(A) Total
1	N-1	Oil Jetty 7	A	75	56.1	39.7	48.2	70	44.3	33.5	38.3
2	N-2	West Gate No.1	A	75	62.3	49.3	56.1	70	49.4	42.3	45.5
3	N-3	Canteen Area	B	65	61.2	45.7	53.8	55	44.7	33.2	40.2
4	N-4	Main Gate	A	75	60.3	44.1	53.9	70	48.7	38.6	46
5	N-5	Main Road	A	75	56.9	46.7	51.7	70	46.6	37.4	45.4
6	N-6	Marin Bhavan	B	65	59.8	40.5	52.2	55	49.7	35.2	45.7
7	N-7	Port & Custom Building	B	65	56.8	42.6	50.3	55	47.5	36.9	45.6
8	N-8	Nirman Building	B	65	55.1	42.5	49.1	55	46.8	38.5	45.4
9	N-9	ATM Building	B	65	59.8	42.5	52.6	55	49.7	38.6	45.8
10	N-10	Wharf Area/ Jetty	A	75	61.5	45.8	54.3	70	45.6	37.9	45.3
11	N-11	Near Main Gate	A	75	63.9	54.1	59	70	54.5	44	49.2
12	N-12	Near Vadinar Jetty	A	75	64.4	57.5	60.9	70	55	49.8	52.4
13	N-13	Port Colony Vadinar	C	55	42.6	36.2	39.4	45	38.6	31.3	34.9

6.3 Data Interpretation and Conclusion

The noise level at both the locations (Kandla and Vadinar) was compared with the standard limits specified in NAAQS by CPCB. During the Day Time, the average noise level at all 10 locations at Kandla ranged from **39.7 dB(A) to 62.3 dB(A)**, while at Vadinar, he noises levels for the three-location ranged from **36.2 dB(A) to 64.4 dB(A).** Whereas, during Night Time the average Noise Level ranged from **33.2 dB(A) to 49.7 dB(A)** at Kandla and **31.3 dB(A) to 55 dB(A)** at Vadinar. In some locations at the Kandla site, spikes in noise levels were observed due to construction and demolition activities.

6.4 Remedial Measures

Though, 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:

Frequency

Monitoring is required to be carried out once a month for both the locations of Kandla and Vadinar.

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: Locations for Soil Quality Monitoring at Kandla

Map 11: Locations for Soil Quality Monitoring at Vadinar

7.2 Result and Discussion

The analysis results of physical analysis of the soil samples collected during environmental monitoring mentioned in **Table 19** are shown below:

Table 19: Soil Quality for the sampling period

Sr. No	Location / Parameters	Unit	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	-	8.41	8.36	9.1	8.52	8.09	7.93
2	Conductivity	µS/cm	11270	14052	221	14560	639	202
3	Inorganic Phosphate	Kg/ha	1.21	1.11	0.42	0.58	0.83	0.91
4	Organic Carbon	%	0.24	0.34	0.06	0.15	0.88	0.23
5	Organic Matter	%	0.37	0.68	0.08	0.27	1.52	0.39
6	SAR	meq/L	2.21	1.8	1.24	1.87	0.28	0.18
7	Aluminium	mg/Kg	7286.3	6076.32	5681.12	2856.3	21794.11	23212.33
8	Chromium	mg/Kg	74.45	72.31	104.6	45.36	73.27	76.89
9	Nickel	mg/Kg	34.26	30.63	32.42	16.3	35.55	29.33
10	Copper	mg/Kg	21.63	33.19	118.63	12.13	105.1	100.12
11	Zinc	mg/Kg	54.22	60.41	66.95	24.72	51.22	54.92
12	Cadmium	mg/Kg	BQL	BQL	BQL	BQL	BQL	BQL
13	Lead	mg/Kg	5.14	7.65	3.25	4.65	BQL	BQL
14	Arsenic	mg/Kg	6.67	6.98	BQL	4.09	BQL	0.08
15	Mercury	mg/Kg	BQL	BQL	BQL	BQL	BQL	BQL
16	Water Holding Capacity	%	68	59.36	55.61	51.91	32	20
17	Sand	%	26.36	36.47	82.36	67.56	84.24	94.24
18	Silt	%	59.14	67.63	18.16	32.18	14.72	4.72
19	Clay	%	27.61	6.82	7.52	6.62	1.04	1.04
20	Texture	-	slit sandy	Sandy loam	sandy loam	Loam	Loamy sand	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:

- The value of **pH** ranges from **8.36 to 9.10,** highest at location S-3 (Khori Creek) and lowest at S-2 (IFFCO Plant) while the average pH for Kandla was observed to be **8.597**.

Whereas, at Vadinar the pH value observed at S-5 i.e., **Near SPM (8.09)** and at S-6 i.e., **Near Jetty Area (7.93).** As per the observation the pH was found to be **moderately to strongly alkaline** both the monitoring station of Kandla and Vadinar**.**

- At entire monitoring locations of Kandla the value of **Electrical Conductivity** ranges from **221-14560 µs/cm**, highest at location S-4 (Nakti Creek) with the average as 10025.75 **µs/cm**. Whereas, at Vadinar the range of conductivity was between the range of **202 to 639 µs/cm** with an average value of 420.5 **µs/cm**.

- At Kandla, the concentration of **Inorganic Phosphate** varied from **0.42-1.21 Kg/ha**, with average **0.83 Kg/ha**. Whereas, at the locations of Vadinar, the Inorganic Phosphate was observed at S-5 i.e., Near SPM (**0.83 Kg/ha**) and detected at S-6 i.e., near Jetty Area (**0.91 Kg/ha**). The phosphorus availability in soil solution is influenced by a number of factors such as Organic matter, clay content, pH, temperature, etc.

- The concentration of **Total Organic Carbon** ranges from **0.06 to 0.34** % while the average TOC at Kandla was detected as **0.197 %.** Whereas, at Vadinar the average TOC was found to be **0.55**% where the observed TOC value found at S-5 i.e. Near SPM (**0.88**%) and S-6 i.e. near Jetty Area to be **0.23** % respectively.

- The concentration of **Water Holding Capacity** in the soil samples of Kandla and Vadinar varies from **51.91-68** % and **20-32** % respectively.

- The concentration of **Sodium Adsorption Ratio** ranges from **1.24–2.21 meq/L** with an average value **1.78 meq/L** at Kandla. Whereas, at Vadinar, the concentration of Sodium Adsorption Ratio ranges from 0.18 to 0.28 **meq/L** with an average SAR was found to be **0.23 meq/L**. A component of conductivity is the SAR. A high SAR indicates a large concentration of sodium ions in the soil, which raises conductivity.

Sandy loam, loa, and silt sandy were the soil textures observed at all the monitoring locations of Kandla and Vadinar.

Heavy Metals

For the sampling period, the concentration of **Aluminium** varied from **2856.30 to 7286.30 mg/kg** at Kandla and **21794.11 to 23212.33 mg/kg** at Vadinar and the average value was observed to be **5475.01 and 22503.22 mg/kg** at Kandla and Vadinar monitoring station, respectively.

- The concentration of **Chromium** varied from **45.32 to 104.6 mg/kg** at Kandla and **73.27 to 76.89 mg/kg** at Vadinar and the average value was observed to be **74.18 and 75.08 mg/kg** at Kandla and Vadinar monitoring station, respectively.

- The concentration of **Nickel** varied from 16.3 **to 34.26 mg/kg** at Kandla and **29.33 to 35.55 mg/kg** at Vadinar and the average value was observed to be **28.40 and 32.44 mg/kg** at Kandla and Vadinar monitoring station, respectively.

- The concentration of **Zinc** varied from **24.72 to 66.95 mg/kg** at Kandla and **51.22 to 54.92 mg/kg** at Vadinar and the average value was observed to be **51.57 and 53.07 mg/kg** at Kandla and Vadinar monitoring station, respectively

- The concentration of **copper** varied from **12.13 to 118.63 mg/kg** at Kandla and **100.12 to 105.1 mg/kg** at Vadinar and the average value was observed to be **46.39 and 102.61 mg/kg** at Kandla and Vadinar monitoring station, respectively.

- The concentration of **Arsenic** varied from 4.09 **to 6.98 mg/kg** at Kandla and the average value was observed to be **5.913** at Kandla while at Vadinar the average value was observed to be **0.08**

- The concentration of **Lead** varied from **3.25 to 7.65 mg/kg** at Kandla and the average value was observed to be **5.172** at Kandla while at Vadinar the average value was observed to be **BQL**.

- While other heavy metals in the Soil i.e., **Mercury, Cadmium** were observed "Below Quantification Limit" for majority of the soil samples collected at Kandla and Vadinar.

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 DW-2 location was replaced by Shramdeep due to demolition of past sampling location (port & custom building)

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	Shramdeep	23.009631N, 70.220877E
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: Locations for Drinking Water Monitoring at Kandla

Map 13: Locations for Drinking Water Monitoring at Vadinar

Methodology

The water samples were collected from the finalized sampling locations and analysed 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

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

Sr. No.	Parameters	Units	Reference method	Instrument
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
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

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) have been summarized in **Table 22** as follows:

Table 22: Summarized results of Drinking Water quality

Sr. No.	Parameters	Units	Standard values as per IS		Kandla																	Vadinar	
			A	P	DW-1	DW-2	DW-3	DW-4	DW-5	DW-6	DW-7	DW-8	DW-9	DW-10	DW-11	DW-12	DW-13	DW-14	DW-15	DW-16	DW-17	DW-18	DW-19	DW-20
1.	pH	-	**6.5-8.5**	**-**	7.52	7.85	7.43	7.74	7.51	7.22	7.21	7.45	7.13	7.01	7.11	7.14	7.25	7.42	6.85	7.32	7.41	7.22	7.02	7.26
2.	Colour	Hazen	**5**	**15**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3.	EC	µS/ cm	**-**	**-**	256	25.6	35.2	31.2	45.8	74.2	30.1	32.3	81.4	122.5	147.5	120.9	56.8	48.2	120	15.6	27.7	98.7	256	100.2
4.	Salinity	PSU	**-**	**-**	0.18	0.07	0.02	0.04	0.01	0.06	0.04	0.05	0.06	0.04	0.09	0.07	0.04	0.01	0.07	0.02	0.03	0.04	0.18	0.03
5.	Turbidity	NTU	**1**	**5**	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
6.	Chloride	mg/L	**250**	**1000**	51.23	4.58	12.65	18.51	9.74	16.23	7.52	10.22	26.35	30.25	41.56	25.62	19.19	14.21	38.52	15.24	14.16	26.72	45.26	18.25
7.	Total Hardness	mg/L	**200**	**600**	8	BQL	6	5.5	7	9	2	3.5	5	15	13	20	3.5	2.5	16	BQL	1.5	7	155	50
8.	Ca Hardness	mg/L	**-**	**-**	3	BQL	4	2	4.5	6	1.5	2	3	10	7	12	2	2	9	BQL	1	4	72	15
9.	Mg Hardness	mg/L	**-**	**-**	5	BQL	2	3.5	2.5	3	BQL	1.5	2	5	6	8	1.5	BQL	7	BQL	BQL	3	75	15
10.	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
11.	TDS	mg/L	**500**	**2000**	122	10	18	20	25	36	17	19	35	55	96	55	32	35	82	19	25	51	150	42
12.	TSS	mg/L	**-**	**-**	BQL	BQL	3	BQL	BQL	BQL	BQL	2	BQL	BQL	2	BQL	BQL	4	BQL	BQL	1	BQL	BQL	BQL
13.	Fluoride	mg/L	**1.0**	**1.5**	0.231	BQL	0.42	BQL	0.56	0.212	0.316	BQL	0.398	0.35	0.31	0.299	0.254	0.244	0.412	0.42	0.202	0.314	0.541	0.158
14.	Sulphate	mg/L	**200**	**400**	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	25.36	BQL
15.	Nitrate	mg/L	**45**	**-**	6.214	BQL	BQL	BQL	BQL	BQL	BQL	BQL	1.245	BQL	BQL	BQL	1.01	BQL	BQL	BQL	BQL	BQL	1.236	BQL
16.	Nitrite	mg/L	**-**	**-**	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
17.	Sodium	mg/L	**-**	**-**	30.21	BQL	1.23	4.25	1.52	1.21	1.2	2.01	3.02	3.58	3.98	5.12	3.25	2.36	8.51	1.01	1.21	2.65	15.24	BQL

Sr. No.	Parameters	Units	Standard values as per IS		Kandla																	Vadinar	
			A	P	DW-1	DW-2	DW-3	DW-4	DW-5	DW-6	DW-7	DW-8	DW-9	DW-10	DW-11	DW-12	DW-13	DW-14	DW-15	DW-16	DW-17	DW-18	DW-19	DW-20
18.	Potassium	mg/L	-	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
19.	Hexavalent Chromium	mg/L	-	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
20.	Odour	TON	Agreeable		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21.	Arsenic	mg/L	0.01	0.05	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
22.	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
23.	Copper	mg/L	0.05	1.5	BQL	BQL	0.010	BQL	0.004	BQL	BQL	BQL	0.003	0.010	0.003	0.015	BQL	BQL	BQL	BQL	BQL	BQL	BQL	0.008
24.	Iron	mg/L	0.3	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
25.	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
26.	Manganese	mg/L	0.1	0.3	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
27.	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
28.	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
29.	Zinc	mg/L	5	15	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
30.	Total Coliform*	MPN/ 100ml	Shall not be detected		50	10	30	BQL	BQL	80	BQL	50	BQL	BQL	15	BQL	BQL	BQL	BQL	23	BQL	BQL	BQL	20

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)

AQL: Above Quantification Limit; Total Coliforms (QL=1000000)

*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 at 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.

- **pH:** The pH values of drinking water samples in Kandla were reported to be in the range of **6.85 to 7.85** with an average pH of **7.32.** In Vadinar, its values ranged from **7.02 to 7.26,** with an average pH of **7.14.** remarkably, the pH values at project locations are within the permissible range of 6.5 to 8.5 specified under IS: 10500:2012.
- **Colour:** The value of Color in Drinking water sample at Kandla is found to be **1 Hazen** in each sample. In Vadinar the Color value is found to be **1 Hazen** in both the locations.
- **Turbidity:** At the drinking water locations of Kandla & Vadinar, the turbidity was reported **BQL** for All the monitoring location.
- **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 10 **to 122 mg/L,** with an average concentration of **41.77 mg/L**. while in Vadinar, it ranged from **42 to 150 mg/L,** with average at **96 mg/L.**

  It is important to note that the TDS concentrations in both Kandla and Vadinar fall well within the acceptable limit of 500 mg/L.
- **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 **15.6 to 256 µS/cm**, with an average value of **76.09 µS/cm**. In Vadinar, the EC values showed variation from **100.2 to 256 µS/cm,** with an average value of **178.10 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.
- **Chlorides:** The concentrations in the drinking water samples collected from Kandla and Vadinar were within acceptable limits, as specified by the BIS. The chloride in Kandla varied from 4.58 **to 51.23 mg/L**, with an average value of **21.25 mg/L**. In Vadinar, it ranged from **18.25 to 45.26 mg/L**, with an average value of **31.76 mg/L.** It's important to note that all the recorded chloride concentrations in both Kandla and Vadinar were well below the acceptable limit of 250 mg/L.
- **Total Hardness (TH):** Total Hardness varied from **1.5 to 20 mg/L**, with the average value as **7.78 mg/L**. While at Vadinar, the variation was observed from **50 to 155 mg/L**; with the average concentration of 102.50 **mg/L**. It's important to note that all the recorded chloride concentrations in both Kandla and Vadinar were well below the acceptable limit of 200 mg/L.
- **Sulphate:** 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. In Kandla, the sulphate concentrations Was found to be **Below Quantification Limit** at all Monitoring locations. In Vadinar, the sulphate

concentration was observed at DW-19 is **25.36 mg/L &** DW-20 is **Below Quantification Limit.**

- **Sodium:** During the monitoring period, at Kandla variation in the concentration of sulphate was observed to be in the range of **1.01 to 30.21 mg/L**, with the average concentration of **4.48 mg/L**. While at Vadinar, the Sodium concentration was Observed to be in range of **BQL to 15.24 mg/L**, with the average Concentration of **15.24 mg/L.**
- **Nitrate:** During the monitoring period, at Kandla & Vadinar variation in the concentration of Nitrate was observed to be in the range of **1.01 to 6.21 mg/L**, with the average concentration of **2.82 mg/L** also majority of the location recorded as "**BQL".** While at Vadinar, the concentration was observed at DW-19 is **1.23 mg/L &** DW-20 is **Below Quantification Limit.**
- **Fluoride:** The concentration was found to be in the range of **0.20 to 0.56** mg**/L** with an average concentration of **0.32 mg/L** at all the monitoring location at Kandla. While at Vadinar the concentration was found to be in the range of **0.15 to 0.54 mg/L** with an average concentration of **0.35 mg/L** for both the monitoring location.
- **Nitrite:** The Concentration was found to be **BQL** in all the monitoring location at Kandla. While at Vadinar its value also reported to be BQL for both the Monitoring location.
- **Iron:** The Concentration was found to be **BQL** in all of the monitoring location for location at Kandla While at Vadinar, the Concentration recorded as Below Quantification Limit.
- **Copper:** During the monitoring period, at Kandla variation in the concentration of copper was observed to be in the range of **0.003 to 0.015 mg/L**, with the average concentration of **0.007 mg/L**. While at Vadinar, the concentration was observed at DW-19 is **Below Quantification limit &** DW-20 is **0.008**
- **TSS:** The Concentration was found to be **BQL** in most of the monitoring location except for location DW-3 (North Gate) i.e. 3 mg/L, DW-8 (Nirman Building) i.e. 2 mg/L and DW-11 (Wharf Jetty Area) i.e. 2 mg/L and more locations at Kandla. While at Vadinar, the Concentration was observed at DW-19 & DW-20 is **Below Quantification limit.**
- **Free Residual Chlorine:** The Concentration was found to be **BQL** in all of the monitoring location at Kandla While at Vadinar, the Concentration recorded at both location is found Below Quantification Limit.
- **Lead:** The Concentration was found to be **BQL** in all of the monitoring location at Kandla. While at Vadinar, the Concentration recorded as Below Quantification Limit at all the Monitoring locations.
- **Potassium:** The Concentration was found to be **BQL** in all of the monitoring location at Kandla While at Vadinar, the Concentration was found to be BQL in both Location.
- **Manganese:** The Concentration was found to be **BQL** in all of the monitoring location at Kandla While at Vadinar, the Concentration was found to be BQL in both Location.
- **Zinc:** The Concentration was found to be **BQL** in all of the monitoring location at Kandla While at Vadinar, the Concentration was found to be BQL in both Location.

- **Arsenic:** The concentration was found to be **Below Quantification Limit** in all of the Monitoring Location at Kandla. While at Vadinar was Observed **Below Quantification Limit** at both the locations.
- The parameters such **as Hexavalent Chromium**, and **the metals like Cadmium, Total Chromium** were all observed to have concentrations "Below the Quantification Limit (BQL)" at majority of the locations during the monitoring period.
- **Total Coliforms:** During the monitoring period, at Kandla variation in the concentration of Total coliform was observed to be in the range of **BQL to 80 MPN/100ml**. While at Vadinar, the concentration recorded at DW-19 is **Below Quantification Limit** and at DW-20 is **20 MPN/100ml.**

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, 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 23** as follows:

Table 23: 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 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 24: Treated effluent Standards (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:

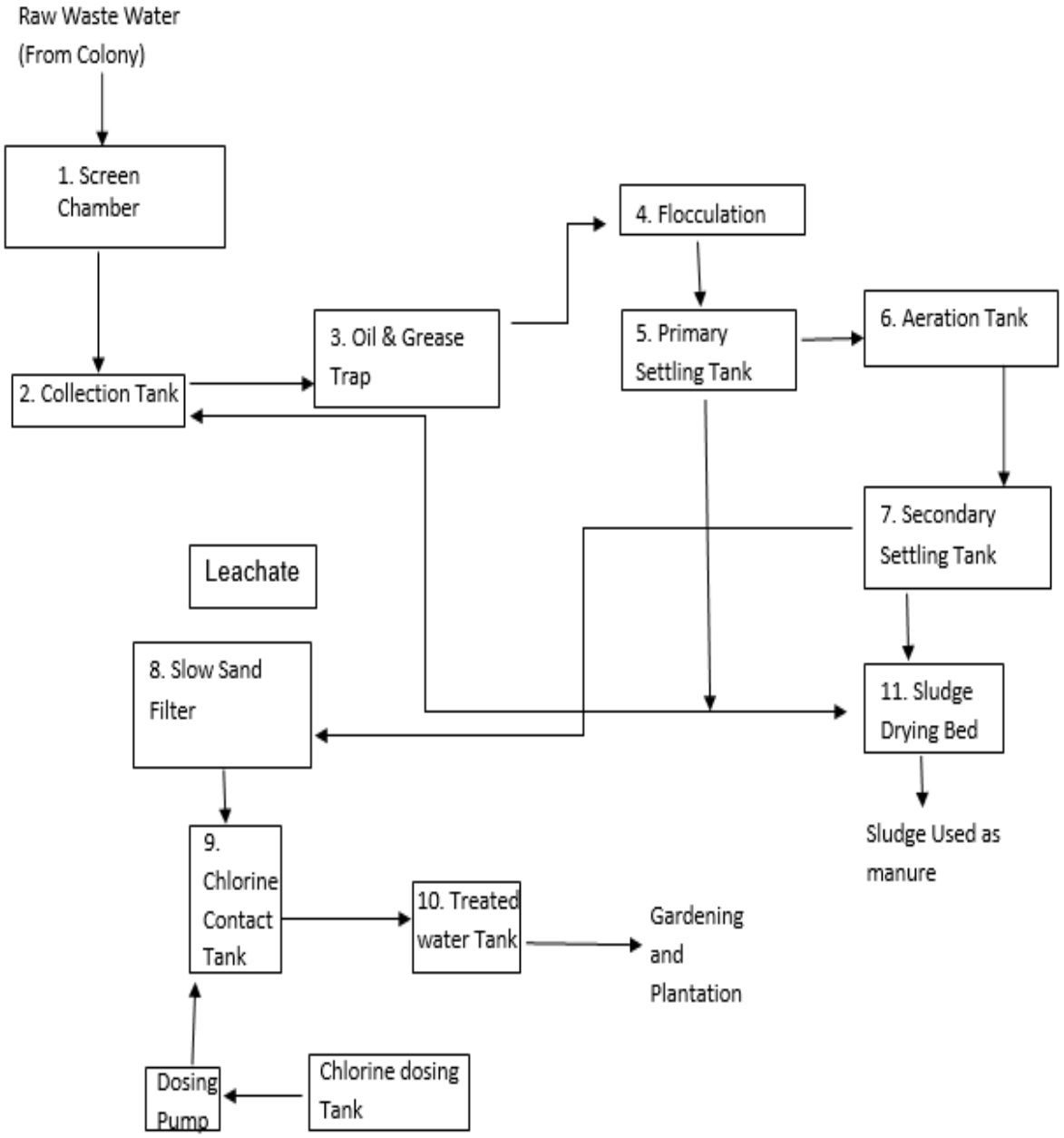


Figure 3: Process flow diagram of STP at Kandla

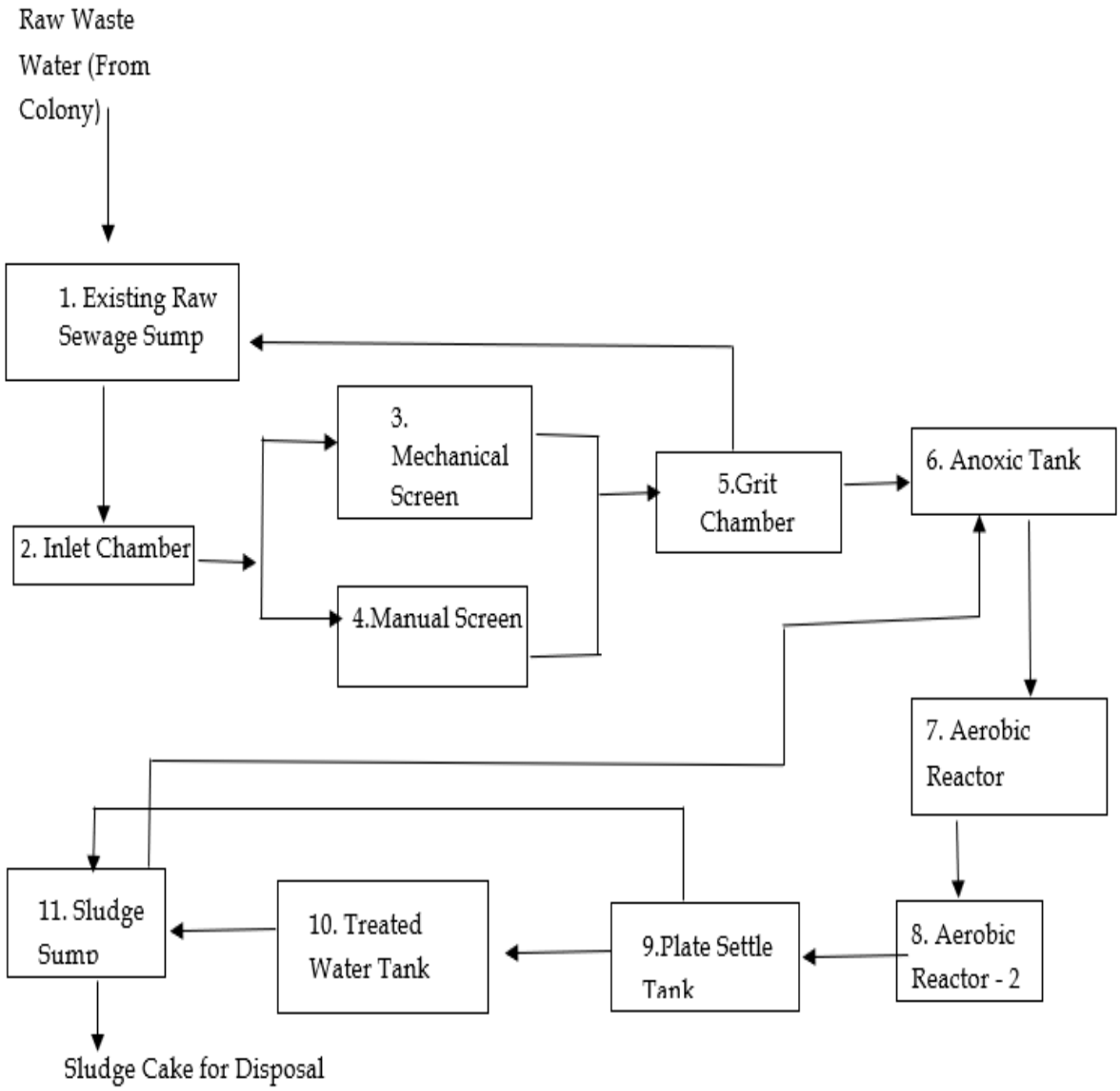


Figure 4: Process flow diagram of STP at Gopalpuri

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 25**. 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 25: 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
5.	COD	50 mg/L

The detailed process flow diagram of the Vadinar STP have been mentioned in **Figure 5** as follows:

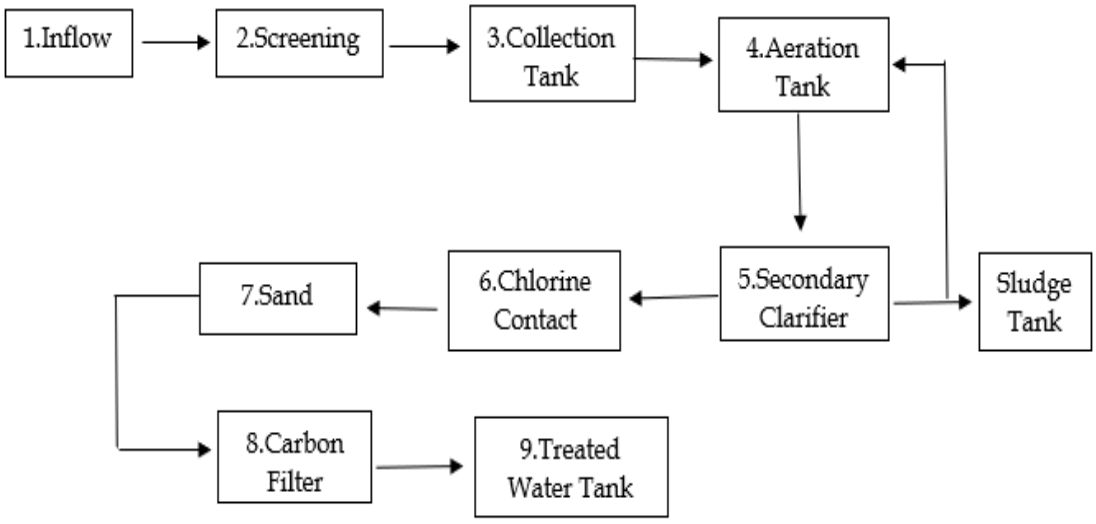
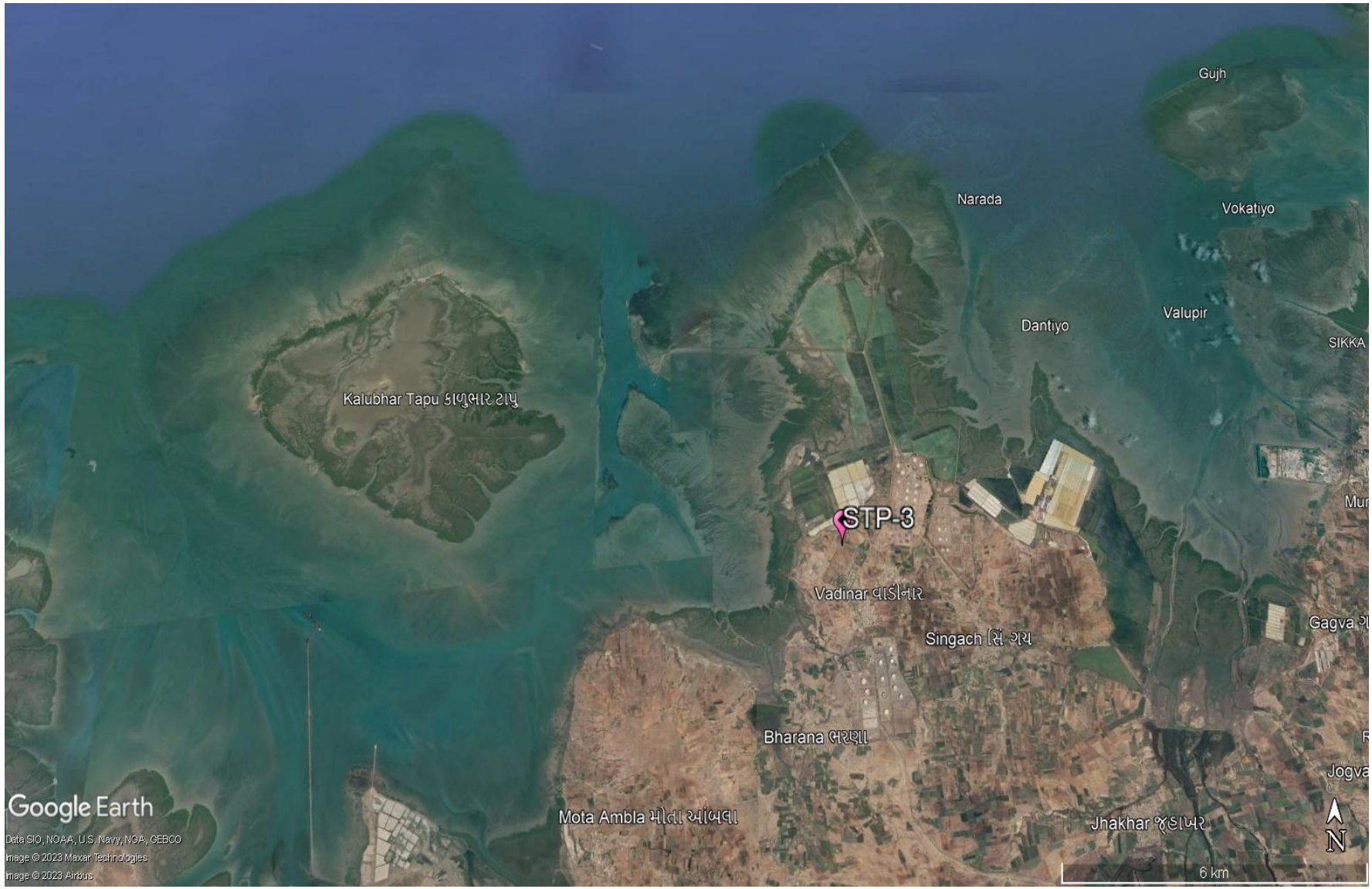


Figure 5: Process flowchart for the STP at Vadinar

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: Locations for STP Monitoring at Kandla



Map 15: Locations for STP Monitoring 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:

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.

Table 26: 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 27 & 28**. Further it was compared with the standard norms specified in the CC&A of the respective STPs.

Table 27: Water Quality of inlet and outlet of STP of Kandla

Sr No.	Parameter	Units	GPCB Norms (Kandla)	Kandla															
				Week 3 of September				Week 4 of September				Week 1 of October				Week 2 of October			
				STP-1 (Inlet)	STP-1 (Outlet)	STP-2 (Inlet)	STP-2 (Outlet)	STP-1 (Inlet)	STP-1 (Outlet)	STP-2 (Inlet)	STP-2 (Outlet)	STP-1 (Inlet)	STP-1 (Outlet)	STP-2 (Inlet)	STP-2 (Outlet)	STP-1 (Inlet)	STP-1 (Outlet)	STP-2 (Inlet)	STP-2 (Outlet)
1.	pH	-	**6.5-8.5**	7.45	7.12	7.01	7.12	7.22	7.06	7.57	7.61	7.55	7.32	7.02	7.46	7.35	7.10	7.40	7.23
2.	TDS	mg/L	-	1326	1255	1508	1425	1412	1302	1792	1764	1295	1122	1662	1652	1326	1250	1744	1625
3.	TSS	mg/L	**100**	45	16	44	20	40	25	96	26	70	32	36	14	39	22	38	20
4.	COD	mg/L	-	112	45.0	115.2	28.8	155	101	174.8	61.0	101.3	42.6	72.6	40.3	120.0	70.0	133.6	36.4
5.	DO	mg/L	-	BQL	3.2	BQL	4.9	BQL	2.5	BQL	6.1	BQL	4.2	BQL	8.8	BQL	3.1	BQL	8.6
6.	BOD	mg/L	**30**	26.34	19.4	17.28	3.60	22.33	11.2	26.22	7.62	40.25	16.32	14.52	5.04	30.12	11.56	25.05	4.55
7.	SAR	meq/L	-	12.24	4.55	6.35	5.85	6.22	3.21	7.72	7.03	9.25	6.14	5.58	5.12	7.51	3.01	7.73	7.19
8.	Total Coliforms	MPN/ 100ml	**<1000**	1600	120	1600	BQL	240	23	900	23	1600	220	30	BQL	900	23	23	240

Table 28: Water Quality of inlet and outlet of STP of Vadinar

Sr No.	Parameter	Units	GPCB Norms (Vadinar)	Vadinar							
				Week 3 of September		Week 4 of September		Week 1 of October		Week 2 of October	
				STP-3 (Inlet)	STP-3 (Outlet)	STP-3 (Inlet)	STP-3 (Outlet)	STP-3 (Inlet)	STP-3 (Outlet)	STP-3 (Inlet)	STP-3 (Outlet)
1.	pH	-	**5.5-9**	6.92	6.98	7.50	7.58	7.70	7.60	7.31	7.37
2.	TDS	mg/L	-	384	346	424	362	374	348	412	328
3.	TSS	mg/L	**20**	6	4	20	4	12	2	6	4
4.	COD	mg/L	**50**	82.3	41.2	122.0	36.6	92.7	44.4	93.1	24.3
5.	DO	mg/L	-	2.5	5.6	1.5	6.0	4.8	7.9	2.5	3.2
6.	BOD	mg/L	**10**	15.43	5.14	18.30	4.57	17.39	5.54	13.97	3.04
7.	SAR	meq/L	-	2.52	2.25	1.97	1.82	1.49	1.40	1.87	1.56
8.	Total Coliforms	MPN/100ml	**100-230**	240	23	1600	4	240	2	1600	23

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 **pH** of treated effluent from STPs at Kandla (STP-1 and STP-2) and Vadinar (STP-3) conform to their respective stipulated norms of **7.06 to 7.61** at Kandla and **6.98 to 7.60** at Vadinar respectively.
- The **TDS** of treated sewage at Kandla was ranges from **1122 to 1764 mg/L**, whereas for Vadinar it ranges from **328 to 362 mg/L**.
- The **TSS** of the Treated effluent for the STP-1 and STP-2 at Kandla and STP-3 at Vadinar falls within the stipulated norms of 14 **to 32 mg/L and 2 to 4 mg/L** respectively as mentioned in their respective CCA.
- **COD** value for Kandla was observed in the range of **28.80 to 101 mg/L**. Whereas for Vadinar the value of COD falls within the range of **24.30 to 44.40 mg/L**.
- The value of **DO** was observed in the range of **2.50 to 8.80 mg/L** at Kandla, whereas for Vadinar it was observed in the range of **3.20 to 7.90 mg/L.**
- The **BOD** of the outlet for the STPs of Kandla and Vadinar falls within the stipulated norms.
- The value of **SAR** for Kandla was observed in the range of **3.01 to 7.19 meq/L**, whereas for Vadinar, it was observed in the range of **1.40 to 2.25 meq/L**.
- The value of **Total Coliforms** for Kandla was observed in the range of **23 to 240 MPN/100 ml**, whereas for Vadinar, it was observed in the range of **2 to 23 MPN/100 ml**.

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 29:**

Table 29: 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: Locations for Marine Water Monitoring at Kandla

Map 17: Locations for Marine Water Monitoring 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 30** along with the analysis method and instrument.

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).

Table 30: 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	

Sr. No	Parameters	Units	Reference method	Instrument
16.	Nitrite	mg/L	APHA, 23rd Edition, 4500 NO2- B: 2017	
17.	Sodium	mg/L	APHA, 23rd Edition, 3500 Na-B: 2017	Flame photometer
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 31**. The said water quality has been represented in comparison with the standard values as stipulated by CPCB for Class SW-IV Waters.

Table 31: Results of Analysis of Marine Water Sample for the sampling period

Sr. No.	Parameters	Unit	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
1.	Density	kg/m³	-	1.021	1.022	1.022	1.021	1.023	1.022	1.022	1.021
2.	pH	-	6.5-9.0	7.21	7.45	7.92	7.54	7.50	7.89	7.23	7.65
3.	Color	Hazen	No Noticeable	1	1	1	1	1	1	5	5
4.	EC	µS/cm	-	51,500	52,100	51,200	51,100	51,600	51,000	52,600	53,100
5.	Turbidity	NTU	-	146	160	179	152	101	79	13.25	10.25
6.	TDS	mg/L	-	37,156	37,521	37,125	37,159	37,212	36,247	36,298	34,156
7.	TSS	mg/L	-	256	229	261	215	219	202	250	292
8.	COD	mg/L	-	38.5	59.3	42.5	35.0	65.8	53.6	62.45	45.21
9.	DO	mg/L	3.0 mg/L	7.2	6.5	7.3	6.8	6.3	6.8	7.9	6.5
10.	BOD	mg/L	5.0 mg/L	3.1	3.9	3.5	BQL	BQL	4.2	BQL	BQL
11.	Oil & Grease	mg/L	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
12.	Sulphate	mg/L	-	2545.2	2687.2	2715.36	2456.31	2511.42	2356.8	2685	2945.36
13.	Nitrate	mg/L	-	3.154	3.358	3.658	3.314	3.111	3.251	1.625	1.248
14.	Nitrite	mg/L	-	BQL	BQL	0.195	BQL	BQL	BQL	BQL	BQL
15.	Phosphate	mg/L		BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
16.	Silica	mg/L	-	4.89	4.26	4.31	4.1	3.89	4.16	1.36	1.11
17.	Sodium	mg/L	-	3,621.0	3,815.0	4,329.0	6,258.0	4,936.0	3,947.0	>10000	>10000
18.	Potassium	mg/L	-	136.0	142.0	149.0	202.0	175.0	161.0	498.0	522.00
19.	Hexavalent Chromium	mg/L	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
20.	Odour	-	-	1	1	1	1	1	1	1	1
21.	Arsenic	mg/L	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
22.	Cadmium	mg/L	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
23.	Copper	mg/L	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
24.	Iron	mg/L	-	1.526	1.625	1.322	1.42	1.369	0.612	0.263	BQL
25.	Lead	mg/L	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
26.	Manganese	mg/L	-	0.054	0.075	0.051	0.067	0.040	0.026	BQL	BQL
27.	Total Chromium	mg/L	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
28.	Zinc	mg/L	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
29.	Mercury	mg/L	-	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
30.	Particulate Organic Carbon	mg/L	-	1.56	1.52	1.72	1.35	1.22	0.45	0.05	BQL
31.	Total Coliforms	MPN/ 100ml	500/100 ml	6	12	2	16	8	20	12	20

Sr. No.	Parameters	Unit	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
32.	Floating Material (Oil grease scum, petroleum products)	mg/L	10 mg/L	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 **1.021 to 1.023 kg/m³**, with the average of **1.02 kg/m³.** Whereas for the location of Vadinar, it was observed **1.022 kg/m³** at MW-7 and **1.021 kg/m³** at MW-8, with the average of **1.022 kg/m³**.
- **pH** at Kandla was observed in the range of **7.21 to 7.92,** with the average pH as **7.59**. Whereas for the locations of Vadinar, it was observed in the range of be **7.23 to 7.65**, with the average pH as **7.44**. For the monitoring location of both the study areas, pH was found to comply with the norms of 6.5-8.5.
- **Color** range varied from **1 Hazen** at all the monitoring locations in Kandla, and for Vadinar, it found **5 Hazen** for the both of the location.
- **Electrical conductivity (EC)** was observed in the range of **51,000 to 52,100 µS/cm**, with the average EC as **51,416.67 µS/cm** for the locations of Kandla, whereas for the locations of Vadinar, it was observed in the range of **52,600 to 53,100 µS/cm**, with the average EC as **52,850 µS/cm**.
- For all monitoring locations of Kandla the value of **Turbidity** was observed in the range of **79 to 179 NTU**, with average value of **136.17 NTU**. For Vadinar it ranges from **10.25 to 13.25 NTU**, with average of **11.75 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 **36,247 to 37,521 mg/L**, with an average value of **37,070 mg/L**. Similarly, at Vadinar, the TDS values ranged from **34,156 to 36,298 mg/L**, with an average value of 35,227 **mg/L**.
- **TSS** values in the studied area varied between **202 to 261 mg/L** at Kandla and **250 to 292 mg/L** at Vadinar, with the average value of **230.33 mg/L and 271 mg/L** respectively for Kandla and Vadinar.

- **COD** varied between **35 to 65.8 mg/L** at Kandla and **45.21 to 62.45 mg/L** at Vadinar, with the average value as **49.12 and 53.83 mg/L** respectively for Kandla and Vadinar.
- **DO** level in the studied area varied between **6.3 to 7.3 mg/L** at Kandla and **6.5 to 7.9 mg/L** at Vadinar, with the average value of **6.82 mg/L and 7.20 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 **3.1 to 4.2 mg/L**, with average of **3.68 mg/L** for the location of Kandla and for the locations of Vadinar, it was detected **Below Quantification Limit** for all sampling locations.
- **Sulphate** concentration in the studied area varied between **2356.81 to 2715.36 mg/L** at Kandla and **2685 to 2945.36 mg/L** at Vadinar. The average value observed at Kandla was **2545.39 mg/L**, whereas **2815.18 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 **3.111 to 3.658 mg/L**, with the average of **3.31 mg/L**. Whereas for the Vadinar, recorded value was observed in the range of **1.248 to 1.625 mg/L**, with the average of **1.437 mg/L.**
- In the study area of Kandla the concentration of **Potassium** varied between **136 to 202 mg/L** and **498 to 522 mg/L** at Vadinar, with the average value as **160.83 mg/L and 510 mg/L** respectively for Kandla and Vadinar.
- **Silica** in the studied area varied between **3.89 to 4.89 mg/L**, with the average of **4.27 mg/L**, at Kandla. Vadinar, observed value was found to be **1.36 mg/L** at location MW-7 and **1.11 mg/L** at MS-8 location.
- **Sodium** in the study area varied between **3621 to 6258 mg/L**, with average of **4484.33 mg/L**, at Kandla whereas at Vadinar the sodium concentration value was detected to be **more than 10,000 mg/L** at both locations.
- **Odour** was observed **1** for all locations of Kandla and Vadinar.
- **Copper** in the study area, was detected **below the quantification limit (BQL)" at** Kandla and whereas Vadinar was detected **below the quantification limit (BQL)"** for the all-sampling location.
- **Iron** in the studied area varied between **0.61 to 1.62 mg/L**, with the average of **1.31 mg/L,** at Kandla, and for Vadinar value were recorded **0.263 mg/L** for location MW-7 and **Below Quantification Limit** for location MW-8.
- **Lead** concentration at Kandla was detected **below the quantification limit (BQL)"** for the all-sampling location. and whereas Vadinar was detected **below the quantification limit (BQL)"** for the all-sampling location.
- **Manganese** in the studied area varied between **0.026 to 0.075 mg/L**, with the average of 0.052 mg/L, at Kandla and whereas Vadinar was detected **below the quantification limit (BQL)"** for the all-sampling location.
- **Particulate Organic Carbon** in the study area was observed in the range of **0.45 to 1.72**, with the average value of **1.30**. Whereas for the Vadinar, the value observed was **0.05** at MW-7 and **Below Quantification Limit** at MW-8.

- **Oil & Grease, Nitrite, Phosphate, Hexavalent Chromium, Arsenic, 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.
- **Total Coliforms** were detected complying with the specified norm of 500 MPN/100ml for all the locations of Kandla and Vadinar.

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).

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 32** as follows:

Table 32: 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: Location of Marine Sediment Monitoring at Kandla

Map 19: Locations of Marine Sediment Monitoring at Vadinar

The list of parameters to be monitored under the projects for the Marine Sediment sampling been mentioned in **Table 33** as follows:

Table 33: 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 has been summarized in the **Table 34.**

Table 34: Summarized result of Marine Sediment Quality

Sr No.	Parameters	Unit	Kandla						Vadinar	
			MS-1	MS-2	MS-3	MS-4	MS-5	MS-6	MS-7	MS-8
1.	Inorganic Phosphate	kg/ ha	1.12	4.62	2.36	1.52	1.02	0.96	0.82	0.56
2.	Phosphate	mg/Kg	362.21	522.31	426.31	316.24	222.31	212.23	396.25	301.45
3.	Organic Matter	%	1.21	1.56	1.42	1.02	1.40	1.18	1.55	1.82
4.	Sulphate as SO^{4-}	mg/Kg	296.43	112.43	120.13	90.34	101.43	95.34	128.66	138.21
5.	Calcium as Ca	mg/Kg	4000.00	1900.00	2500.00	1500.00	2000.00	1600.00	2500.00	1800.00
6.	Magnesium as Mg	mg/Kg	812.00	955.00	1450.00	721.00	1012.00	850.00	956.00	1125.00
7.	Silica	g/Kg	402.31	333.21	182.43	320.13	309.47	412.43	196.32	250.24
8.	Nitrite	mg/Kg	1.2	1.1	1.21	1.05	1.02	1.09	0.52	0.31
9.	Nitrate	mg/Kg	5.84	5.31	4.21	5.36	6.12	5.98	16.25	10.58
10.	Sodium	mg/Kg	2851	2316	2746	2164	2946	3526	7458	8569
11.	Potassium	mg/Kg	1924	1854	1955	2201	2415	2954	1524	2958
12.	Copper	mg/Kg	40.21	43.28	46.36	35.26	41.6	30.29	18.54	23.12
13.	Aluminium	mg/Kg	34287.4	36245	38645.1	26431.2	35246.5	30258.6	15236.2	26158.4
14.	Chromium	mg/Kg	70.46	76.43	72.16	73.54	65.13	56.43	36.58	40.25
15.	Nickel	mg/Kg	30.21	26.35	25.42	23.65	31.27	22.51	21.36	32.59
16.	Zinc	mg/Kg	103.63	185.24	156.27	112.25	90.22	81.26	19.22	40.32
17.	Cadmium	mg/Kg	BQL	BQL	BQL	0.62	BQL	BQL	0.09	BQL
18.	Lead	mg/Kg	7.65	11.23	20.65	14.25	10.61	7.25	4.21	9.25
19.	Arsenic	mg/Kg	5.32	4.21	7.25	8.26	5.29	4.21	2.91	4.17
20.	Mercury	mg/Kg	BQL	BQL	BQL	BQL	BQL	BQL	BQL	BQL
21.	Texture	-	Silt Loam	Sandy Loam	Silt Loam	Loam	Silt Loam	Silt Loam	Sandy 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 2024. The detailed interpretation of the parameters is given below:

- **Inorganic Phosphate** for the sampling period was observed in range of **0.96 to 4.62** Kg/ha for Kandla. Whereas for Vadinar the value observed at location MS-7 (Nakti creek) is 0.82 Kg/ha and MS-8 (Near Vadinar Jetty) is 0.56 Kg/ha. For Kandla and Vadinar the average value of Inorganic Phosphate was observed 1.93 and 0.69 Kg/ha respectively.
- The concentration of **Phosphate** was observed in range of **212.23 to 522.31 mg/Kg** for Kandla and for Vadinar the value observed at location MS-7 (Nakti creek) as 396.25 mg/Kg and MS-8 (Near Vadinar Jetty) as 301.45 mg/Kg. For Kandla and Vadinar the average concentration of Phosphate was observed 343.60 and 348.85 mg/Kg respectively.

- The **Organic Matter** for the sampling period was observed in the range of 1.02 **to 1.56**% for Kandla with the average value of 1.30% and for Vadinar the value recorded at location MS-7 and MS-8 was observed 1.55% & 1.82% respectively, with average concentration as 1.69 %.
- The concentration of **Sulphate** was observed in the range of **90.34 to 296.43 mg/Kg** for Kandla and for Vadinar the value observed at MS-7 is 128.66 mg/Kg and at MS-8 is 138.21 mg/Kg. For Kandla and Vadinar the average value of Sulphate was observed 136.02 and 133.44 mg/Kg respectively.
- The value of **Calcium** was observed in the range of **1500 to 4000 mg/Kg** for Kandla and for Vadinar the value observed at MS-7 is 2500 mg/Kg and at MS-8, is 1800 mg/Kg. The average value of Calcium for the monitoring period was observed 2250.00 mg/Kg and 2150 mg/Kg at Kandla and Vadinar, respectively.
- The value of **Magnesium** for the sampling period was observed in the range of **721 to 1450 mg/Kg** for Kandla and for Vadinar the value observed at MS-7 is 956 mg/Kg and at MS-8, is 1125 mg/Kg. For Kandla and Vadinar the average value of Magnesium was observed 966.67 mg/Kg and 1040.50 mg/Kg respectively.
- For the sampling period **Silica** was observed in the range of **182.43 to 412.23 mg/Kg** for Kandla with average value 326.66 mg/Kg and for Vadinar the value observed to be 196.32 and 250.24 mg/Kg at MS-7 and MS-8, respectively with average 223.28 mg/Kg.
- The value of **Nitrate** was observed in the range of **4.21 to 6.12 mg/Kg** for Kandla with average value 5.47 mg/Kg and for Vadinar the value observed to be 16.25 and 10.58 mg/Kg at MS-7 and MS-8, respectively with average 13.42 mg/Kg.
- The value of **Nitrite** was observed in the range of **1.02 to 1.21 mg/Kg** for Kandla with average value 1.11 mg/Kg and for Vadinar the value observed to be 0.52 and 0.31 mg/Kg at MS-7 and MS-8, respectively with average 0.42 mg/Kg.
- The value of **Sodium** was observed in the range of 2164 **to 3526 mg/Kg** for Kandla with average value 2758.17 mg/Kg and for Vadinar the value observed to be 7458 and 8569 mg/Kg at MS-7 and MS-8, respectively with average 8013.50 mg/Kg.
- The value of **Potassium** was observed in the range of **1854 to 2954 mg/Kg** for Kandla with average value 2217.17 mg/Kg and for Vadinar the value observed to be 1542 and 2958 mg/Kg at MS-7 and MS-8, respectively with average 2241 mg/Kg.
- The value of **Aluminium**, was observed in the range of **26431.2 to 38645.1 mg/Kg** for Kandla with average value 33518.97 mg/Kg and for Vadinar the value observed to be 15236.2 and 26158.4 mg/Kg at MS-7 and MS-8, respectively with average 20697.30 mg/Kg.
- The value of **Mercury** was observed "Below the Quantification Limit" at all the eight-monitoring location of Kandla and Vadinar.
- Texture was observed to be "**Sandy Loam**" and "Slit Loam" at location MS-1, MS-2, MS-3, MS-4, MS-5, MS-6 in Kandla. "**Sandy Loam**" at location MS-7 & "**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 35.**

Table 35: 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 36: Comparison of Heavy metals with Standard value in Marine Sediment

Sr. No.	Parameters	Unit	Kandla						Vadinar	
			MS-1	MS-2	MS-3	MS-4	MS-5	MS-6	MS-7	MS-8
1.	Arsenic	mg/Kg	5.32	4.21	7.25	8.26	5.29	4.21	2.91	4.17
2.	Copper	mg/Kg	40.21	43.28	46.36	35.26	41.6	30.29	18.54	23.12
3.	Chromium	mg/Kg	70.46	76.43	72.16	73.54	65.13	56.43	36.58	40.25
4.	Nickel	mg/Kg	30.21	26.35	25.42	23.65	31.27	22.51	21.36	32.59
5.	Lead	mg/Kg	7.65	11.23	20.65	14.25	10.61	7.25	4.21	9.25
6.	Zinc	mg/Kg	103.63	185.24	156.27	112.25	90.22	81.26	19.22	40.32
7.	Cadmium	mg/Kg	BQL	BQL	BQL	0.62	BQL	BQL	0.09	BQL

- **Arsenic** was observed in the range of **4.21 to 8.26 mg/Kg** for Kandla with average value 5.76 mg/Kg and for Vadinar the value observed to be 2.91 and 4.17 mg/Kg at MS-7 and MS-8, respectively with average 3.54 mg/Kg. With reference to the guidelines mentioned in table 35, the sediment quality with respect to arsenic falls in moderately polluted class.
- **Copper** was observed in the range of **30.29 to 46.36 mg/Kg** for Kandla with average value 39.50 mg/Kg and for Vadinar the value observed to be 18.54 and 23.12 mg/Kg at MS-7 and MS-8, respectively with average 20.83 mg/Kg. With reference to the guidelines mentioned in table 35, the sediment quality with respect to copper falls in Moderately polluted class.
- **Chromium** was observed in the range of 56.43 **to 76.43 mg/Kg** for Kandla with average Value 69.03 mg/Kg and for Vadinar the value observed to be 36.58 and 40.25 mg/Kg at MS-7 and MS-8, respectively with average 38.42 mg/Kg. With reference to the guidelines mentioned in table 35, the sediment quality with respect to chromium falls under moderately polluted class.

- **Nickel** was observed in the range of **22.51 to 31.27 mg/Kg** for Kandla with average value 26.57 mg/Kg and for Vadinar the value observed to be 21.36 and 32.59 mg/Kg at MS-7 and MS-8, respectively with average 26.98 mg/Kg. With reference to the guidelines mentioned in table 35, the sediment quality with respect to nickel falls in moderately polluted class.
- **Lead** was observed in the range of **7.25 to 20.65 mg/Kg** for Kandla with average value 11.94 mg/Kg and for Vadinar the value observed to be 4.21 and 9.25 mg/Kg at MS-7 and MS-8, respectively with average 6.73 mg/Kg. With reference to the guidelines mentioned in table 35, the sediment quality with respect to lead falls in Not polluted class.
- **Zinc** was observed in the range of **81.26 to 185.24 mg/Kg** for Kandla with average value 121.48 mg/Kg and for Vadinar the value observed to be 19.22 and 40.32 mg/Kg at MS-7 and MS-8, respectively with average 29.77 mg/Kg. With reference to the guidelines mentioned in table 35, the sediment quality with respect to zinc falls in moderately polluted class
- **Cadmium** was observed BQL for all locations at Kandla and Vadinar except MS-7 during sampling period. With reference to the guidelines mentioned in table 35, 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 37** as follows:

Table 37: 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: Locations of Marine Ecological Monitoring at Kandla

Map 21: Locations of Marine Ecological Monitoring at Vadinar

The various parameters to be monitored under the study for Marine Ecological Monitoring are mentioned in **Table 38** as follows:

Table 38: 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.

- **Benthic Organisms Estimation**

Benthic macroinvertebrates are small aquatic animals and the aquatic larval stages of insects. They include dragonfly and stonefly larvae, snails, worms, and beetles. Use of benthic macroinvertebrates has been in vogue as indicator organisms for water quality monitoring since long. Traditional methods of water quality monitoring incorporates mostly monitoring of physicochemical parameters. Benthic macroinvertebrates are

majorly insects that dwell on the floor of water bodies. They are found in all water bodies, as they have a wide range of pollution tolerance among various species. The benthic macro-invertebrate's community structure depends on the exposure to pollution it receives. Benthic macroinvertebrates have been used as indicator organisms to measure the water quality of water bodies across the world. Evaluating the abundance and variety of benthic macroinvertebrates in a waterbody gives us an indication of the biological condition of that waterbody. Generally, waterbodies in healthy biological condition support a wide variety and high number of macroinvertebrate taxa, including many that are intolerant of pollution. Samples yielding only pollution–tolerant species or very little diversity or abundance may indicate a less healthy waterbody. Biological condition is the most comprehensive indicator of waterbody health. When the biology of a waterbody is healthy, the chemical and physical components of the waterbody are also typically in good condition.

- **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:

$$d = \frac{N_{max}}{N_i}$$

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.

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 39.**

Table 39: Values of Biomass, Net Primary Productivity (NPP), Gross Primary Productivity (GPP), Pheophytin and Chlorophyll for Kandla and Vadinar

Sr. No.	Parameters	Unit	Kandla						Vadinar	
			ME-1	ME-2	ME-3	ME-4	ME-5	ME-6	ME-7	ME-8
1.	Biomass	mg/L	212	96	62	135	62	105	95	121
2.	Net Primary Productivity	mg/L/hr	BQL	0.52	BQL	BQL	0.31	BQL	BQL	BQL
3.	Gross Primary Productivity	mg/L/hr	0.25	0.33	0.96	1.23	1.35	0.42	0.75	1.01
4.	Pheophytin	mg/m^3	BQL	1.22	0.82	1.32	1.1	0.55	1.12	1.28
5.	Chlorophyll-a	mg/m^3	3.21	1.22	1.38	1.16	1.2	1.14	1.5	1.65
6.	Particulate Oxidisable Organic Carbon	mg/L	1.53	1.32	0.39	0.8	1.12	0.95	0.62	0.81
7.	Secchi Depth	ft	0.75	0.65	0.42	0.82	0.96	0.72	1.28	1.35

- **Biomass:**
  With reference to the **Table 39**, the concentration of **Biomass** reported from location ME-1 to ME-6 in range between **62 to 212 mg/L** where lowest biomass presents in ME-3 (Near Coal Berth) and highest biomass present in ME-1 (Near Passenger Jetty One) during sampling period. In Vadinar, the value of biomass was observed **95 mg/L** at ME-7 (Near SPM) and **121 mg/L** in 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. The monitoring location of Kandla reported GPP value in range between 0.25 to 1.35 mg/L/ Hr where the highest value recorded for ME-5 and lowest recorded at ME-1 (Near Passenger Jetty One). In Vadinar, the value of GPP was observed 0.7 at ME-7 (Near SPM) and 1.01 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. The Net primary productivity of the monitoring location at Kandla from (ME-1 to ME-6) has been recorded in as **BQL (Below Quantification Limit) except ME-2 and ME-5.** While in Vadinar, the value of **NPP** was observed **BQL (Below Quantification Limit).** at ME-7 (Near SPM) and ME-8 (Near Vadinar Jetty) monitoring station.

- **Pheophytin**
  The level of Pheophytin was detected in the range from **0.55 to 1.32 mg/m^3** where the highest value observed at ME-4 (Khori Creek) and the lowest value observed at ME-1 (Near Passenger Jetty One). While in Vadinar, the value of Pheophytin was observed 1.12 mg/m3 at ME-7 and **1.28 mg/m^3** at ME-8 monitoring station.

- **Chlorophyll-a**

In the sub surface water, the value of Chlorophyll-a reported in range from **1.14 to 3.21 mg/m^3**. The highest value observed at ME-1 (Near Passenger Jetty One) while the lowest value observed at ME-6 (Nakti Creek (near NH - 8A)). In Vadinar, the value of chlorophyll-a was observed **1.50 mg/m^3** at ME-7 (Near SPM) and **1.65 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 **0.39 to 1.53 mg/L** from monitoring location ME-1 to ME-6 at Kandla, whereas for Vadinar, the value of POC observed **0.62 mg/L** at ME-7 (Near SPM) and **0.81 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 **0.42 to 0.96 ft** whereas at Vadinar, the value recorded at ME-7 i.e. Near SPM is **1.28 ft** and in Near Vadinar Jetty is **1.35 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 are mentioned in **Table 40**.

Table 40: Phytoplankton variations in abundance and diversity in sub surface sampling stations

Genera	ME-1	ME-2	ME-3	ME-4	ME-5	ME-6	ME-7	ME-8
Bacillaria sp.	252	-	136	390	290	-	236	145
Biddulphia sp.	-	-	241	121	-	150	-	216
Chaetoceros sp.	145	172	-	-	-	98	210	-
Chlamydomonas sp.	162	-	255	-	-	-	-	187
Cyclotella sp.	147	303	-	-	-	216	-	-
Coscinodiscus sp.	-	165	-	125	100	-	-	-
Ditylum sp	-	-	-	-	190	-	241	-
Fragilaria sp.	-	-	139	-	159	-	-	-
Bacteriastrum sp.	185	-	-	157	142	-	-	256
Pleurosigma sp.	-	265	145	-	-	256	-	-
Navicula sp.	-	-	-	240	-	-	-	230
Merismopedia sp.	192	-	201	-	-	-	125	-
Synedra sp.	-	280	-	189	-	231	153	215
Skeletonema sp.	-	-	-	-	-	-	-	-
Oscillatoria sp.	161	-	-	-	210	156	-	-
Thallassiosira	-	-	-	-	-	-	-	-
Gomphonema sp.	-	116	-	122	-	112	255	-
Density-Units/L	**1244**	**1301**	**1117**	**1344**	**1091**	**1219**	**1220**	**1249**
No. of genera	**7**	**6**	**6**	**7**	**6**	**7**	**6**	**6**

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 14 genera; green algae were represented by 1 genera and filamentous Cynobacteria were represented by 2 genera during the sampling period.

The density of phytoplankton of the sampling stations from ME-1 to ME-6 (Kandla) varying from **1091 to 1301 units/L,** while for Vadinar its density of phytoplankton observed **1220 units/L at ME-7 and 1249 units/L at ME-8.** During the sampling, phytoplankton communities were dominated, *Bacillaria sp., Coscinodiscus sp., Cyclotella sp , Gomphonema sp, in* Kandla, while *Bacillaria sp., Synedra sp., Navicula sp.* in Vadinar.

The details of Species richness Index and Diversity Index in Phytoplankton are mentioned in **Table 41**.

Table 41: Species richness Index and Diversity Index in Phytoplankton

Indices	ME-1	ME-2	ME-3	ME-4	ME-5	ME-6	ME-7	ME-8
Taxa S	7	6	6	7	6	7	6	6
Individuals	1244	1301	1117	1344	1091	1219	1220	1249
Shannon diversity	1.66	1.77	1.67	1.91	1.64	1.87	1.22	1.18
Simpson 1-D	0.85	0.82	0.82	0.83	0.82	0.84	0.82	0.83
Species Evenness	0.85	0.99	0.93	0.98	0.92	0.96	0.68	0.66
Margalef richness	0.84	0.70	0.71	0.83	0.71	0.84	0.70	0.70
Berger-Parker	0.20	0.23	0.23	0.29	0.27	0.21	0.21	0.20
Relative abundance	0.56	0.46	0.54	0.52	0.55	0.57	0.49	0.48

- **Shannon- Wiener's Index (H)** of phytoplankton communities was in the range of **1.64 to 1.91** between selected sampling stations from ME-1 to ME-6 with an average value of **1.75** at Kandla creek and its nearby creeks. While for Vadinar, Shannon Wiener's index of phytoplankton communities recorded to be **1.22** at location ME-7 and **1.18** at ME-8 with an average value of **1.20**. The apportionment of the numbers of individuals among the species observed higher stability at all monitoring location of Kandla.

- **Simpson diversity index (1-D)** of phytoplankton communities was ranged between **0.82 to 0.85** at all sampling stations in the Kandla creek and nearby creeks, with an average of **0.83** Similarly, for Vadinar Simpson diversity index (1-D) of phytoplankton communities was **0.82** at location ME-7 and **0.83** at ME-8 with an average of **0.83**.

- **Margalef's diversity index** (Species Richness) of phytoplankton communities in Kandla and nearby creeks sampling stations was varying from **0.70 to 0.84** with an average of **0.77** during the sampling period. While for Vadinar, Margalef's diversity index (Species Richness) of phytoplankton communities observed **0.70** at ME-7 and **0.70** at ME-8 with an average value of **0.70**

- **Berger-Parker Index (d)** of phytoplankton communities was in the range of **0.20 to 0.29** between selected sampling stations from ME-1 to ME-6 with an average value of **0.24** at Kandla creek and nearby creeks. Berger-Parker Index (d) of phytoplankton communities in the sampling stations of Vadinar, was in the range of **0.20 to 0.21** with an average value of **0.21**. All the monitoring station signifies a low diversity with an even distribution among the different species.

- The **Species Evenness** is observed in the range of **0.85 to 0.99** for all the six-monitoring station of Kandla and for the Vadinar the species evenness is observed **0.68** at location ME-7 & **0.66** at ME-8 location.

- During the sampling period, **Relative Abundance** of phytoplankton communities was in range of **0.46 to 0.57** between selected sampling stations from ME-1 to ME-6 with an average value of **0.53** at Kandla creek and nearby creeks. Whereas for Vadinar the Index

value **0.49** at ME-7 and **0.48** at ME-8 with an average value **0.49**, 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 are mentioned in **Table 42**.

Table 42: Zooplankton variations in abundance and diversity in sub surface sampling stations

Genera	ME-1	ME-2	ME-3	ME-4	ME-5	ME-6	ME-7	ME-8
Acartia sp.	1	2	1	-	1	-	-	1
Acrocalanus	2	-	-	1	-	1	1	-
Amoeba	-	1	1	-	-	1	2	2
Brachionus sp.	2	-	-	-	1	-	-	-
Calanus sp.	1	-	-	1	1	2	-	1
Cladocera sp.	-	2	2	2	1	-	1	1
Cyclopoid sp.	-	-	1	-	-	-	-	1
Copepod larvae	1	1	-	-	-	2	1	-
Diaptomus sp.	-	1	2	-	2	1	1	-
Eucalanus sp.	1	-	-	1	1	-	-	-
Mysis sp.	-	-	1	1	1	-	1	-
Paracalanus sp.	-	1	-	1	-	1	1	1
Density Unit/L	**8**	**8**	**8**	**7**	**8**	**8**	**8**	**7**
No. of genera	**6**	**6**	**6**	**6**	**7**	**6**	**7**	**6**

A total of 12 zooplankton genera were recorded in Kandla and Vadinar during the study period. The zooplankton community was mainly composed of *Acartia sp., Amoeba, Cladocera sp., Copepod larvae, and Diaptomus sp.*, which showed the highest occurrence across stations. From **ME-1 to ME-6** (Kandla), the density of zooplankton ranged between **7 to 8 units/L**. In Vadinar (**ME-7 and ME-8**), the density ranges from **7 to 8 units/L**. At Kandla stations, *Acartia sp., Cladocera sp., Acrolanus sp., Copepod larvae, and Diaptomus sp* were the most frequently observed genera, while *Amoeba, Cladocera sp. and paracalanus sp.* also had strong representation at Vadinar stations.

The details of Species richness Index and Diversity Index in Zooplankton communities are mentioned in **Table 43**.

Table 43: Species richness Index and Diversity Index in Zooplankton

Indices	ME-1	ME-2	ME-3	ME-4	ME-5	ME-6	ME-7	ME-8
Taxa S	6	6	6	6	7	6	7	6
Individuals	8	8	8	7	8	8	8	7
Shannon diversity	1.73	1.73	1.73	1.65	1.91	1.73	1.91	1.65
Simpson (1-D)	0.93	0.93	0.93	0.95	0.96	0.93	0.96	0.95
Species Evenness	0.97	0.97	0.97	0.92	0.98	0.97	0.98	0.92
Margalef	2.4	2.4	2.4	2.57	2.89	2.4	2.89	2.57
Berger-Parker	0.25	0.25	0.25	0.29	0.25	0.25	0.25	0.29
Relative abundance	75	75	75	85.71	87.5	75	87.5	85.71

- **Shannon- Wiener's Index (H)** of zooplankton communities was in the range of **1.65 to 1.91** between selected sampling stations from ME-1 to ME-6 with an average value of **1.74**

at Kandla creek and its nearby creeks. While for Vadinar, Shannon Wiener's index of zooplankton communities recorded to be **1.91** at ME-7 and **1.65** at ME-8 with an average value of 1.78**.** 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)** of zooplankton communities was ranged between **0.93 to 0.96** at all sampling stations in the Kandla creek and nearby creeks, with an average of **0.96.** Similarly, for Vadinar Simpson diversity index (1-D) of zooplankton communities was **0.96** ME-7 and **0.95** at ME-8 with an average of **0.95.**

- **Margalef's diversity index** (Species Richness) of zooplankton communities in Kandla and nearby creeks sampling stations was varying from **2.40 to 2.89** with an average of **2.51** during the sampling period. While for Vadinar, Margalef's diversity index (Species Richness) of zooplankton communities observed **2.89** at ME-7 and **2.57** at ME-8 with an average value of **2.73**.

- **Berger-Parker Index (d)** of zooplankton communities was in the range of **0.25 to 0.29** between selected sampling stations from ME-1 to ME-6 with an average value of **0.256** at Kandla creek and nearby creeks. Berger-Parker Index (d) of zooplankton communities in the sampling stations of Vadinar, was observed **0.25** at ME-7 and **0.29** at ME-8 with an average value of **0.27**. All the monitoring station signifies a low diversity with an even distribution among the different species.

- The **Species Evenness** is observed in the range of **0.92 to 0.98** for all the six-monitoring station of Kandla whereas, for the Vadinar the species evenness was observed **0.98** at ME-7 and **0.92** at ME-8 the locations**,** during the monitoring month.

- During the sampling period, **Relative Abundance** of zooplankton communities was in range of **75 to 87.5** between selected sampling stations from ME-1 to ME-6 with an average value of **78.68** at Kandla creek and nearby creeks. Whereas for Vadinar the Index value **87.5** at ME-7 and **85.7** at ME-8 with an average value **86.61**, 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** are mentioned in **Table 44.**

Table 44: Benthic Fauna variations in abundance and diversity in sub surface sampling

Family/Class	ME-1	ME-2	ME-3	ME-4	ME-5	ME-6	ME-7	ME-8
Thiaridae	2	1	-	-	1	2	1	-
Mollusca	1	-	2	-	-	1	1	2
Odonata	2	-	1	-	1	-	-	-
Lymnidae	2	1	-	1	-	1	-	-
Planorbidae	-	2	1	2	-	1	-	1

Family/Class	ME-1	ME-2	ME-3	ME-4	ME-5	ME-6	ME-7	ME-8
Talitridae	-	-	-	-	1	-	1	2
Trochidae	-	1	-	2	-	1	-	1
Atydae	-	1	1	2	1	-	2	-
Gammaridae	1	-	-	-	-	-	-	-
Portunidae	-	1	1	-	1	-	1	1
Turbinidae	1	1	1	1	-	1	2	-
Palaemonidae	-	-	-	1	2	1	-	2
Density-Units/l	**9**	**8**	**7**	**9**	**7**	**8**	**8**	**9**
No of Class	**6**	**7**	**6**	**6**	**6**	**7**	**6**	**6**

Few benthic organisms were observed in the collected samples using Van-Veen grabs at Deendayal Port (Kandla and Vadinar). The dominant macro-benthic groups included *Thiaridae, Mollusca, Planorbodae, Trochidae, Atydae, and Turbinidae,* which were present across multiple stations. *Turbinidae* was observed at all sites (**ME-1 to ME-8**) except ME-5. While *Atydae and Thiaridae* occurred at most of the locations, indicating their broad distribution. The number of benthic families/classes varied between 6 to 7 across all stations.

At ME-1, the most dominant groups were *Thiaridae, Odonata sp. and lymnidae* each with a density of **2 units/L**. The least represented benthic fauna included *Mollusca sp. and Turbinidae* which was observed only at ME-1 with a Density of **1 units/L**.

The details of Species richness Index and Diversity Index in Benthic Organisms are mentioned in **Table 45.**

Table 45: Species richness Index and Diversity Index in Benthic Organisms

Indices	ME-1	ME-2	ME-3	ME-4	ME-5	ME-6	ME-7	ME-8
Taxa S	6	7	6	6	6	7	6	6
Individuals	9	8	7	9	7	8	8	9
Shannon diversity	1.74	1.8	1.55	1.74	1.55	1.8	1.65	1.74
Simpson 1-D	0.92	0.96	0.95	0.92	0.95	0.96	0.93	0.92
Species Evenness	0.97	0.93	0.87	0.97	0.87	0.93	0.92	0.97
Margalef's	2.28	2.89	2.57	2.28	2.57	2.89	2.4	2.28
Berger-Parker	0.22	0.25	0.29	0.22	0.29	0.25	0.25	0.22
Relative abundance	66.67	87.5	85.71	66.67	85.71	87.5	75	66.67

- **Shannon- Wiener's Index (H)** of benthic organism was in the range of **1.46 to 1.80** between selected sampling stations from ME-1 to ME-6 with an average value of **1.68** at Kandla creek and its nearby creeks. While for Vadinar, Shannon Wiener's index of benthic organism recorded to be **1.65** at ME-7 & **1.74** at ME-8 location with an average value of **1.69**. 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)** of benthic organism was ranged between **0.92 to 0.96** at all sampling stations in the Kandla creek and nearby creeks, with an average of **0.**94. Similarly, for Vadinar Simpson diversity index (1-D) of benthic organism was **0.93** at ME-7 and **0.92** at ME-8 location with an average of **0.92.**

- **Margalef's diversity index** (Species Richness) of benthic organism in Kandla and nearby creeks sampling stations was varying from **2.28 to 2.89** with an average of **2.58** during the sampling period. While for Vadinar, Margalef's diversity index (Species Richness) of benthic organism observed to be **2.40** at ME-7 and **2.28** at ME-8 location with an average of **2.34**.

- **Berger-Parker Index (d)** of benthic organism was in the range of **0.22 to 0.29** between selected sampling stations from ME-1 to ME-6 with an average value of **0.25** at Kandla creek and nearby creeks. Berger-Parker Index (d) of benthic organism in the sampling stations of Vadinar, was observed to be **0.25** at ME-7 and **0.22** at ME-8 location with an average value of **0.23**. All the monitoring station signifies a low diversity with an even distribution among the different species.

- The **Species Evenness** is observed in the range of **0.87 to 0.97** for all the six-monitoring station of Kandla and for the Vadinar the species evenness is observed in the range of **0.92** at ME-7 and 0.97 at ME-8.

- During the sampling period, **Relative Abundance** of Benthic organisms was **66.67 to 87.5** between selected sampling stations from ME-1 to ME-6 with an average value of **79.96** at Kandla creek and nearby creeks. Whereas for Vadinar the Index value **75** at ME-7 and **66.67** at ME-8 location, with an average value **70.84**, thus it is concluded that the studied species can be stated as neither highly dominant nor rare.

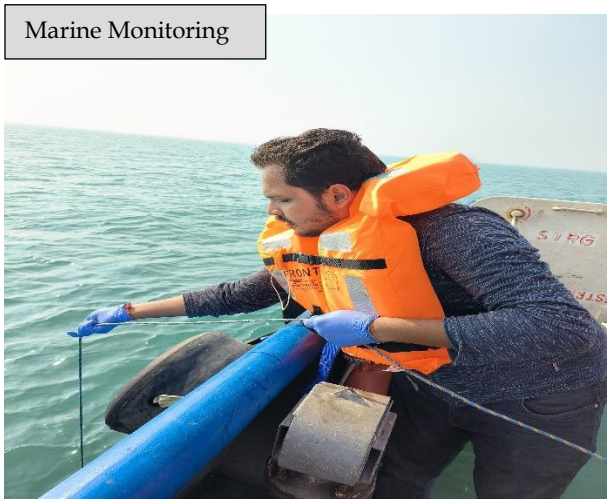
Annexure 1: Photographs of the Environmental Monitoring conducted at Kandla

STP Monitoring

Noise Monitoring

Soil Monitoring

Marine Monitoring



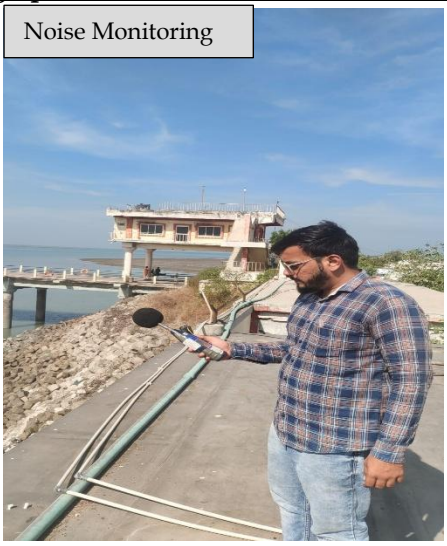
Air Monitoring

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

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