BEFORE THE NATIONAL GREEN TRIBUNAL WESTERN ZONE BENCH, PUNE

O.A. 60/2021

Aryavart Foundation ... Applicant

Versus

M/s Hemani Industries & ors. ... Respondents

AFFIDAVIT OF RESPONDENT NO. 4 (GUJARAT INDUSTRIAL DEVELOPMENT AUTHORITY)

I, Parth R. Suthar, Age: 38 years, Occupation: Public Sector, serving as Executive Engineer (W/D) with Gujarat Industrial Development Authority having office address at: 2nd Floor, Block No. 4, Udyog Bhawan, GH Road, Near Bank of Baroda, Sector-11, Gandhinagar, Gujarat-382011, do hereby beg to state on solemn affirmation as under:

1. I say and submit that, I have gone through the records of the present matter and after going through the relevant office records I am filing the present Affidavit.
2. I say and submit that the present proceeding is related to the wastewater management by the industries and Gujarat Industrial Development Corporation (GIDC) in the Dahej industrial area. That application was filed against the violation of environmental norms by industrial units operating in the complex of Gujarat Industrial Development Corporation (GIDC), Dahej, District Bharuch, Gujarat.

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3. I further say and submit that Hon'ble NGT vide order dated 04.10.2021 directed CPCB and GPCB for joint inspection of Red category industries discharging wastewater in the drainage network maintained by Respondent no. 4. That the Hon'ble Tribunal also directed the Joint Committee to come out with solutions. Based on the detailed findings certain actions/measures were suggested by the Joint Committee to the Respondent Nos. 1, 2 and 4. I say and submit that this Hon'ble Tribunal has also issued certain directions vide Order sated 02.02.2022 to the parties including the present Respondent and to submit the next report of the joint committee. It is further submitted that the Respondent No. 2 has issued Notice no. 624737 dated 05-03-2022, Notice no. 624751 dated 05-03-2022 and Notice no. 675314 dated 16-06-2022 to the present Respondent; I say and submit that pursuant to all the above mentioned directions of this Hon'ble Tribunal and the regulatory Authority i.e. GPCB; the Respondent has immediately adopted short term measures and planned Long Term measures and the compliances of the notices are uploaded on GPCB XGN Portal.

The updated Compliance of which is mentioned hereunder.

Dredging of top soil/sediments from the identified industrial area and scientific disposal of the same:

4. I say and submit that as per the suggestions and recommendations of the Joint Committee the Respondent No. 4 shall have an immediate short-term action like Dredging of top soil/sediments from the identified industrial area where contaminations are observed. It is pertinent to note that the contaminated soil has been transferred to sludge drying bed and shall be disposed to CHWTSDF (Common Hazardous Waste Treatment Storage and Disposal Facility) site as directed by CPCB and GPCB officials during their site visit dated 05-05-2022. Action taken report was submitted to office of the Regional Officer, GPCB, Bharuch vide letter no

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GIDC/BRH/EE/WD/547 dated 02-06-2022. The present Respondent has also obtained membership from Bharuch Enviro Infrastructure Limited (BEIL), Dahej; the Agency which will scientifically dispose off the sludge through manifest. The Copy of the said letter is annexed herewith and marked as "**Annexure – 1**". I say and submit that the compliance with respect to the removal of contaminated soil is completed by the present Respondent.

Upgradation of Effluent Collection System & The work of providing express line with identified industry specific discharge should be complete at the earliest:

5. I say and submit that the compliance of the above mentioned direction and/or recommendation has been completed by the Industries by installing aboveground pipeline. The present Respondent has upgraded effluent collection system in Dahej-I area i.e. 05 nos of collection well with pumping station (PS-A1, PS-A2, PS-C, PS-C1 and PS-C2) are constructed and connections are released through above ground pipeline to avoid any unauthorized connection. Existing manholes systems are closed in SEZ-I Estate and Dahej Chemical Zone. I say and submit that due to the abovementioned infrastructural development, the possibility of ghost connection pipeline/ overflow will not arise. I say and submit that in addition to the abovementioned steps; directions have been given to the Industrial Units for installation of auto-sampler. Once the Auto Sampler is installed by the units; monitoring can be strengthened. Thus efforts have been taken to eradicate the possibility of bad quality effluent entering the Pumping Stations. The Present Respondent also made it clear that each Industry shall put name of the Unit on every 30mtrs on the pipeline so that it will become easier to identify any problem of leakage; if arisen.

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Photographs of above-ground effluent disposal pipeline are attached as **"Annexure -2".**

Following industries have laid above-ground effluent disposal through express pipeline is as under:

1. Dahej Chemical zone (PS-A1, PS-A2, PS-A)

Following industries have completed above-ground network through express pipeline up to nearest Pumping station is as under:

Sr. No.	Name of Industry
1	Indian Peroxide Ltd.
2	Meghmani Specialty Chemicals LLP
3	Insecticides (I) Ltd.
4	Bharat Rasayan Limited (ZLD now)
5	Tagros Chemical India Pvt Ltd.
6	Universal Chemicals & Industries Pvt Ltd.
7	The Dharamsi Morarji Chemical Company Ltd.
8	Meghmani Orgonics Limited
9	Xenon Chem LLP
10	Meghmani Finechem Ltd.
11	Hemani Industires Ltd.
12	Meghmani Unichem LLP
13	Sun farben Incorporation
14	Expanded polymer. (New Connection)

2. SEZ-I (PS-C1, PS-C2, PS-C)

Following industries have completed above-ground network through express pipeline up to nearest Pumping station is as under:

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Sr. No.	Name of Industry
1	Sun Pharmaceuticals Industries Ltd.
2	Aries Colour Chem Pvt. Ltd.
3	Meghmani Organics Ltd.
4	Meghmani Unichem LLP
5	Kumar Organics
6	Accent Microcell Pvt. Ltd.
7	Sigachi Cellulose Pvt. Ltd.
8	Ramdev Chemical Ltd.
9	Indofil Industries Ltd.
10	Firmenich Aromatics Pvt Ltd.
11	Meghmani industries
12	Shiva Pharmachem Ltd.
13	Vidhi Speciality Food Ingredients Ltd (New Connection)

Following industries have not connected effluent discharge pipeline with GIDC network. The following industries are ZLD industries. Currently underground manhole network with pipeline is removed. Hence, they are not connected with any drainage system.

Sr. No.	Name of Industry
1	Macson Colour Chem Pvt Ltd. (SEZ-I)
2	Roxul Rockwool Insulation India Pvt Ltd. (SEZ-I)
3	Glomet Technology (SEZ-I)
4	Bharat Rasayan Limited (Dahej I)

Installation of CCTV Cameras at Pumping Stations and Construction of Boundary Wall:

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6. I say and submit that the Respondent No. 4 has awarded the work of Construction of Compound wall at the drainage pumping stations at Dahej. The work is in progress and the same is completed. In addition to that the Respondent No. 4 has completed the installation of the CCTV cameras at 29 nos out of 29 nos of drainage pumping stations. The coverage of all the CCTV Cameras can be monitored through online system. Photograph is annexed herewith and marked as "**Annexure – 3**". Further that, GIDC has awarded the work of installation of CCTV Cameras at every junction of the road crossing/Hotspot vide letter no GIDC/EE/M&E/BRH/AB/90 dated: 19.05.2023 and will be completed by 18.05.2024.

GIDC has made necessary arrangement to improve results of Pumping station A and C listed below.

- GIDC has upgraded effluent collection system in Dahej-I area i.e. 05 nos of collection well with pumping station are constructed and connection is released only above ground pipeline to avoid any unauthorized ghost connection.
- GIDC has removed all underground drainage system in Dahej chemical zone and SEZ-I area.
- GIDC has conduct several meetings with all members industries regarding effluent discharge through above ground drainage line. Also convince all industries to lay effluent discharge through above ground express line instead of existing underground drainage system. In this regards industries of Dahej chemical zone (PS-A) and SEZ-I (PS-C) has already completed the above ground work as per instruction given by GIDC.
- For continuous monitoring, GIDC has installed TOC, COD, BOD, TSS, pH, NH4N analyzers at all drainage pumping stations. The same has

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been connected to GIDC server. The data has been shared with GPCB so that they can observe online data of all analyzers.

- GIDC has diverted the effluent of PS-A in to Dahej CETP and also Tender for effluent of PS-C in to Dahej CETP is under approval. Hence, PS A has to follow CETP inlet norms.

- GIDC has started to disconnect the drainage connection of non-complying member industries. GIDC has published SOP on dated 04/08/22 for non-compliance of industries which effluent discharge beyond permissible limit.

- At present GIDC has appointed third party agency for regular monitoring of environment for 90 MLD liquid monitoring with higher frequency of industrial effluent sampling at Dahej PCPIR.

Compliance regarding CETP at Dahej:

7. I say and submit that the Joint Committee suggested the Respondent No. 4 to have a time bound action plan to make CETP operational and functional to achieve discharge norms covering all techno-feasibility aspects. Such action plans may be formulated by Respondent No. 4 and 2 in coordination with the industries in the area to achieve effective implementation. **It is submitted that regarding the Operation & Maintenance of the CETP;** an agency has been finalized and the work order has been issued on 01/03/2022.The CETP is maintained & operated on a regular basis. The said work order is annexed herewith and marked as **"Annexure – 4".**

I say and submit that initially very less quantity (700 KL) effluent is received from the industries. The CETP is designed for 40 MLD (4 Stream each of 10 MLD), so it's treatment unit needs to receive at least 7MLD to 10 MLD effluent for optimum performance of the CETP. In this regards, a meeting was held on 07-03-2022 under the chairmanship of Hon'ble Chairman, GPCB regarding review of directions (vide order dated 02-02-

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2022) of the Hon'ble National Green Tribunal. As per their instruction, every member industry shall obtain membership of Dahej CETP under intimation to GPCB and GPCB shall amend the CCA of the industrial unit accordingly with no change in existing discharge norms except TDS. Accordingly, GIDC has issued letters to all member industries to obtain provisional membership of Dahej CETP. Initially only Dahej II and Dahej III was connected to Dahej CETP. Then after, GIDC has diverted Dahej Chemical Zone (PS A) to Dahej CETP. Total 162 industries have obtained provisional membership of Dahej CETP for 27.45 MLD. Currently 59 member industries are discharging effluent in Dahej CETP. Hence, Dahej CETP is now receiving 6MLD to 7 MLD effluent for treatment from member industries. In addition to that, for more effluent at inlet of dahej CETP, GIDC has planned for connectivity of SEZ-I (PS C) and SEZ-II (PS D) to Dahej CETP and the tender for the said work is under approval of competent authority. **It is pertinent to note that the present Respondent has made appeal to the Industries to be member of the CETP.**

Also, CETP is designed on TDS 8000 mg/lit, but as per request of member industries allow industries having effluent TDS 25000mg/lt. **The Respondent is planning to upgrade and retrofitting of the present CETP**. For the same; work of treatability study more than 25000mg/lt to implementation of Automated Chemostat technology(ACT) or best available treatment technology is awarded to M/s Bio Petro Clean India Private Limited vide letter no GIDC/EE/M&E/AB/297 dated: 17.08.2023. Work of the study is completed and submission of final report is awaiting. The work order is annexed herewith and marked as "**Annexure – 5**". After implementation of upgrade and retrofitting of the present CETP, industries with high TDS value effluent will also obtained membership of Dahej CETP.

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I say and submit that **TOC Meter has been installed to monitor performance of CETP.** The same has been connected to the Servers of CPCB / GPCB making it possible to monitor. I say and submit that with respect to the performance of CETP; not only Respondent No. 4 but all other factors should cooperate to achieve optimum performance. Specific directions in this regard may kindly be given.

I say and submit that the SCADA has already been provided in CETP for automation to control the effluent discharge.

I say and submit that the SPV Company has been formed, after due procedure, and the operation and maintenance of the CETP will be handed over to SPV Company for smooth operation.

The CETP is maintained & operated on a regular basis, outlet results are achieved as per CCA. Photos of results showing in TOC Meter is annexed herewith and marked as "**Annexure – 6**". The performance can be monitored by GPCB. Any technical suggestions / recommendations by the GPCB; being the regulatory Authority; will be adopted by the present Respondent. Recommendation and Suggestion of GPCB Auditor is enclosed as "**Annexure – 7**".

<u>Laying down the deep-sea disposal pipeline with diffusers as suggested by NIO:</u>

8. I say and submit that the said Joint Committee suggested that the Respondent No. 4 shall stop discharge of wastewater in CRZ 1B area and also to lay down the deep-sea disposal pipeline with diffusers as suggested by NIO at the earliest and as per CCA condition. So also the Respondent No. 4 shall take the requisite permission from statutory authorities for laying new pipeline and changes in any.

It is pertinent to note that, GIDC has awarded the work of Offshore effluent disposal pipeline with diffuser to M/s Kshrishna

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Corpindia Pvt ltd JV R C Patel JV Flowline network vide work order no. GIDC/EE/BRH/AB/1129 dated 04/10/2022. As of now 1.4 KM out of 3.46 KM laying of offshore pipeline work is completed as per CRZ permission and remaining work will be completed by Dec 2024. It is to be noted that the work shall be carried out by taking all required permissions. The work order of the deep sea pipeline is annexed as "**Annexure – 8**".

Short-term action taken by Present Respondent:

I say and submit that as per actual site conditions, present respondent could lay 1000 mm dia HDPE pipeline up to length of 800 meter from Landfall point by local available machineries and the effluent is being discharged by said pipeline.

More Vigilance and strict action against the Non-complying Industries in the area.

9. I say and submit that as regards to strict action against the non-complying industries in the area, the Respondent No. 4 has taken several measures. GIDC has started taking appropriate actions against non-complying member industries. It is further submitted that the Respondent No. 4 has engaged the expert agency for sampling and analysis of industrial effluent. In addition, Respondent No. 4 has planned to invited online tender for 90 MLD liquid monitoring with higher frequency of industrial effluent sampling including Surprize sampling / night sampling at Dahej PCPIR. The said tender includes, marine water analysis, Surprise / Night sampling and analysis of effluent discharged by member, sampling and analysis of effluent receiving at all drainage pumping stations, sampling and analysis of ground water at various locations, preparation of six-monthly compliance report of CRZ clearance. It is to be noted that the Respondent No. 2 being a pollution control board, should also take appropriate actions against such units so that results can be achieved.

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GIDC has taken further following steps to co achieve the prescribed norms of wastewater.

- For continuous monitoring, GIDC has installed TOC, COD, BOD, TSS, pH, NH4N analyzers at all drainage pumping stations. The same has been connected to GIDC server. The data has been shared with GPCB so that they can observe online data of all analyzers. Moreover, it will be done for all member industries also, at pumping station and the said work is under progress and shall be completed.
- GIDC has diverted the effluent of PS-A in to Dahej CETP and also planned effluent of PS-C in to Dahej CETP. Hence, PS A has to follow CETP inlet norms.
- GIDC has started to disconnect the drainage connection of non-complying member industries. GIDC has published SOP on dated 04/08/22 for non-compliance of industries whose effluent discharge is beyond permissible limit.

Measures for preventing leakage and overflow

10.I further say and submit that the GIDC has awarded the M&R (Maintenance & Repair) of underground drainage work to the agency. At present there in no leakages found from drainage lines.

The M & R work is attended immediately whenever leakage is observed in drainage line, Dahej & Vilayat Estate.

GIDC has removed underground manhole network with pipeline. Hence, there is no any possibility of overflow.

Augmentation of the infrastructure like replacing the subsided drainage lines near OPAL in SEZ-1 and replacing damaged/leaking other drainage line on priority basis:

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GIDC has converted all drainage network of SEZ-I into above ground effluent discharge pipeline. Moreover, GIDC has removed all underground manhole network with existing pipeline from SEZ I area. Hence, possibility of damage/ leakage is almost nil.

Detailed impact assessment study from institute of repute involved in the research of coastal/marine ecology:

I say and submit that with respect to the suggestion that Joint Committee That the Respondent No. 4 was also expected to submit detailed impact assessment study from institute of repute involved in the research of coastal/marine ecology considering the years of non-compliance and discharge of high polluted wastewater into CRZ area which has potential to create effect on Marine ecology. It is pertinent to note that the Respondent No. 4 has issued work order to NIO vide order no. GIDC/EE/BRH/AB/360 dt. 27/04/2022 for compliance of detailed impact assessment study involved in the research of coastal/marine ecology considering the years of non-compliance and discharge of high polluted wastewater into CRZ area which has potential to create effect on Marine ecology. In respect to the report of NIO, present respondent shall implement the measures for the restoration of the marine ecology. GIDC has awarded the work of marine ecology to CSIR-National institute of oceanography. The said study is completed and the detail report of study is annexed as "**Annexure - 9**".

Measures taken for avoiding scaling and choking problem in pipeline:

11. I say and submit that the Respondent No. 4 was also suggested to explore technology for regular cleaning or select such material of construction of pipeline to avoid scaling and chocking. So also it was suggested that the

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Respondent No. 4 shall conduct technical study through reputed institute to identify reasons of scaling and choking problem in pipeline. GIDC will survey for scaling in pipeline and there is no any scaling in pipeline found. However, GPCB should guide and help in identifying & restricting some restricting some parameters of effluent by which scaling and chocking can be avoided.

I say and submit that with respect to the suggestion that Joint Committee shall explore and implement measures to help in removal of salts formation at final pumping station before discharge of wastewater to avoid choking & scaling in the pipeline again in future. It is important to understand that it is the Respondent No. 2 who should identify and restrict some parameters of effluent by which salt formation took place in side collection well as well as pipeline. So that scaling and chocking can be avoided in future. In addition, to that the respondent No. 4 has appointed M&R agency for removing sludge from final drainage pumping station. After drying the sludge in sludge drying bed at FPS, dry sludge is being disposed off to approve TSDF (BEIL) site. Hence, now choking & scaling in the pipeline is not observed.

I say and submit that the Respondent No. 4 was suggested to stop accepting effluent of industries which are responsible for scaling and choking problem in pipeline. It is submitted that the Respondent No. 2 is expert in identification of parameters, production, and type of effluent. That the Respondent No. 2 should give list of such industry so that the respondent No. 4 can stop accepting effluent.

<u>Provide flow measuring system and to make online TOC/COD meter operational:</u>

12. I say and submit that the Respondent No. 4 was suggested to provide flow measuring system and to make online TOC/COD meter operational at all

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the pumping stations. It was further suggested that proper records of flow and COD shall be maintained by the respondent No. 4. It is pertinent to note that the Respondent No. 4 has installed Flow measuring device at various drainage pumping stations but due to scaling inside pipeline, flow measuring device doesn't work properly. However, the Respondent No. 4 is trying to do the cleaning and calibration frequently to run with accuracy. Furthermore, the Respondent No. 4 has installed 29 nos. of TOC/COD meter at Drainage pumping stations. Moreover, all this TOC/COD meter is connected to GPCB / CPCB server. The said photographs are annexed herewith as "**Annexure – 10**".

SCADA and Automization system for monitoring, surveillance and discharge control:

13. Respondent no 4 is planning to install on-line Continuous Effluent Monitoring System (OCEMS) SCADA is mandatory at each Industries for controlling and monitoring the effluent quality and discharge Quantity. OCEMS is sensing and monitoring effluent quality like COD BOD TSS pH TDS and Amonical Nitrogen, calcium, sulfate etc. on real time basis at industries discharge point. If any industry's effluent quality goes to beyond limit of CCA, immediately three way valve will be activated & automatic shut-off industry's discharge line and same time bad Quality of effluent return to industry's guard pond and Valve will be open once when effluent will be resumed normal limit as per CCA. It means only good quality of effluent will be received.

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Payment of Environment Damage Compensation (EDC):

14. I say and submit that the Respondent No. 4 is asked that it shall pay Environment Damage Compensation (EDC) as and when communicated

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by the Board. It is pertinent to note that the Respondent No. 4 provides infrastructural facilities only in industrial estates. Given all of the above issues, it is clear that damage to infrastructure due to wastewater discharged from industries is the responsibility of the Respondent No. 2. To meet the standards set by the Respondent No. 2 as well as missing some important parameters in CCA that causes damages infrastructure which parameters need to be included in CCA. If only the Respondent No. 2 had addressed all the above issues and controlled the discharge of effluents by the industries, then the infrastructure of Respondent No. 4 would not have been damaged. Therefore, the Respondent No. 4 is not liable to pay Environmental Damage (EDC) as the Respondent No. 4's liability only facilitates to receive treated industrial effluent from industries within standards set by the Respondent No. 2. Considering the steps taken and progress made by the present Respondent; the Environmental Compensation levied may kindly be waived.

15.I say and submit that the Respondent No. 4 is asked to immediately take corrective measures for above non-compliances and submit compliance report/time bound action plan for it and shall comply all conditions mentioned in CCA judiciously. It is pertinent to note that the present issues could be avoided if Respondent No. 2 had been more vigilant and made sure that all member industries had discharged their effluent as per norms. The Respondent No. 4 is continuously upgrading and maintaining drainage related infrastructure.

16.I say and submit that by way of this Affidavit, the present Respondent would like to appraise this Hon'ble Tribunal the steps taken by the GIDC for adopting recommendations and suggestions of the Authorities, the Joint Committee etc. The result of the same can be evident in near future and the

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same can be monitored by the Respondent No.2 being the regulatory Authority. I say and submit that the present Respondent shall make every endeavour to comply with all the recommendations and suggestions as well as directions with regard to issue involved.

For betterment of drainage network and to avoid environment damage GIDC has incurred Rs. 60.04 Crore and will continuously incurred Rs. 136.67 Crore for major concerned activities.

Solemnly affirmed on this the 21st day of February 2024 at Bharuch.

Affiant

I know the affiant.

Advocate.

Executive Engineer (W/D)
G.I.D.C., Bharuch.

Sr. No. 440/24
Date 21 FEB 2024

RAHULKUMAR J. SOLANKI
ADVOCATE & NOTARY
GOVT. OF INDIA
Dist. Bharuch (Gujarat)

NOTARY
R. J. SOLANKI
Reg. No. 8657/2011
Di. Bharuch
GOVT. OF INDIA

he under signed does not takes any Responsibility of these Contents of these Documents.
Only............
SOLEMNLY AFFIRMED BEFORE ME

RAHULKUMAR J. SOLANKI
ADVOCATE & NOTARY
GOVT. OF INDIA
DIST. BHARUCH. (GUJARAT)

21 FEB 2024

This document is registered only Signatory does exists now. and the signatory has put his signature in my presence therefore the entire responsibility of it shall be born by me

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NOTARY
R. J. SOLANKI
Reg. No. 8657/2011
Di. Bharuch
GOVT. OF INDIA

Annexure-1

BEIL INFRASTRUCTURE LIMITED
(Formely Known As Bharuch Enviro Infrastructure Limited)

REF: BEIL/ANK/2023

06TH MAY, 2023

To,
GUJARAT INDUSTRIAL DEVELOPMENT CORPORATION - DAHEJ - 90 MLD
PLOT No.13/A,
NEAR VILLAGE AMBHETA,
GIDC, DAHEJ.

Sub: Membership Certificate for Common Solid Waste Disposal Facility

Dear Sir,

We hereby certify that you have become member of the common Solid/Hazardous Waste Disposal Facility developed by For, BEIL INFRASTRUCTURE LIMITED (Formerly Known as Bharuch Enviro Infrastructure Ltd)., at GIDC, DAHEJ. You have booked solid waste quantity **1000 MT/Year** (Original Booked Quantity **350 MT** + Increased Quantity **650 MT**). Your Membership No. **is OTH/615.**

1) **Total TSDF Capacity of BEIL Dahej:** 1900000 MT
2) **Total Consented Capacity:** 1900000 MT
3) **Total Occupied Capacity:** 1058511.719 MT
4) **Spare Capacity:** 0841488.281 MT

Thanking you,

Yours faithfully,
For, BEIL Infrastructure Limited
(Formerly Known as Bharuch Enviro Infrastructure Ltd)

AUTHORISED SIGNATORY

Executive Engineer (W/D)
G.I.D.C., Bharuch.

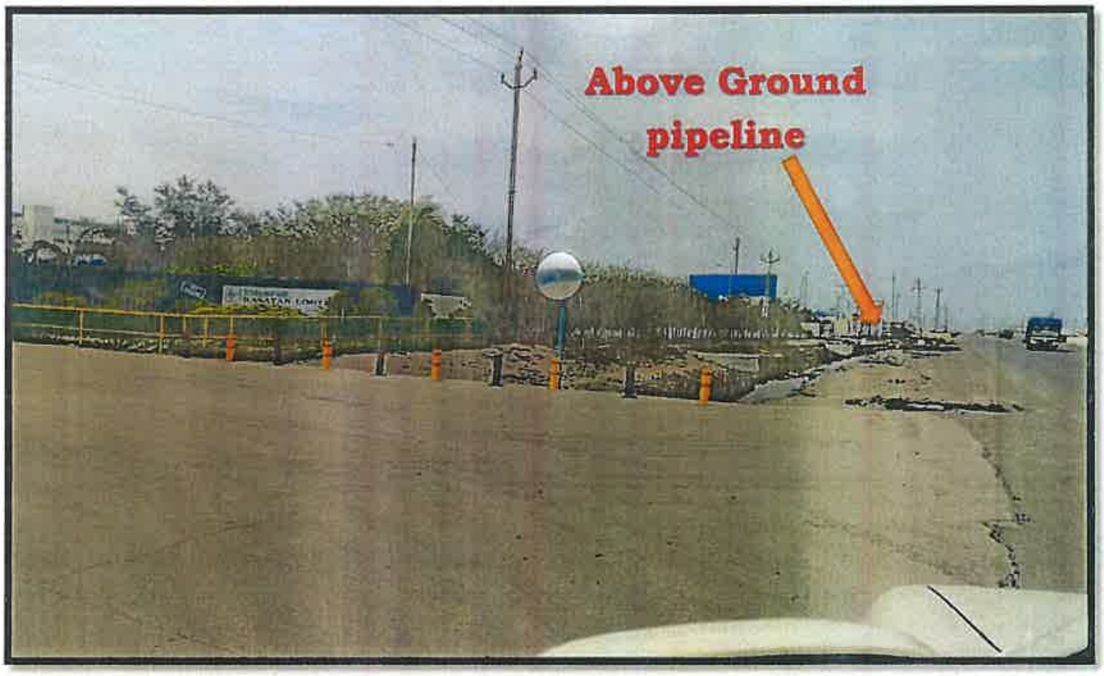
CIN No.: U45300GJ1997PLC032696
Regd. Office : Plot No. 9701-16 GIDC Estate, Post Box No. 82, Ankleshwar 393 002, Dist. : Bharuch (Gujarat)
Phones (02646) 253135, 225228 • Fax : (02646) 222849 • E-mail : dalwadibd@beil.co.in Website: www.beil.co.in

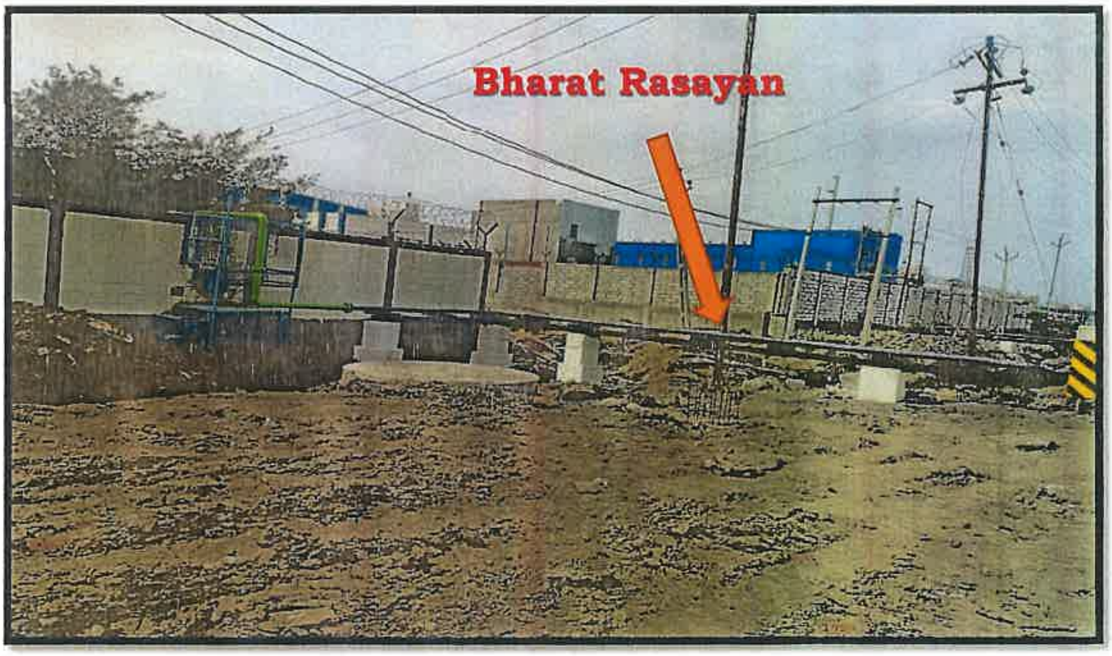
Annexure 2

Above ground effluent Express line work (Dahej Chemical Zone)

- **Pumping station A1**

1) M/s. BHARAT RASAYAN LTD. (CH-42/4)





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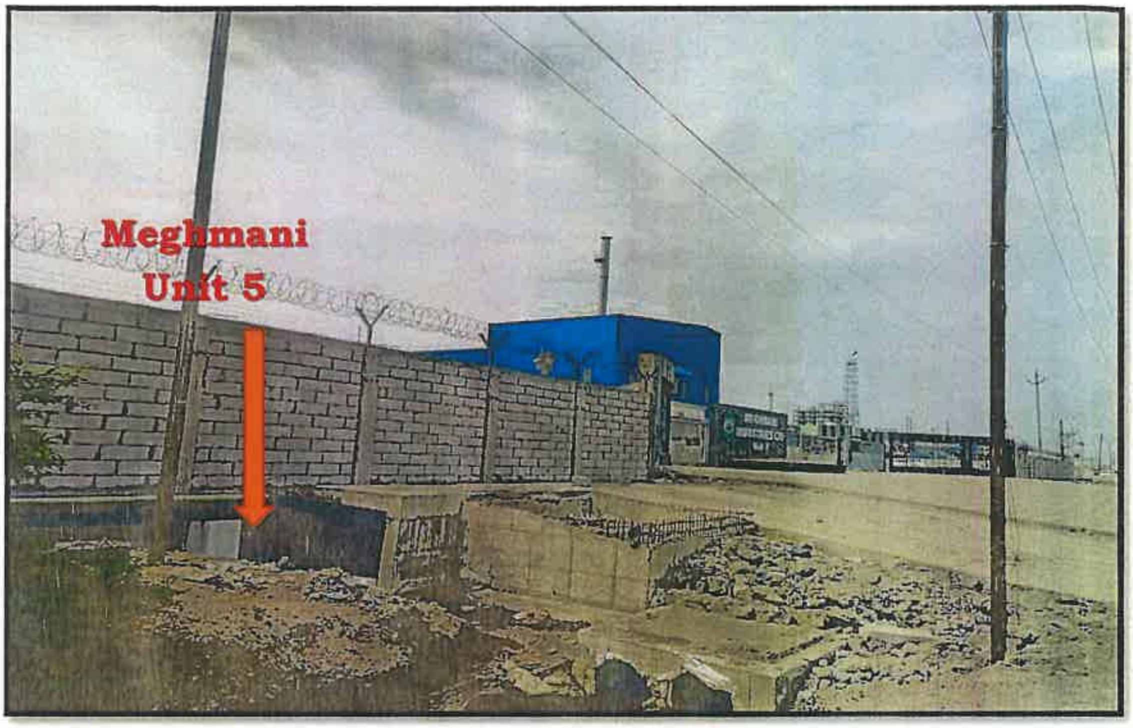
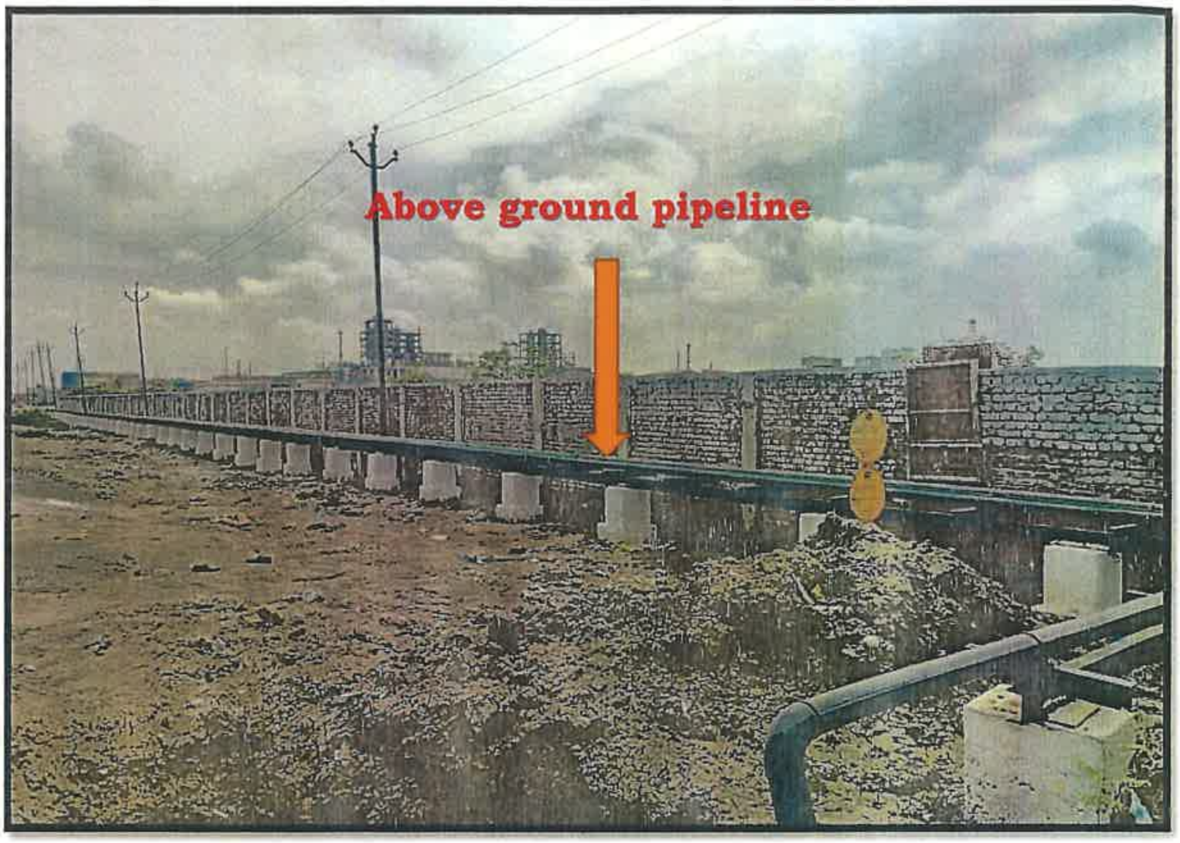
2) M/s. MEGHMANI Unit 5 (42/5)



3) M/s. INDIAN PEROXIDE LTD. (CH-43/2)

4) M/s. TAGROS CHEMICALS INDIA LTD. (CH-43/1)



5) M/s. INSECTICIDES INDIA LTD. (CH-21)

6) M/s. MEGHMANI SPECIALTY CHEMICALS LLP. (CH-22)

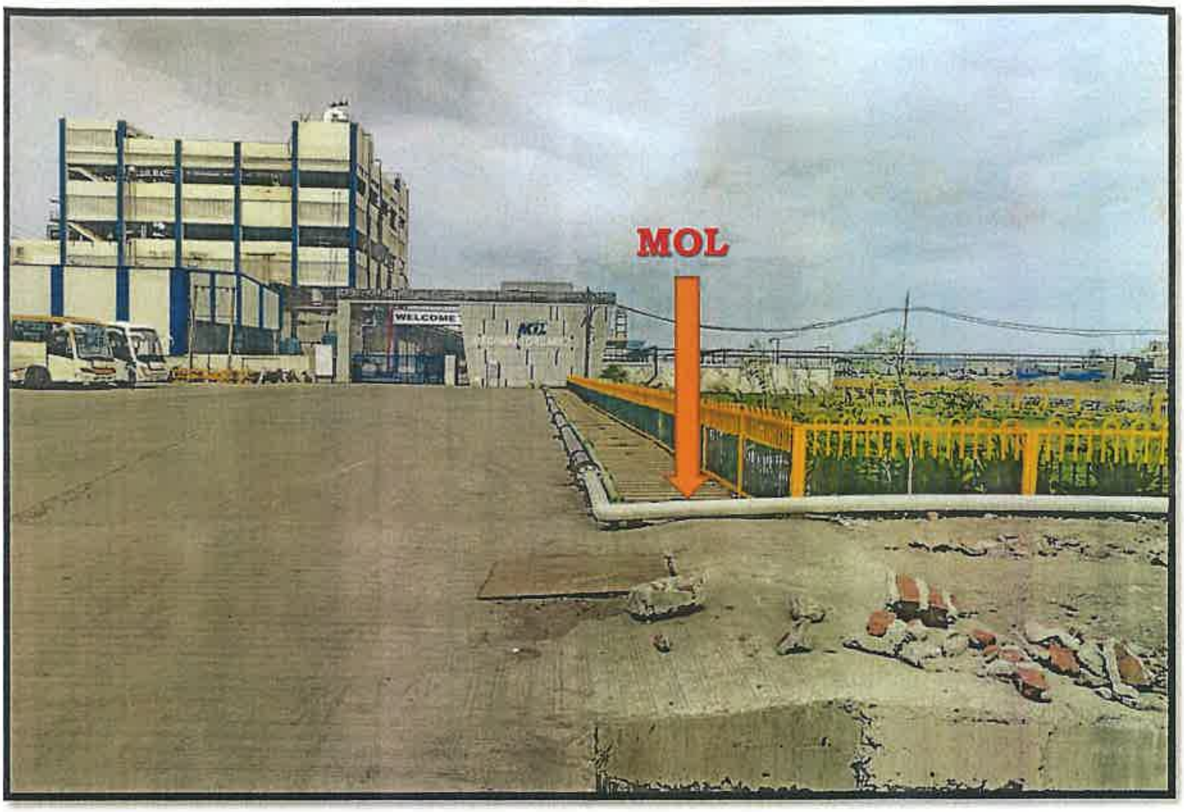
PUMPING STATION A1

➤ **Pumping station A2**

1) **M/s. UNIVERSAL CHEMICALS & INDUSTRIES PVT. LTD. (CH-5/A)**

2) M/s. THE DHARAMSI MORARJI CHEMICAL CO LTD (CH-5/1)

3) M/s. MEGHMANI ORGANICS LTD. UNIT – 3 (CH-1&2A)

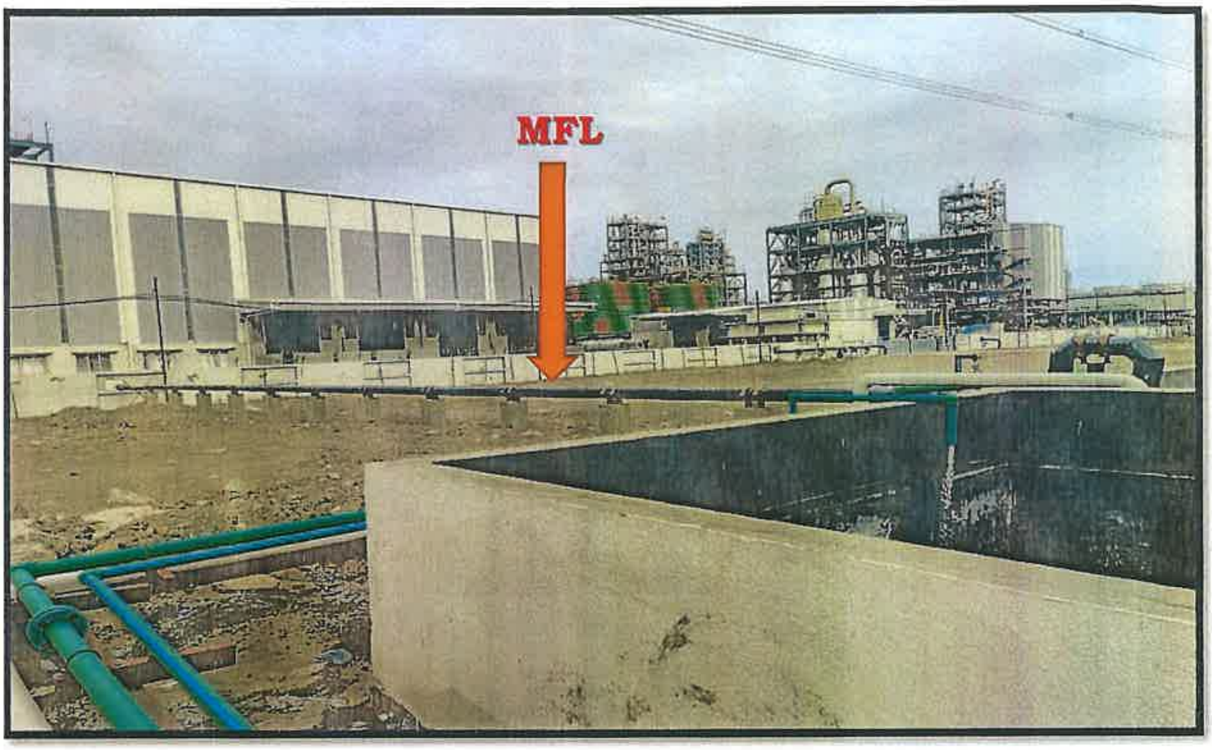


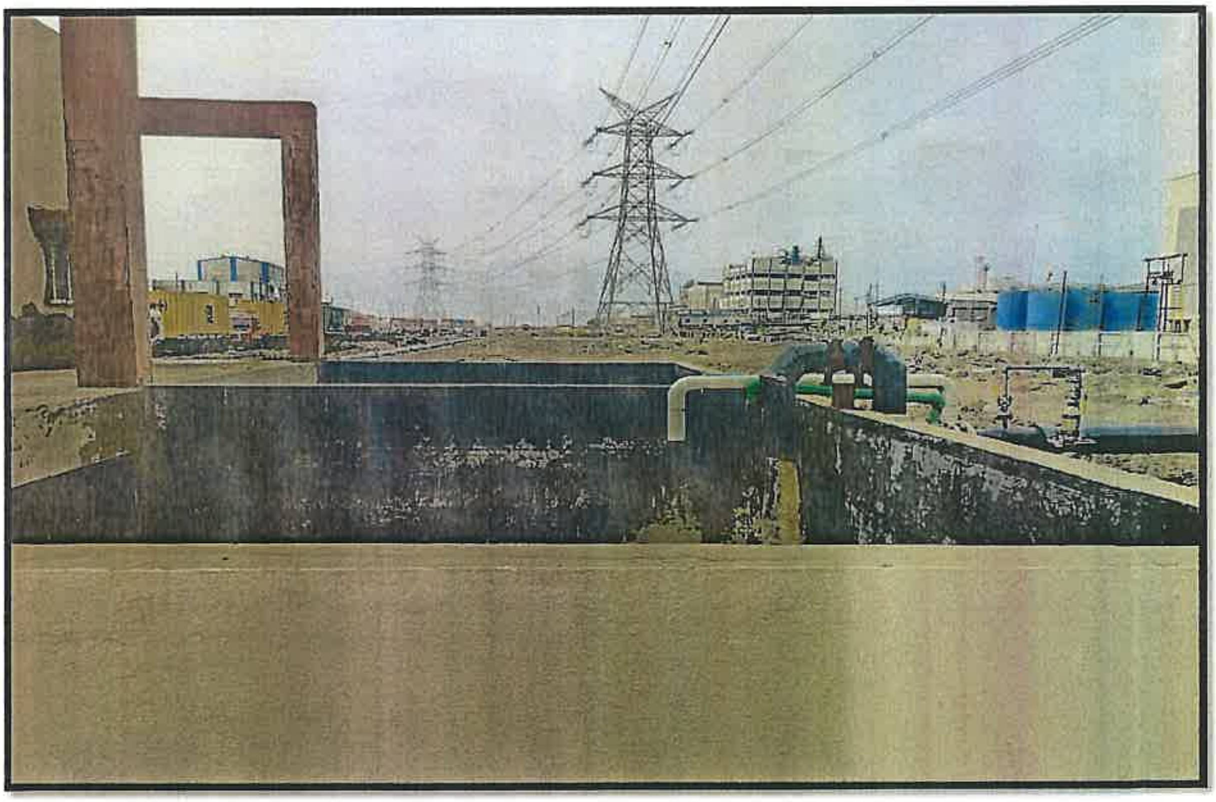
4) M/s. MEGHMANI UNICHEM LTD (CH-3)


MUL

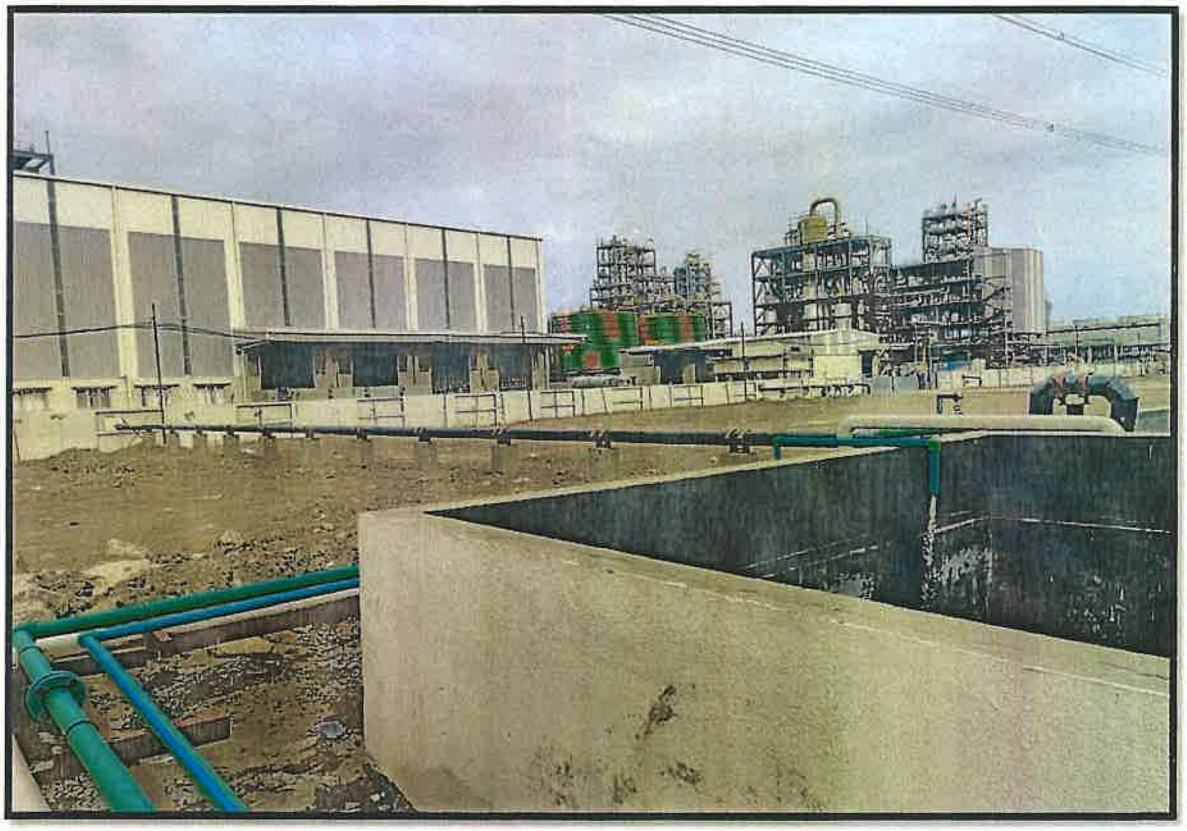

MEGHMANI LLP UNIT-1
STATION A2

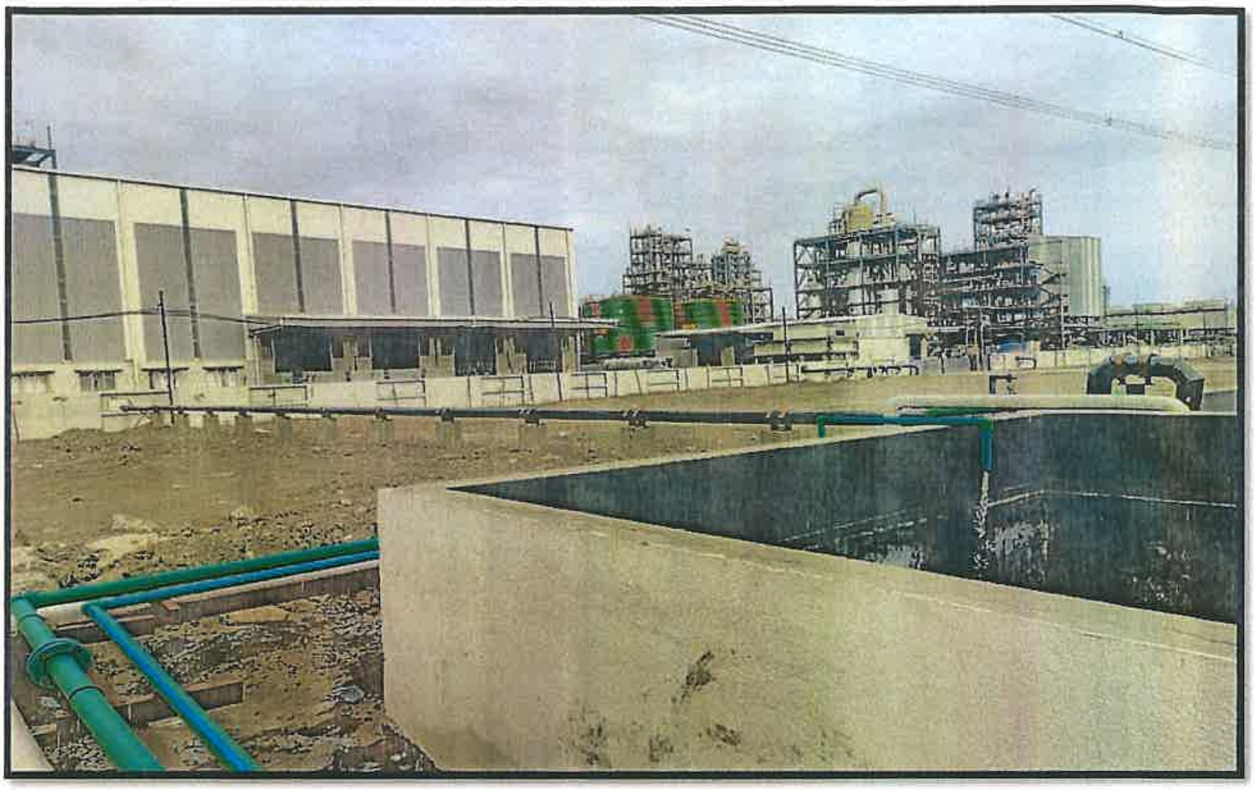
5) M/s. MEGHMANI FINECHEM LTD. (CH-1 & CH-2)





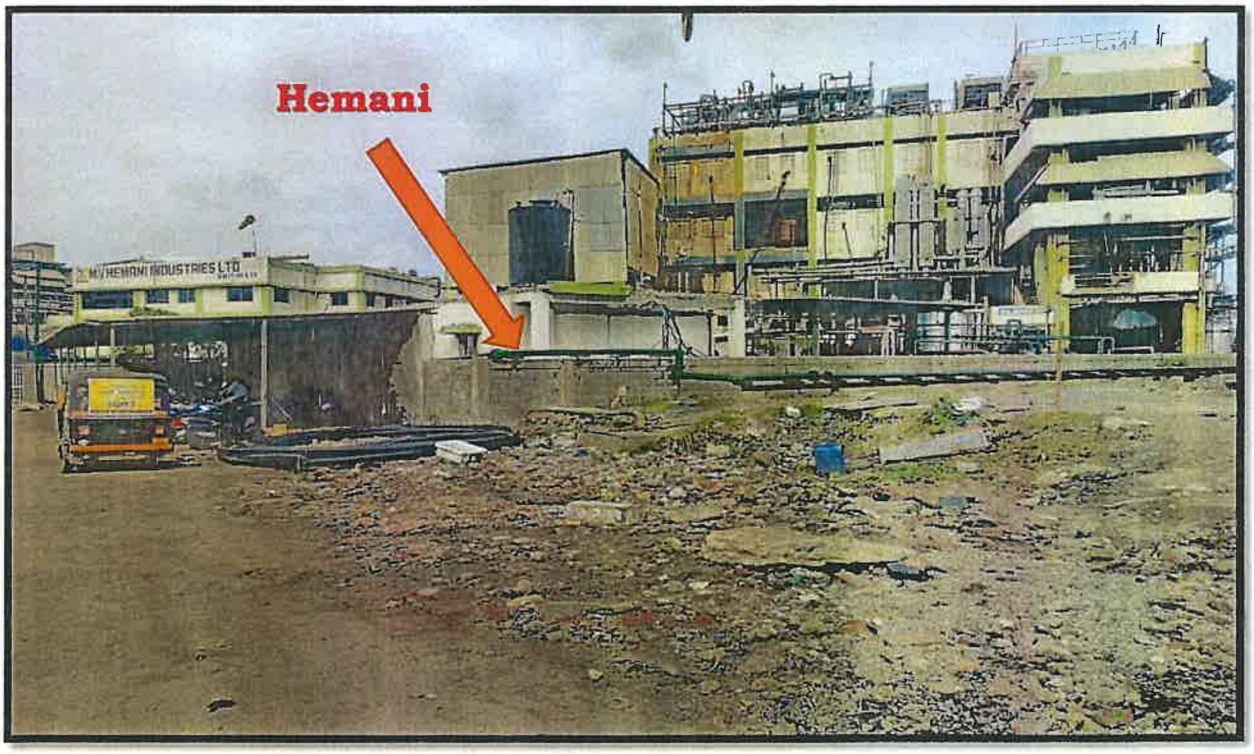
PUMPING STATION A2





➢ **Pumping station A**

1) M/s. HEMANI INDUSTRIES LTD. (CH-5 & E-362)



2) M/s. SUN FARBEN INCORPORATION (CH-11)

PUMPING STATION A

Above ground effluent Express line work (SEZ I)

- Pumping station C1

1) M/s Indofil Industries Limited.

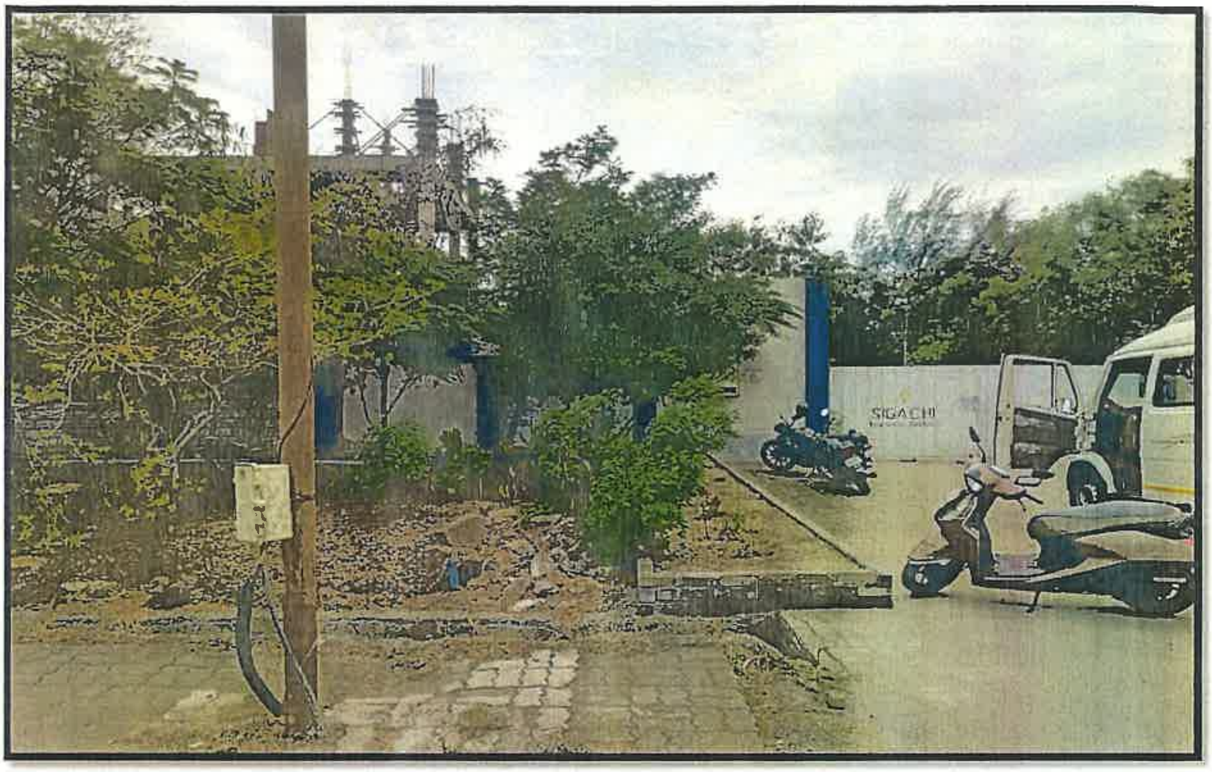
2) M/s Meghmani Industries Ltd.

3) M/s Firmenich Aromatics Production (I) Pvt Ltd.

PUMPING STATION C1

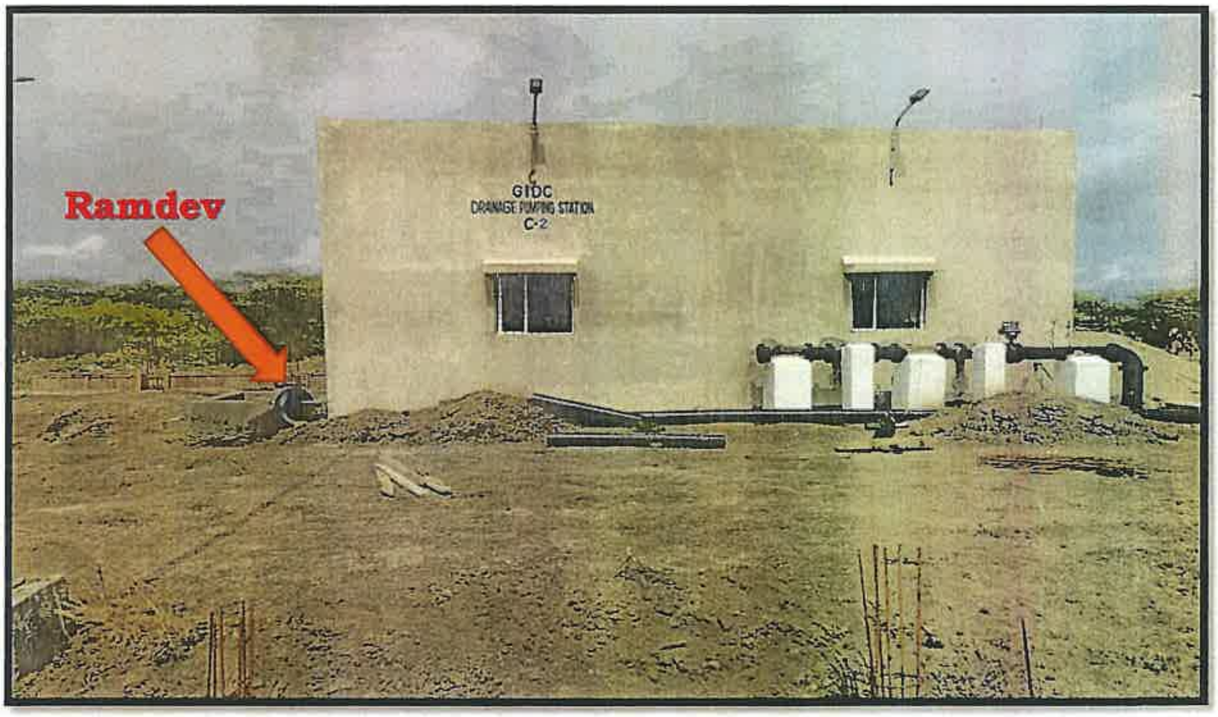
- Pumping station C2

1) M/s Sigachi Cellulose Pvt. Ltd.



2) M/s Sun pharmaceutical Industries Ltd

3) M/s Ramdev Chemical Industries.



4) M/s Meghmani Organics Limited.

5) M/s Meghmani Unichem LLP.

6) M/s Kumar Organic products Ltd.

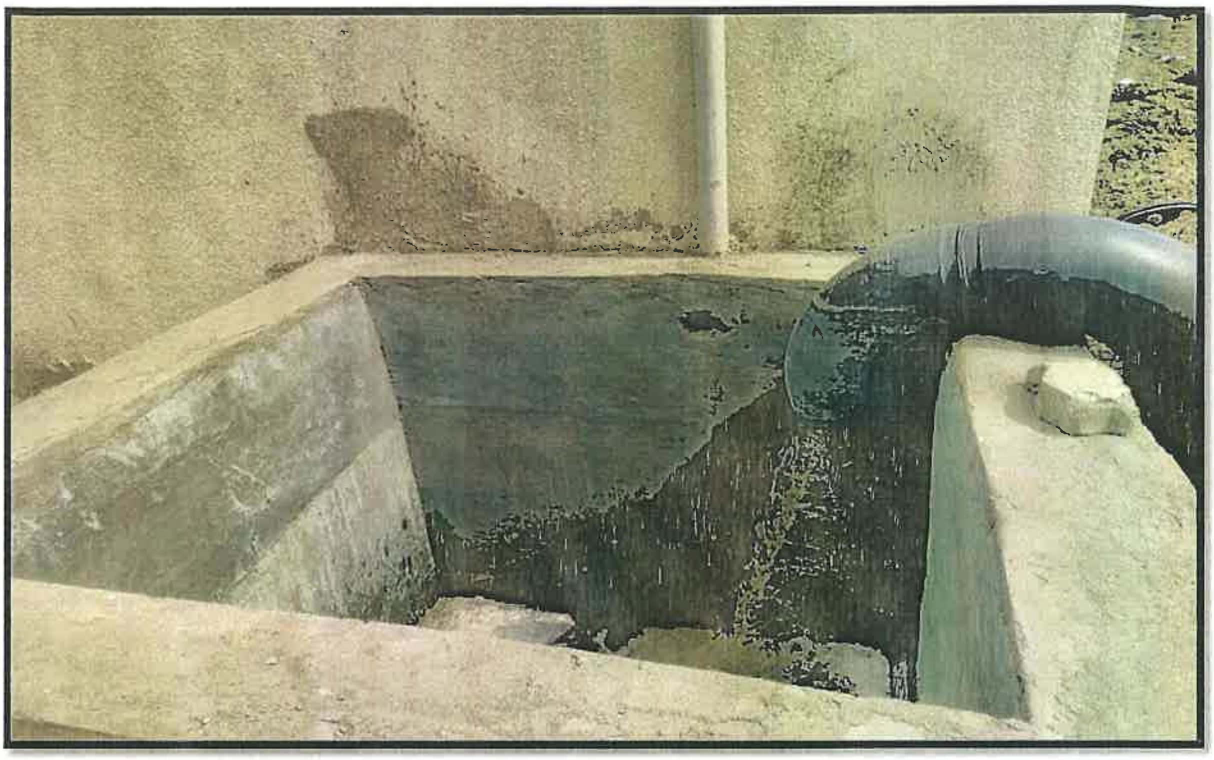
7) M/s Accent Microcell.

ESR I

ESR II

ESR III

PUMPING STATION C2



➢ **Pumping station C**

1) M/s Shiva Pharmachem Limited.

PUMPING C

Executive Engineer (W/D)
G.I.D.C., Bharuch.

Annexure 3

CCTV Camera Details in all Pumping Stations at Dahej PCPIR

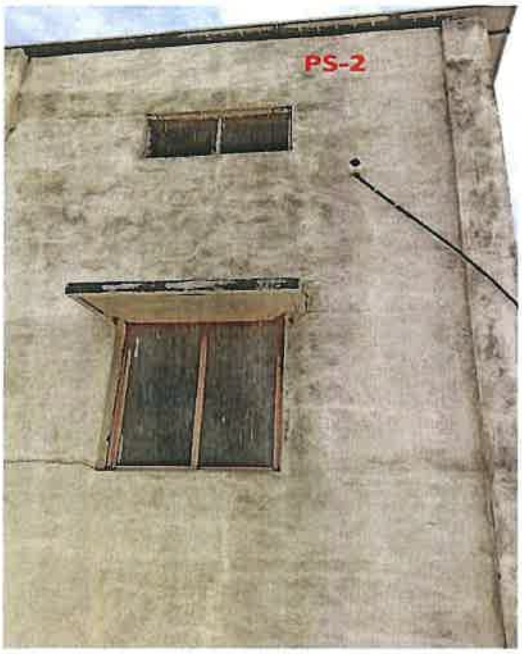
Final Pumping Station

Pumping Station A

Executive Engineer (W/D)
G.I.D.C., Bharuch.

Pumping Station 1

Pumpig Station 2



Pumpig Station 4

Pumpig Station 5

Vilayat Pumping station

CETP – Dahej

Executive Engineer (W/D)
G.I.D.C., Bharuch.

Annexure-4

BY R.P.A.D.

GUJARAT INDUSTRIAL DEVELOPMENT CORPORATION

GUJARAT INDUSTRIAL DEVELOPMENT CORPORATION

Azadi Ka Amrit Mahotsav

(A Govt. of Gujarat Undertaking)
Office of the Executive Engineer (M&E)
2nd Floor, Narmada Commercial Complex,
M.G.Road, PanchBatti, Bharuch-392001
Ph: (02642)242432 FAX:(02642)241902
Email ID : xenme-brc@gidcgujarat.org

NO.GIDC/EE/M&E/BRH/AB/565 **DATE : 24/02/2022.**

To,
M/s. SVR Construction Co.
U-13 Sajani Complex,
Near Siddharth Complex,
City Light Road,
Surat.

Sub : Work order of Tender For the work of :
Operation, maintenance & repairing of 40 MLD Common Effluent Treatment Plant with allied components including Electro - Mechanical and PLC SCADA system at GIDC, Dahej Industrial Estate

Tender ID No. 494304. TENDER NOTICE NO.17 OF 2021-2022 SR.NO.01.

Ref :
1. E - Tender Notice No. 17 of 2021-2022. Tender Sr.No.01. Tender ID No. 494304.
2. Your tender offered approved by Hon'ble VC and MD and conveyed vide letter No. NO.GIDC/ENG/CE/51 dtd.17/02/2022.
3. SE(CG) Letter No.127 dtd.17/02/2022.
4. This office acceptance letter No. NO.GIDC/EE/M&E/BRH/AB/548 dtd.17/02/2022.
5. Agreement No.B1/5 of 2021-2022.
6. Computerized measurement Book No.30.

DRAINAGE SUB DIVISION Inward No. 1554 Date 28/02/2022 G.I.D.C. BHARUCH

Dear Sir,

We are please to inform you that your tender (Price Bid offer) for the above subject work an amounting to Rs. 7,16,62,685.32 (Rupees Seven Crore, Sixteen Lakh Sixty Two Thousand Six Hundred Eighty Five and Thirty Two paisa Only) i.e. 0.60 % above the estimated cost put to tender Rs. 7,12,35,273.68 (Rupees Seven Crore Twelve Lakh Thirty Five Thousand Two Hundred Seventy Three and Sixty Eight paisa Only) has involving excess of Rs.4,27,411.64 has been accepted by competent Authority of GIDC , which was conveyed to you vide this office letter No.GIDC/EE/M&E/BRH/AB/548 dtd. 17/02/2022.

Since you have paid 3% Initial Security Deposit / Performance Bond of Rs.21,37,100.00 (Rupees Twenty One Lakh Thirty Seven Thousand One Hundred Only) in form of FDR advice No.FDR1902225607 dtd. 19/02/2022 of Bank of Baroda city light Surat in the Name of Executive Engineer, GIDC Bharuch having validity of One year & completed contract agreement formalities, you are hereby awarded the above said work and issued work order for commencement of the work and complete the same strictly within 12(Twelve)

Executive Engineer (W/D)
G.I.D.C., Bharuch.

Months and or as per applicable tender specification, terms and conditions and provision / clause of tender agreement.
Please note that the order to start work from 01/03/2022 and schedule date of completion is 12 (Twelve) Months. i.e 28/02/2023.

Please note that remaining 2.5% Security Deposit i.e. Rs. 17,80,840.00 (Rupees Seventeen Lakh Eighty Thousand Eight Hundred Forty Only) shall be deducted from running account bills as security deposit.

You are also required to apply for registration with Labour Commissioner, Bharuch, Gujarat State as per contract Act - Labour Regulation and Abolition Act - 1970 and rule there under and maintain prescribed recorde, registers as per the Act.

Thanking You,

Yours Faithfully,

Executive Engineer (M&E)
GIDC, Bharuch.

Details of Security Deposit :

1. **Rs. 21,37,100.00** 3 % Initial Security Deposit / Performance Bond in form of FDR advice No.FDR1902225607 dtd. 19/02/2022 at Bank of Baroda city light area Surat Gujarat for the period of 1 year.
2. **Rs.17,80,840.00** 2.5 % Balance SD is to be deducted from RA Bill.

Copy S.W.R. to :
1) The Chief Engineer, GIDC, Udhyog Bhavan Gandhinagar for information Please.
2) Superintending Engineer (CG), G.I.D.C., Bharuch .. for information please.
CC to :
3) The Executive Engineer (W/D), GIDC, Bharuch for information please.
4) The Deputy Executive Engineer (Drg), GIDC, Bharuch for information please.
5) The Deputy Executive Engineer (M&E), GIDC, Bharuch for information please.
6) Labour Officer, Gayatri Nagar, Bharuch for information please.

Executive Engineer (W/D)
G.I.D.C., Bharuch.

Annexure-5

BY R.P.A.D.

GUJARAT INDUSTRIAL DEVELOPMENT CORPORATION

GUJARAT INDUSTRIAL DEVELOPMENT CORPORATION

(A Govt. of Gujarat Undertaking)
Office of the Executive Engineer (M&E)
2nd Floor, Narmada Commercial Complex,
M.G.Road, PanchBatti, Bharuch-392001
Ph: (02642)242432 FAX:(02642)241902
Email ID : xenme-brc@gidcgujarat.org

Azadi Ka Amrit Mahotsav

NO.GIDC/EE/M&E/BRH/AB/297 **DATE : 17/08/2023.**

To,
M/s Bio Petro Clean India Private Limited
2nd Floor, Apex Square 2,
Property No. 5, Pocket B3,
Sector 17, Dwarka, New Delhi,
Delhi, India – 110075
Phone No. 011-43028513

Sub : Work Order of Tender For the work of :
Appointment of Expert Agency for carrying out Treatability study and Lab scale trial demonstration of Industrial Effluent from Member industries in Dahej PCPIR as per revised TDS norms of CETP Dahej. TENDER NOTICE NO.03 OF 2022-2023 SR.NO.04. Tender ID No. 526623

Ref :
1. E - Tender Notice No. 03 of 2022-2023. Tender Sr.No.04. Tender ID No. 526623.
2. No. GIDC/ENG/CE/217 Dtd. 07/08/2023.
3. This office acceptance letter NO.GIDC/EE/M&E/BRH/AB/287 Date : 08/08/2023.
4. Agreement No. G/5 of 2023-2024.
5. Computerized measurement Book No.29.

Dear Sir,

We are please to inform you that your tendered offer for the above subject work an amounting to Rs. 56,55,000.00 (Rupees Fifty Six Lakh Fifty Five Thousand Only) i.e. 5.75% Below involving saving of Rs. 34,5000.00 the estimated cost put to tender Rs. 60,00,000.00 (Rupees Sixty Lakh Only) has been approved by competent authority of GIDC which was conveyed to you vide this office Letter NO.GIDC/EE/M&E/BRH/AB/287 dtd. 08/08/2023.

Since you have paid 3% Initial Security Deposit / Performance Bond of Rs. Rs. 1,80,000.00 (Rupees One Lakh Eighty Thousand Only) in form of FDR A/C No.923040087113644 dtd. 11/08/2023 of Axis Bank in the Name of Executive Engineer, GIDC Bharuch having validity of 12 Month, you are hereby awarded the above said work and issued work order for commencement of the work and complete the same strictly within 03 (Three) Months and or as per applicable tender specification, terms and conditions and provision / clause of tender agreement.

You have to submit the Bank Guarantee against stage 1 & 2 payment and stage wise payment to be released as mentioned in tender payment terms. Also, Minutes of Meeting held on 13.12.2022 is part of tender documents. First stage submitted Bank Guarantee shall be released after second stage bill.

Executive Engineer (W/D)
G.I.D.C., Bharuch.

Please note that remaining 2.5% Security Deposit i.e. Rs. 1,50,000.00 (Rupees One Lakh Fifty Thousand Only) shall be deducted from running account bills as security deposit.

You are also required to apply for registration with Labour Commissioner, Bharuch, Gujarat State as per contract Act - Labour Regulation and Abolition Act - 1970 and rule there under and maintain prescribed record, registers as per the Act.

Thanking You,

Yours Faithfully,

Executive Engineer (M&E)
GIDC, Bharuch.

Details of Security Deposit :

1. **Rs. 1,80,000.00** 3 % Initial Security Deposit / Performance Bond in form of FDR A/C No. 923040087113644 dtd. 11/08/2023 of Axis Bank for the period of 12 Month.
2. **Rs. 1,50,000.00** 2.5 % Balance SD is to be deducted from RA Bill.

Copy S.W.R. to :

1) Superintending Engineer (CG), G.I.D.C., Bharuch... For information please.
2) Superintending Engineer (M&E), G.I.D.C., CG, SG, ABD... For information please.

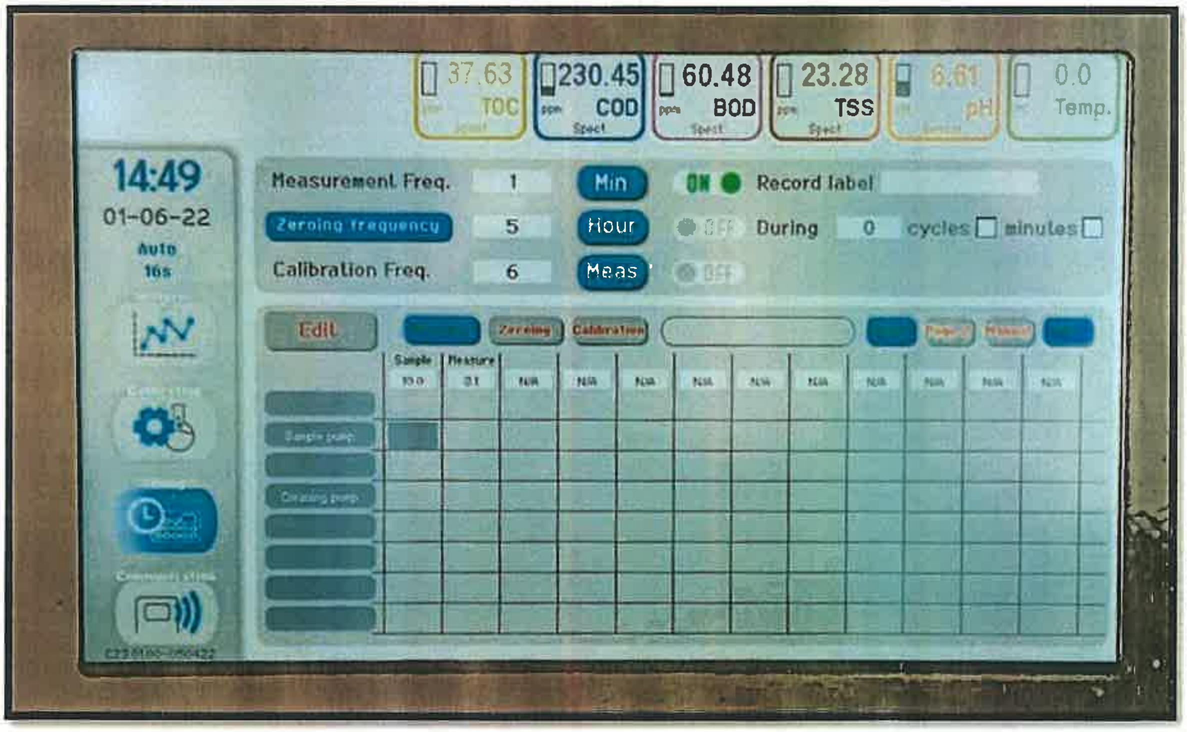
CC to :

3) The Executive Engineer (W/D), GIDC, Bharuch for information please.
4) The Deputy Executive Engineer (M&E), GIDC, Bharuch for information please.
5) Labour Officer, Gayatri Nagar, Bharuch for information please.

Executive Engineer (W/D)
G.I.D.C., Bharuch.

Annexure 6

Result showing in TOC Meter at outlet of CETP



Executive Engineer (W/D)
G.I.D.C., Bharuch.

3783

Annexure-7

ENVIRONMENTAL AUDIT REPORT

FOR AUDIT PERIOD

OCTOBER 2022 TO MARCH 2023

Industry

M/s. CETP of Dahej Industrial Estate
Plot No: D-2/14/A, GIDC Dahej
Tal: Vagra, Dist: Bharuch-392140

Auditor

SHROFF S R ROTARY INSTITUTE OF CHEMICAL TECHNOLOGY (SRICT)
Block No. 402, At & Post Vataria, Dist. Bharuch

Executive Engineer (W/D)
G.I.D.C., Bharuch.

PREFACE

We thank **Gujarat Pollution Control Board, Gandhinagar and Honorable High Court of Gujarat** for entrusting us to carry out Schedule – I Environmental Audit.

We thank **M/s. CETP of Dahej Industrial Estate**, CETP & other plant personnel's for giving us their kind cooperation and helping us in carrying out the monitoring work.

- Environment Audit of **M/s. CETP of Dahej Industrial Estate** was carried out by making three comprehensive visits and monitoring & analysis including Air, Wastewater, Noise and Solid Waste analysis.
- Grab samples of untreated and treated effluent were taken and analyzed during different seasons.
- The audit report is based on data furnished by industry and data collected by the audit team during visits to the industry.
- The data collected and information received from the industry like energy consumption, water consumption, material balance etc. with analysis of the effluent, Ambient air, stack emission, solid waste has been used in judging the adequacy and efficacy of Environmental Pollution Control Measures.

EXECUTIVE SUMMARY

The Environmental Audit Scheme was introduced by the Gujarat High Court vide its orders dated 20/12/96 & 13/3/97 and modified vide order dated 16/9/99, 22/04/2010 & 23/01/2015, **SHROFF S R ROTARY INSTITUTE OF CHEMICAL TECHNOLOGY** is nominated to carry out Environmental Audit work for the industries falling under Schedule - I category.

INTRODUCTION

M/s. CETP of Dahej Industrial Estate, located at Plot No: D-2/14/A, GIDC Dahej Tal: Vagra, Dist: Bharuch-392140 operates as a Common Effluent Treatment Plant (CETP).

GPCB has appointed **SHROFF S R ROTARY INSTITUTE OF CHEMICAL TECHNOLOGY** as Environmental Auditor to carry out environmental audit for the year 2022-2023.

OBJECTIVES

(1) To check the Adequacy & Efficacy of the common effluent treatment plant, i.e. Waste water, Air, solid waste, health and safety systems of **M/s. CETP of Dahej Industrial Estate.**
(2) To check various records of Environment Management System.
(3) To check whether **M/s. CETP of Dahej Industrial Estate** meets all required norms of state regulatory agency that is Gujarat Pollution Control Board regarding environmental pollution control.

OPERATIONAL BRIEFING:

The above mentioned objectives have been fulfilled through meaningful inspection visits and precise study of its manufacturing system & pollution control facilities.

1) GPCB has appointed **Shroff S R Rotary Institute of Chemical Technology** to prepare Environmental Audit Report for the year of 2022-23. This report consists of concerned data for the month of October 2022–March 2023 verified by our authorized representatives.
2) The findings reported in this audit report are entirely based on data furnished by the industry & data collected by the audit team during the month of October 2022–March 2023.
3) Thus the findings reported in this audit report are subjected to physical surveys & monitoring conducted by the audit team representatives.

OBSERVATIONS

- M/s CETP of Dahej Industrial Estate is organization having valid consent vide order No. **AWH 107883** dt.20/04/2020 which is **valid up to 14/01/2025**.
- It has a design capacity of 40 MLD for treatment of industrial effluent through Primary, secondary and tertiary treatment facilities.
- The member industries send their industrial effluent to Dahej CETP through designated pumping station.
- Industry has installed flow measuring devices at Inlet of CETP for quantity of effluent received from member units for treatment and at Final Outlet for the quantity of effluent discharged to GIDC sea disposal pipeline.
- Industry has installed TOC analyzer at final treated effluent discharge line to sea disposal pipeline for composite treated effluent sample collection and analysis.
- Industry has installed CCTV camera at various locations for better monitoring and control of plant operation as required.
- Total power consumption during the current audit period (Oct'22-Mar'23) is 50.3 KWh which is 44.35 % less as compared to 90.4 KWh in the Half year (Apr'22-Sep'22) and 2869.92 % higher as compared to 12.9 KWh in the Half year (Oct'21-Mar'22). As per industry, there was only one oxidation ditch working during Half year (Oct'21-Mar'22) and after that two oxidation ditch working during Half year (Apr'22-Sep'22) because of increase in effluent load, so that Total power generation was become very high.
- Total Water consumption during the current audit period (Oct'22-Mar'23) is 11550 KL which is decreased by 8.33 % as compared to 12600 KL in the half year (Apr'22-Sep'22) and 1.04 % increased as compared to 11431 KL in the Half year (Oct'21-Mar'22).
- Total Waste water generation during the current audit period (Oct'22-Mar'23) is 556670 KL which is increased by 457.29 % as compared to 99888 KL in the half year (Apr'22-Sep'22) and 492.73 % increased as compared to 93916 KL in the Half year (Oct'21-Mar'22). AS per the industry, number of industries was taken membership of CETP and their effluents were come in CETP than waste water generation was increased.
- Water Intake (**83522M^3 / Month**) is less compared to the Outflow (**92778M^3 / Month**). As per the industry, two aeration tanks were under maintenance, because of which they had to be emptied and thus the outflow has increased. Industry also has practice of recirculating the effluent wherein the parameters are not under limit.
- Industry has consumed avg. 3270.5 liters/Month of diesel during audit period of October'22 to March'23 due to MGVCL Power failure and Electrical Breakdown.
- The Total sludge generation during half year (October 2022 to March 2023) is 10 MT and Industry did not send the sludge to TSDF during half year (October 2022 to March 2023).
- The port holes in DG Set stack is not available during half year (October 2022 to March 2023).
- Industry achieved average 84.58 % efficiency of Biological System during half year (October 2022 to March 2023).
- CETP receives effluent from different industries are by pipeline system so industry has no records of actual quantity of effluent received by individual industries.

- Industry has no ISO Certificate.
- Industry has PLI Policy.
- Industry has no on site emergency plan.
- Chlorine tonner safety hood stack was not running during half year (October 2022 to March 2023).
- TSS found out of the limit in Equalization tank during 4th and 6th audit.
- Hexavalent chromium found out of the limit in Equalization tank during 5th and 6th audit.
- Phenol and Sulphide found out of the limit in Equalization tank during all three audits.
- TSS found out of the limit in Final O/L during 4th audit.
- Hexavalent chromium found out of the limit in Final O/L during 5th and 6th audit.
- Show cause notices were received by GPCB and their compliance ware given by industry as follow.

Notice No.	Date	Remarks	Compliance and compliance Date
624737	05/03/2022	CETP shall provide SCADA and automation system for monitoring, Surveillance and discharge control.	Noted (12/04/2022)
624737	05/03/2022	CETP shall carry out regular maintenance and proper operation of its treatment units.	GIDC shall appoint the agency for maintenance and proper operation of treatment units (12/04/2022)
675314	16/06/2022	Fully fledged operation of CETP was not stated.	GIDC have dicided to upgrade and retrofitting of the CETP and invited the tender for treatability study more than 25000 mg/l to implementation to ACT technology. (30/06/2022)
675314	16/06/2022	TOC meter at final outlet of CETP was not working and not connected to CPCB/GPCB server	TOC meter at final outlet of CETP, now it is working condition and connected to GPCB Server. (30/06/2022)
675314	16/06/2022	SPV (Special Purpose Vehicle) had not found for proper operation and maintenance of the CETP.	SPV company has been formed. After completion procedure, CETP will be handed over to SPV company for proper operation. (30/06/2022)
675314	16/06/2022	ETP did not have any record	Now operation record

		book for operation of CETP and no any record of chemical consumption were maintained.	books and chemical consumption record are maintained. (30/06/2022)
675314	16/06/2022	CETP found under acclimatization stage during inspection.	Now, CETP is acclimatization. (30/06/2022)
675314	16/06/2022	There was no biomass in oxidation ditch.	Bio mass is observed but low quantity of received at CETP. F/M ratio should not be maintained throughout, so bio mass is not continuous stable. (30/06/2022)
675314	16/06/2022	CETP did not have adequate in-house HW storage facility with leachate management system.	Hazardous waste storage is facilitated with water tight roof and also leachate management system facility is available. (30/06/2022)

RECOMMENDATIONS

- Maintenance of the records should be more elaborative and regular.
- Online DO meter should be maintained.
- The provision for sampling port should be made in D.G. Set stacks.
- The unit should strictly control the parameters which were found out of the limit in audit visits.
- Industry should go for more green belt development.
- Achieving zero discharge can be the next goal for the CETP.
- Company should get ISO certification for better quality management.
- Company should develop an onsite/offsite emergency plan.
- Company should change the position of the outlet meter i.e it should be after the recirculation valve.
- Company must have full time Medical Officer to ascertain the health of workers.

Sr. No.	Observations	Audit Date of Observation	Compliance status
1.	Sampling port was not available on D.G Sets stack during 4th audit.	15/11/2022	Not Complied in the 5th & 6th audit.
2.	Chlorine tonner safety hood stack was not running during 4th audit.	15/11/2022	Not Complied in the 5th & 6th audit.
3.	TSS was out of the limit in Equalization tank during 4th audit.	15/11/2022	Complied in the 5th audit.
4.	TSS was out of the limit in Equalization tank during 6th audit.	02/02/2023	Not Complied till date.
5.	Hexavalent chromium was out of the limit in Equalization tank during 5th & 6th audit.	06/01/2023 02/02/2023	Not Complied till date.
6.	Phenol and Sulphide were out of the limit in Equalization tank during 4th, 5th & 6th audit.	15/11/2022 06/01/2023 02/02/2023	Not Complied till date.
7.	TSS was out of the limit in Final O/L during 4th audit.	15/11/2022	Complied in the 5th & 6th audit.
8.	Hexavalent chromium was out of the limit in Final O/L during 5th & 6th audit.	06/01/2023 02/02/2023	Not Complied till date.

COMPLIANCE OF RECOMMENDATIONS GIVEN BY SCHEDULE - I AUDITOR DURING PREVIOUS YEAR 2022-23

Sr. No.	Observations	Compliance status
1.	Immediate action is needed from concerned authorities to increase the membership of CETP, Dahej.	CETP gets more membership but CETP should take more membership for full potential of the plant must be utilized.
2.	Maintenance of the records should be more elaborate and regular.	Not complied
3.	The provision for sampling port should be made in D.G. Set stacks.	Not complied

Executive Engineer (W/D)
G.I.D.C., Bharuch.

Annexure-8

GUJARAT INDUSTRIAL DEVELOPMENT CORPORATION
(A GOVT. OF GUJARAT UNDERTAKING)

Azadi Ka Amrit Mahotsav

**Office of the Executive Engineer
(WS & Drg.)**
1st floor, Narmada Commercial Complex,
Panch Batti, Bharuch.

Phone : (02642) 242432 / 244183
E-Mail : xen-brc@gidcgujarat.org

No.GIDC/EE/BRH/AB/ 1129 **Date : 04/10/2022**

Work Order

To,
**M/s. Krishna Corpindia Pvt Ltd JV M/s R C Patel Jv M/s Flowline System Pvt Ltd (KCPL-RCP-FSPL(JV),
1ST Floor, ACME Centre,
44, Shrimali Soc,
Netaji Road,
Ahmedabad 380 009
Ph : 079-26494004
E Mail: team@krishnacorpindia.com, dhruv@krishnacorpindia.com**

**Computerized MB No. 63 (Drainage)
Computerized MB No. 64 (M&E Work)**

SUB :Work order for the work of Engineering, Procurement & Construction (EPC) Design, erection, Testing, Commissioning of 90 MLD offshore and onshore Effluent disposal pipeline from Saykha Pumping Station to LFP (Z-93, Dahej SEZ-II) including Civil Structure, Electro-Mechanical & PLC SCADA components including 5 years Operation & Maintenance at Dahej PCPIR (Re-Invited)

REF : 1. Your office letter No KCPL/GIDC-Dahej/2022-23/13 dated 30/09/2022
2. This office letter No. GIDC/EE/BRH/AB/1001 dated 14/09/2022.

DRAINAGE SUB DIVISION G.I.D.C. BHARUCH Inward No. 961 Date 7/10/22

Agreement No.:- C/01 of 2022-23.

Dear Sir,

This office is pleased to inform you that your tender for the above mentioned work is accepted at your quoted rate of **17.5713% above** of the estimated cost having tender amount of **Rs.5,58,00,00,180.610** (Rupees Five Hundred Fifty Eight Crore, One Hundred Eighty & Sixty One Paisa Only) against the estimated cost put to tender of Rs.4,74,60,57,599.63 and informed to you vide this office above mentioned letter. Since you have paid security deposit and have executed the contract agreement, you are hereby informed to start the work with the issue of this work order and to carry out work as per tender conditions. Your time limit for the work is for **24 (Twenty Four)** months from the date of work order & trail run shall be 6 (Six) Months immediately after completion of work, so as to complete the work on or before **03/10/2024 & Trail run shall be six months after completion date.**

You are requested to go through the terms & condition of the tender agreement & to execute and complete the work accordingly. It is requested to contact Deputy Executive

**Executive Engineer (W/D)
G.I.D.C., Bharuch.**

Engineer (Drg) & Deputy Executive Engineer (M&E) for day to day monitoring, execution of work as per the tender conditions & specifications. It is to state that any work in excess of tender quantity for any item shall not be executed without prior permission of GIDC.

The agency is requested to apply for Registration with Commissioner of Labour of Gujarat State, under the contract Labour act. (Regulation & abolition, Act 1970) and rules there under and to maintain prescribed records and registers as per the Act.

The agency is also required to register and inform to the department as per THE BUILDING AND OTHER CONSTRUCTION WORKERS' (REGULATION OF EMPLOYMENT AND CONDITIONS OF SERVICE) ACT, 1996 and rules there under and maintain prescribed records and registers as per the Act.

The Contractor shall be responsible for complying with the provision of the employees Provident Fund and miscellaneous provision Act-1952 Scheme and modifications of the act from time to time.

Thanking You.

Yours Faithfully,

Executive Engineer, (W/D)

GIDC, Bharuch

Executive Engineer (W/D)
G.I.D.C., Bharuch.

SD Details:

1. Initial S.D./PB :- **Rs 14,23,81,800.00** paid by the agency vide Bank Guarantee No.0333IGP002595422, dtd 27/09/2022 of Bank of Baroda valid upto 30/03/2025.
2. Remaining SD: - **Rs. 11,86,51,440.00** to be recovered from R.A. bills.

Copy S.W.R to:

1. The Chief Engineer, GIDC, Gandhinagar for information please.
2. The Superintending Engineer (HO), GIDC, Gandhinagar for information please.
3. The Superintending Engineer (CG), GIDC, Bharuch for information please.

Copy to:

1. Executive Engineer (M&E), GIDC, Bharuch for information please.
2. DEE(M&E), GIDC, Bharuch for information please.
3. DEE (Drg), GIDC, Bharuch for information & further necessary action.
4. PB, GIDC, Bharuch for information.

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Annexure-9

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NIO/SP-9/2023
SSP3467

Marine ecological monitoring and assessment around the GIDC discharge locations at Dahej, Gujarat

SPONSORED BY

Gujarat Industrial Development Corporation

October 2023

सीएसआईआर – राष्ट्रीय समुद्र विज्ञान संस्थान
CSIR-NATIONAL INSTITUTE OF OCEANOGRAPHY
(वैज्ञानिक तथा औद्योगिक अनुसंधान परिषद)
(COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH)
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Executive Engineer (W/D)
G.I.D.C., Bharuch.

Marine ecological monitoring and assessment around the GIDC discharge locations at Dahej, Gujarat

Project Leader

Umesh Kumar Pradhan

Associate Project Leader

Soniya Sukumaran
Udayakrishnan P.B.

October 2023

सीएसआईआर – राष्ट्रीय समुद्र विज्ञान संस्थान
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Contents

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Dr. Umesh Kumar Pradhan	Chemical Oceanography
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Dr. Soniya Sukumaran (SIC)	Biological Oceanography
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Dr. Sabyasachi Sautya	Biological Oceanography
Dr. Haridevi C.K.	Biological Oceanography
Dr. Abhay B. Fulke	Biological Oceanography
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Mr. Harshal Satish Jadhav	Biological Oceanography
Ms. Shrushti Sudhir Eranezhath	Biological Oceanography

EXECUTIVE SUMMARY

INTRODUCTION

Hon'ble NGT western zone, in their order no. 60/2021 (WZ) dt. 02.02.2022 [Aryavart Foundation versus Hemani Industries Ltd. & Ors.] has directed M/s. Gujarat Industrial Development Corporation (GIDC) to conduct a detailed impact assessment study for the marine ecology considering the non-compliance and discharge of highly polluted wastewater into the Dahej CRZ area. The matter concerns wastewater management by industries and GIDC located in Dahej industrial area. Accordingly, on the request of M/s. GIDC, the CSIR National Institute of Oceanography (CSIR NIO) has conducted a detailed marine survey in the intertidal and subtidal region of Dahej coastal area during October 2022 and studied the chemical, microbiological and biological characteristics of water and sediments to assess the marine environment. The rsults of the study conducted in Oct-22 were compared with the data of previous monitoring studies around the same region as available with CSIR NIO. The comparison of the study results have helped in better assessment of the prevelant marine ecological status around the region.

The non-functioning of diffuser implanted for the treated effluent discharge by GIDC at an offshore location suggested by CSIR NIO in its report year 2000, have caused effluent disposal into the intertidal region after released from the Final Pumping Station (FPS). The combined effluents those received from GIDC CETP and other industial treatment units are collected at FPS, before discharged into the sea at off Luvara. Due to the non-functioning of diffuser and discontinuous pipeline, the effluent from the FPS was found to be discharged in the intertidal region during the sampling period, briefly at a location around 600-800 m away from the High Tide Line (HTL) off Luvara, which thereafter spread and flow through a snaky channel across the intertidal region, and mixed with the gulf water. Marine water and sediment samples collected by CSIR NIO from the intertidal and subtidal regions during Oct-22 were analysed for their physicochemical, microbiological, and biological study. The sampling was done during different tidal conditions and over a diurnal scale at different locations to acquire every possible signal of water and sediment quality changes due to the prevailing natural and anthropogenic activities around Dahej. Downcore sediment sections along the intertidal region were collected covering the northern sector, disposal area, before and after the disposal point, and in the Narmada estuary (located in the south) to obtain the information on contaminants those sccumulated over the period of time (if any). Water and sediments near the disposal and flow pathway were analyzed, and the effluent sample was collected before its discharge to the FPS at Ambheta (Section 4). The main objectives of this study are the following;

1. To collect and analyze physicochemical and biological data on water and sediment samples around the GIDC discharge location and its surroundings in Dahej.
2. To evaluate the current marine ecological status in the region.
3. To recommend a suitable mitigation measure for restoring the marine ecology in the region if found impacted.

The present report contained information on physicochemical, microbiological, and biological study results in water and sediment samples determined at scientifically selected sampling stations, covering a wide area between a reference point (less human interference) in the north and the Narmada estuary in the south long the Gulf of Khambhat. The results include studies performed at 10 subtidal and intertidal stations. Besides, 26 locations were chosen for extenshive intertidal sediment quality study, which includes 7 locations for sediment core study and 3 intertidal transacts for chemical and biological studies. Information on the fisheries and mangroves were collected and compared with their secondary published data. The prevalent water and sediment quality results were compared with the previous study results available with CSIR NIO reports/literatures and detailed in Section 5. The impact assessment study and suggested mitigation are presented in Section 6.

As observed during the survey in Oct-22, a pipeline (1000 mm OD) carrying effluents from the landfall point (around Lat: 21°39'51.956"N Long: 72°32'20.442"E) was laid perpendicular to the HTL, discernable with other pipelines exposed and laid in parallel. The effluents released from the pipe at location Lat: 21°39'50.010"N Long: 72°31'56.690"E was approximately 0.6 km from the HTL, which spread across and rooted through a snaky channel till the gulf, primarily visible during the low tide. The effluents mixed with overlying tidally borne waters spread during the high tide. The channel ends near the gulf (Lat: 21°39'59.464"N Long: 72°31'20.568"E) after crossing approximately 2.5 km of intertidal section. The addition of unknown effluents from the different pipelines were recorded at several places, identified through foul-smelling and bubbling. The temperature and color of the effervesced waters differed from the malodourous effluent. The photographs associated with the sampling activities and essential landmarks in the marine region are presented in Plates 1-5. Depending on the hydrography variation, the entire subtidal region has been categorized into three segments viz. estuary, nearshore, and offshore. The intertidal region has been categorized into northern, central, and southern segments, where the central segment is close to the disposal area.

PREVAILING MARINE ECOLOGICAL CONDITION

Chemical Characteristics

i) The average water temperatures in the intertidal and subtidal waters during Oct-22 were 28.8 °C and 28.6 °C, respectively, with wide variation in the intertidal region due to diurnal temperature change and shallow water column. A temperature maximum of 34.2 °C was at the disposal region, which was aligned with highest air temperature (35.7 °C). Overall, the water temperature was less than 35 °C in most of the data set and broadly comparable with the historical limits, therefore less vulnerable to the sustenance of tropical aquatic specie.

ii) The average pH changes between subtidal and intertidal waters was minimal (i.e., 7.9 and 7.5, respectively) during Oct-22 and remained comparable with historical pH variation in the region. The temporal pH changes at the intertidal and subtidal disposal locations were marginal and aligned with the natural marine waters sustaining low primary productivity.

iii) The salinity was lower than seawater and averaged at 20.7 and 16.6 PSU, respectively at the subtidal and intertidal regions during Oct-22. The low salinity was caused by the freshwater input through rivers (Narmada, Vishwamitri etc.) during the preceding monsoon, and highlighting natural seasonal variation. The segment-wise low salinity values were random when compared with historical limits. The increase in salinity due to addition of treated effluent was not evidenced during the study.

iv)The average SS, turbidity, and TDS values in subtidal waters during Oct-22 were 1483 mg/L, 1232 NTU, and 26159 mg/L, respectively, much higher than the limits observed in the intertidal region. The SS variability was natural, with significantly higher limits in the subtidal bottom water and random during the sampling period. The disposed effluent and intertidal waters have lower SS, turbidity, and TDS than the subtidal waters.

v) The disposed effluents were mainly anoxic and have impacted the DO levels in surrounded water in the intertidal region. The subtidal waters were ecologically healthy, with average DO levels of 6.7 mg/L, during this study. Historically, the nearshore waters off Dahej remained well-oxygenated with low BOD_3. The average COD in the subtidal and intertidal regions were 112 and 190 mg/L during this study, as similar to their limits generally found in Indian coastal waters. The temporary COD enrichment in the intertidal region was due to higher COD (~300 mg/L) of disposed effluents.

vi)The average phosphate and TP concentrations in the Dahej subtidal waters were 1.9 µmol/L and 2.4 µmol/L, several times lower than those found in the intertidal water (13.2 and 15.9 µmol/L, respectively). The subtidal water nitrogen and phosphorous compounds have disproportionately increased, without any significant modifications in the stoichiometric ratios during the last few years. The intertidal waters were enriched with nitrite, ammonium, and TN with maximum values of 110, 149, and 213 µmol/L, respectively, and showed random increases between the tidal epochs, indicating disproportional inputs from the effluents. The high nitrite and ammonium resulted due to the effects of low oxygen that inhibited nitrite oxidation in the intertidal disposal area.

vii) The SO_4^{2-}: Cl^- ratio in subtidal water was averaged at 0.13, close to the normal seawater, whereas it was higher in the intertidal region (avg. 0.54), indicating sulphate enrichment aligned by dispersed effluents. The petroleum hydrocarbon (PHc) and phenolics were low, randomly varied in the subtidal waters, and have not highlighted any oil contamination due to the effluent disposal around the intertidal region.

viii) The surficial sediments from the intertidal and subtidal regions have comparable PHc, organic carbon, and phosphorous contents, markedly lower than their limits generally found in western India coastal and nearshore environments. The lower contents of these compounds can be attributed to larger grain sizes of sediment and lower absorption.

ix) During the present study, occasional moderate enrichment of Cu, Zn, Co, and Fe compared to their geological limits was found in the estuary and offshore segments. The central intertidal segment (ITC), predominated with developmental activities, showed significant enrichment of Mn, Cu, Zn, Co, and Fe in sediment during this study.

x) During this study, the sediment near the disposal area and the channel had noticeably higher metal contents than those in the subtidal region. The downcore variability of metals across the disposal region has indicated moderate to significant enrichment of most metals in the bottom layer (50 cm), indicating their accumulation due to rapid settling. Alternatively, the area before disposal and the sea limit of the disposal pathway have shown moderate enrichment of metals towards the upper layer (30 cm from the surface), affected by the tidal disturbances that displaced the upper sediment layer.

Biological Characteristics

i) The microbial counts in subtidal water (TVC: 12×10^3 CFU/mL to 28×10^3 CFU/mL) and sediments (TVC: 19×10^4 CFU/g to 56×10^4 CFU/g) were generally low during Oct-22 than their limits found in other coastal regions of India. *Escherichia coli* like organisms (ECLO) and *Streptococcus faecal* like organisms (SFLO) were also absent at most stations, indicating that the study area was primarily free from fecal pollution concerning the standard specified by the CPCB for seawater quality.

ii) The average chlorophyll *a* was 0.4 mg/m³ in the subtidal region, with the highest value of 2.7 mg/m³ at the estuary and intermediate values of 0.3-1.0 mg/m³, recorded at the disposal area during Oct-22. Historically, chlorophyll *a* around Dahej remained <1 mg/m³, indicating lower productivity potential, and in the nearshore waters, chlorophyll *a* decreased over time. The variations in the phytoplankton cell counts were insignificant, with higher cell counts and genera found near the disposal area and estuary. Species such as *Merismopedia sp., Surirella sp., Amphiprora sp.,* and *Amphora sp.* were dominant in the disposal area. *Mermopedia* sp., *Nitzschia* sp., *Synedra* sp., *Nitzschia acicular, Navicula* sp., and *Coscinodcus* sp. were the major species in the Estuary zone.

iii) The zooplankton community structure was dominated by copepods (87.1%). Overall, 18 groups of zooplankton were identified from samples collected during Oct-22. The zooplankton biomass has decreased in the nearshore waters of Dahej over time. The zooplankton density and faunal groups were higher in the estuary and nearshore after Dahej industrial development (2007). After that, the density reduced, and the faunal groups remained more or less comparable. The zooplankton group diversity was consistent during post-industrialization.

iv) The subtidal macrobenthic biomass (max. 1.3 g/m²) and population (max. 75 No. /m²) found in Dahej during Oct-22 and earlier samplings were low in numbers compared to the productive coastal regions of India. The low macrobenthic productivity can be attributed to high turbidity and unstable bottom conditions associated with strong tidal currents prevailing in the Gulf of Khambhat. The major faunal components were polychaetes (76.5 %) among the 9 faunal groups recorded during Oct-22 in the region. The intertidal transect ITC surrounded by a developmental zone had the highest average population and faunal group diversity compared to the northern and southern regions. The faunal groups found in the nearshore and offshore areas were comparable before and after industrialization. Only polychaetes were observed in the area. The meiofauna also displayed poor density and group diversity, indicating that the area was not conducive for benthic organisms.

v) The marine region off Dahej is not an active commercial fishing ground. Shore-based fishing using bag nets or other traditional gear was noticeable during Oct-22 in the northern region. Based on the inquiries with the local fishermen and the Department of State Fisheries, Ghogha, trawlers generally do not operate in the Gulf between Dhadhar and Luvara and in the estuarine segment of Narmada. The low fishery potential of the region is due to high turbidity, strong currents, and low biological potential at different trophic levels. The fish samples collected from the shore had variable PHc (0.1 to 5.2, µg/g wet. wt.; avg. 1 µg/g wet. wt.) in gills and muscles tissue, which are comparable or lower than the values found in the north and central Arabian Sea.

vi) About 5 km north of Birla Copper Jetty (Lat 21° 43' 960"N and long 72° 33' 076"E) a dense patch of *Avicennia marina* approximately 4.5 km^2 exists along the open shore, Dhadhar and Dahej creeks. Obligate halophytes such as *Sesuvium portulacastrum* and *Suaeda maritima* is commonly noticed along with *A. marina* in the region just above the mean high tide level. *S. maritima* is dominant at the supralittoral zone. *Salvodora persica* appears commonly beyond the supralittoral zone.

The present study results broadly highlighted the enrichment of metals in the intertidal sediment of the central segment surrounded by major developmental activities, with metal accumulation in the bottom sediment near the disposal area and effluent flow pathway across the intertidal region. The subtidal waters have evidenced increased nutrients (N and P) with minimal stoichiometric variations. Elevated chemical constituents in the effluents have affected the intertidal water quality in the vicinity but had a negligible impact on the nearshore and offshore water owing to the strong hydrodynamic condition of the gulf. Lower biological productivity in the nearshore and offshore areas has been related to the general gulf characteristics, which randomly fluctuated during the post-industrialization (2007) in Dahej. The benthic biota has restrained their group diversity by a single dominant group, such as polychaetes, and no biomass was found in the disposal area. No significant changes have been noticed concerning the fisheries and mangroves, which were of lower potential and located far from the disposal region.

IMPACT ASSESSMENT AND MITIGATION

The GIDC CETP and other treated effluent disposal through FPS occurs at a location around 600-800 m away from the HTL off Luvara, Dahej. The disposal of effluent in the intertidal region have accumulated major chemical constituents around the region. The absence of a diffuser and prevalent low-energy conditions have triggered the enhanced levels of BOD_3, COD, and nutrients in the intertidal waters. The toxic metals scavenged by SS rapidly settled in the bottom sediment. Enriched chemical constituents in the intertidal region have caused acute toxicity to flora and fauna, leaving no biomass close to the disposal location. The exposure of aquatic biota to these contaminated waters is possibly short-term, owing to the naturally lower biomass and diversity in the nearshore region. However, for the restoration of sediment quality and to have a healthy intertidal ecological status, the present study recommended appropriate and immediate measures to relocate the present disposal to the offshore location and implantation of an efficient diffuser system for appropriate dispersion in the marine water. The incredible variety of chemical products that are established to be poisonous can be monitored in water and sediment samples. Identifying and repairing broken pipeline networks buried in the intertidal region is necessary to minimize the unaccounted other discharges. Reducing pollution and eutrophication are relatively straightforward to restore the damaged intertidal communities to bring them into a more natural and healthy state. Once the effluent influx into the intertidal ecosystems has stopped, the original state can be gradually expected. The poor biodiverse state of the intertidal region inhabited only by a single dominant group (polychaete) probably requires more than many years without disturbances.

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GENERAL ABBRIVIATIONS

Abbreviations	Details
avg.	Average
B	Bottom
BOD_3	Biochemical Oxygen Demand (3 days at 27°C)
BDL	Below Detectable Limit
OC	Organic Carbon
DO	Dissolved Oxygen
Eb	Ebb tide
FL	Flood tide
Max.	Maximum
Min.	Minimum
mL	Mililitres
mg/L	Milligrams per Litre
MESS	Marine Sediment Certified Reference Material
%	Percentage
µmol/L	Micromoles per Litre
µg/L	Micrograms per Litre
µg/g	Micrograms per gram
°C	Degree Centigrade
ND	Not Detectable
NG	No Growth
NTU	Nephelometric Turbidity Unit
NH_4^+-N	Ammonium-Nitrogen
NO_2^--N	Nitrite-Nitrogen
NO_3^--N	Nitrate-Nitrogen
PACS	Marine Sediment Certified Reference Material
PHc	Petroleum Hydrocarbons
PSU	Practical Salinity Unit
PO_4^{3-}-P	Phosphate-Phosphorus
S	Surface
SS	Suspended Solids
CFU	Colony Forming Unit
EC	*Escherichia coli*
FC	Faecal Coliforms
SFLO	Streptococcus Faecalis Like Organsims
TC	Total Coliforms
TVC	Total Viable Counts

1. INTRODUCTION

1.1 Background

The treated effluent discharge network of Gujarat Industrial Development Corporation (GIDC) has 4.5 km long pipeline laid till the offshore region from Final Pumping station (FPS). The pipeline is buried in the intertidal zone and in the sea bed of GoKh around the location off Luvara. The discharge location was identified and suggested earlier by the CSIR National Institute of Oceanography (CSIR NIO) in 2000 through a comprehensive oceanographic study and mathematical modeling. In the matter of Hon'ble NGT OA no. 60/2021 (WZ) dt. 02.02.2022 [Aryavart Foundation versus Hemani Industries Ltd. & Ors.] related to the wastewater management by the industries and GIDC in the Dahej industrial area, Hon'ble NGT has ordered GIDC to carry out a detailed impact assessment study for the marine ecology in consideration of the non-compliance and discharge of high polluted wastewater into the CRZ area, given the above, M/s. GIDC has requested the CSIR-NIO to conduct a detailed marine ecological assessment study in the region of their present discharge and surrounding locations in their letter No. GIDC/EE/BRH/AB/360 received dt. 31.05.2022.

CSIR NIO conducted marine environmental sampling in October 2022 (Oct-22) and studied physicochemical, microbiological, and biological parameters in the water and sediment samples from the intertidal and subtidal regions around the project area. The sampling stations selected scientifically covering the Narmada estuary region in the south and the subtidal waters of GoKh in the west and north. Temporal studies for water quality was carried out at the location where present disposal from the FPS is taking place and also at the location of diffuser which was earlier recommended by CSIR NIO in its study during 2000. Spot sampling was done covering a wide area around the intertidal region, where there are possibilities of effluent dispersion at present and along the exposed channel formed by the disposal in the intertidal region, briefly the region from the disposal point to the meeting point of GoKh. Downcore sediment sections were studied to understand the accumulation of contaminants released from the effluent. The study results were compared with historical data available with CSIR NIO in the same region. The differences in the average limits of parameter before and after the Dahej industrial devlopement (2007) were assessed.

1.2 Objectives

The objective of the present study are the followings;

1. To collect and analyze physicochemical and biological data on water and sediment samples around the GIDC discharge location and its surroundings in Dahej.
2. To evaluate the current marine ecological status in the region.
3. To recommend a suitable mitigation measure for restoring the marine ecology in the region if found impacted.

1.3 Scope of work

CSIR NIO shall conduct observations on water and sediment chemical characteristics, microbiology, plankton, and benthos, to evaluate the current ecological status around the disposal location and the marine regions surrounding the activity. The study shall include information on marine fisheries and mangroves, which shall be from the field observation and secondary published data. The study shall include seasonal water, sediment, and biota sampling results of post-monsoon (Oct-22) based on the sampling around subtidal and intertidal regions. The marine monitoring study shall cover nearshore and offshore regions of the GoKh, estuarine areas of the Narmada, and the intertidal regions, vicinity of the disposal. Sampling shall include temporal and tidal observations at selected locations within the boundary of the Narmada and in GoKh to understand the spatial variability of ecological parameters. Temporal observations are to be near the present intertidal disposal location and one at the offshore location suggested earlier by CSIR NIO, and the spot sampling shall be covering the offshore areas. The present study shall assess prevailing marine ecological conditions around the region and suggest appropriate mitigation measures concerning the disposal in the intertidal region. The following parameters are under the scope of this study;

(a) Water quality

Seawater quality analysis for physicochemical parameters study at 10 locations including temporal and tidal observations are under the scope. The chemical parameters considered are attributable to their scientific importance in marine ecological processes. The seawater quality parameters of this study are; temperature, pH, salinity, SS (Suspended Solid), turbidity, DO (Dissolved Oxygen), BOD_3 (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), essential nutrients (N: nitrate, nitrite, ammonium; P: reactive phosphate, total N and P), petroleum compounds (hydrocarbon and phenolics), sulphate, chlorides, and Total Dissolved Solids (TDS).

(b) Sediment quality

Surficial sediments shall be from intertidal and subtidal locations, analyzed for grain-size distribution, OC (organic carbon) content, concentrations of P (phosphorus), metals such as Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Pb, Cd (aluminum, chromium, manganese, iron, cobalt, nickel, copper, zinc, lead, cadmium, respectively), and petroleum hydrocarbon (PHc) during the study.

(c) Biological characteristics

The biological parameters shall be studied to analyze the microbial population, phytopigments, phytoplankton population and diversity, zooplankton biomass, population, and group diversity present in the collected seawater. Microbiology, macrobenthic biomass, population, and group diversity study performed shall be on collected sediment samples at different locations. The results shall include information on fisheries status from the secondary published reports and observation of mangroves during the sampling periods.

(d) Impact Assessment

Based on the information collected, the present study shall establish the prevailing ecological status and compare the results with the earlier data of the CSIR NIO database to assess the changes (if any) in the water and sediment. The impact of effluent disposal in the intertidal region on the nearby marine environment shall be evaluated based on the water, sediment, and biota analysis. The study shall suggest appropriate mitigation toward maintaining a healthy ecosystem around the project site.

1.4 Approach strategy

The release of treated industrial effluent into the coastal waters would inevitably cause specific impacts on the marine environment. The intensity depends on various factors, viz., quality and quantity of effluent, the assimilative capacity of the receiving water, and the degree of ecological sensitivity of the region. Detailed data collection and reliable information on the ambient quality of water, sediment, and biota near the project activities are required to delineate potential perturbations due to the activities.

The release of treated effluent in the intertidal region by the project activity would inevitably cause specific impacts on the marine environments nearby and on the GoKh waters. These adverse effects depend upon the tidal volume available at the location, which may have potential to dilute and disperse the effluent away from the released location. Hence, the location of intertidal effluent discharge point was monitored over the tidal cycle for 12h, aligned with similar observation at the offshore disposal point suggested earlier by CSIR NIO. As the effluent plume rises in the receiving water column, it gets transported and dispersed away from the discharge location under prevalent dynamic conditions. Hence, the spot sampling of other locations in the subtidal area was considered adequately in this study.

The pipeline from the FPS to the offshore marine discharge point was buried in the intertidal zone and sea bed, recommended in the study of CSIR NIO in the year 2000. Later, the pipeline was disrupted due to the choking of diffuser, which had caused network breakage, and the disposal begun in the intertidal region i.e., between the high tide line (HTL) and low tide line (LTL), roughly 600-800 m away from the HTL. The direct disposal into the intertidal region has substantial potential for the deposition of chemical constituents (e.g., contents of heavy & trace metals, organic carbon) in nearby water and sediments. The addition and removal of sediment during the epochs of high and low tide events would cause partial burial of these constituents, causing enrichment in the bottom layer over the period. Depending on the biogeochemical properties and hydrodynamic condition, residual sediments in the intertidal region shall act as a natural sink or release the contaminants through passive or active diffusion affected by the tidal action that may cause deterioration of the water quality in the vicinity, and ultimately affecting marine ecological health. To take suitable mitigation measures, detailed and reliable information on water and sediment properties are essential to understand.

To evaluate the prevalent marine ecological status possibly affected by the disruption of the pipeline network and discharge of treated effluents in the intertidal region, a proper scientific method, ensuring the preservation of the quality of the aquatic environment, is implemented. Assessing the impacts of the above activities on the marine ecosystem would require general and detailed baseline information about the activities in the region and their probable impact on the marine ecological processes. For this purpose, the chemical, microbiological, and biological parameters were studied in the water and sediment samples in 10 scientifically selected locations around the subtidal and intertidal regions. The stations in the subtidal region were selected in the nearshore and offshore regions at different radii (5 and 10 km) from the project site, respectively. Temporal observation for 12 hr was carried out at the present disposal point also one at the disposal point suggested earlier by CSIR NIO in the subtidal region. Tidal observations were carried out at the nearshore stations located in radii of 5 km landward. The tidal water dilutes and disperses the pollutants away from the released location. One site in the Narmada estuarine area was monitored over the tidal cycle. Sediments from the intertidal region were studied at 26 locations, including the cores, intertidal transacts and the effluent flowing channel. Intertidal sediments were studied for benthos, and chemical constituents at 3 transacts and the downcore sediment was collected along the north-south gradient centering the present disposal location.

CSIR NIO has undertaken several investigations in the region earlier and acquired data. Understanding the relevant ecosystem health, water quality, sediment characteristics, and biological data would facilitate the assessment and changes taking place in due course of time.

2. PROJECT INFORMATION

GIDC is the nodal agency responsible for developing industrial estates in Vilayat and Dahej in Gujarat State. The agency has received consent (WH-110550 dt. 03/12/2020) for collecting treated effluents from the GIDC-Vilayat and GIDC-Dahej estates member units to a final quantity of 90,000 m^3/day (90 MLD). The agency received consent for laying a conveyance pipeline of 52.5 km and discharging the treated effluent. The pipeline length of about 4.5 km was to be buried in the intertidal region before the final discharge at the offshore location 21°39' 26" N and 72°29'50" E (depth: 20 m below the Chart Datum, off Luvara) recommended through study by CSIR NIO.

The inland facilities, such as effluents from GIDC-Vilayat (25,000 m^3/day), are collected in a sump having 220 m^2 area and 2.5 m depth below the invert level. The GIDC-Dahej effluents (40,000 m^3/day) are also collected in the sump, serving as the receiver from GIDC-Vilayat. The provision of handling an additional capacity of 25,000 m^3/day is available at these sites. The treatment facility has a bar screen and a grit chamber to trap floating matter and grit in the effluent before they flow into the sumps by gravity. The treated effluent passed through the pipeline networks between Vilayat and Dahej reaches the landfall point and is disposed of through a carbon steel pipeline (1000 mm OD), buried in the intertidal area, and anchored using concrete blocks in the subtidal area. The outfall was proposed through a 130 m long diffuser with 20 discharge ports to achieve a conservative 200 times effluent dilution from the original.

The treated effluent discharged into the intertidal region flows through a naturally built channel, spreads around, and mixes with the GoKh water (Fig.1). The channel carrying the treated effluents can be noticed during the low tide and submerged during the high tide (Fig. 2). The laid pipeline and concrete blocks remain exposed in the intertidal region and the diameter of the pipeline is about 1000 mm (OD; HDPE pipe). The low and high tide conditions, effluent-carrying channel, and the exposed pipeline section are visualized in Plate-2.

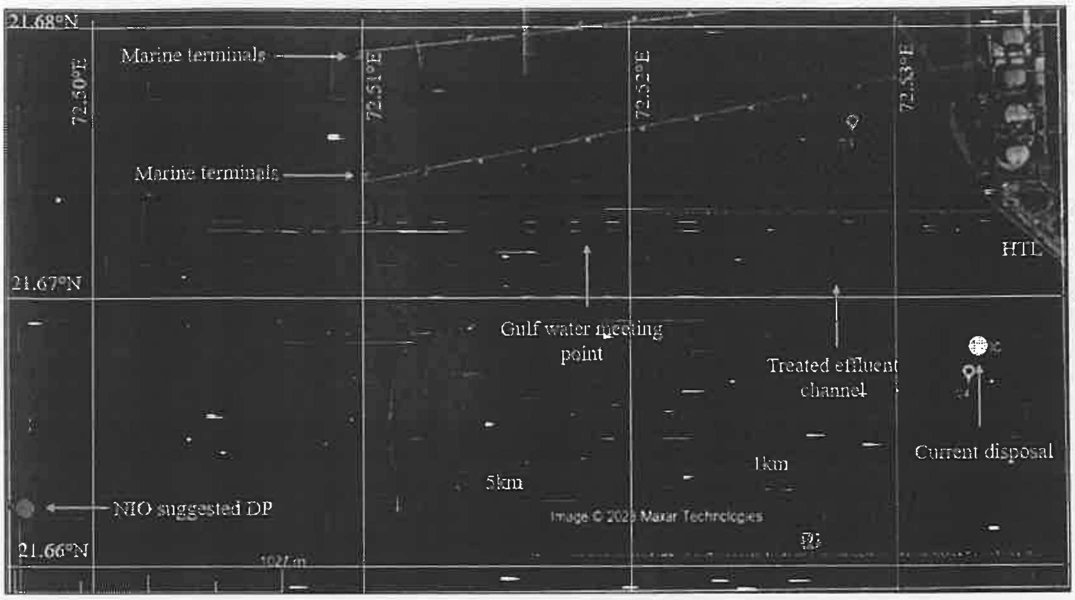

Fig. 1: Effluent discharge channel in the intertidal region off Luvara during low tide.

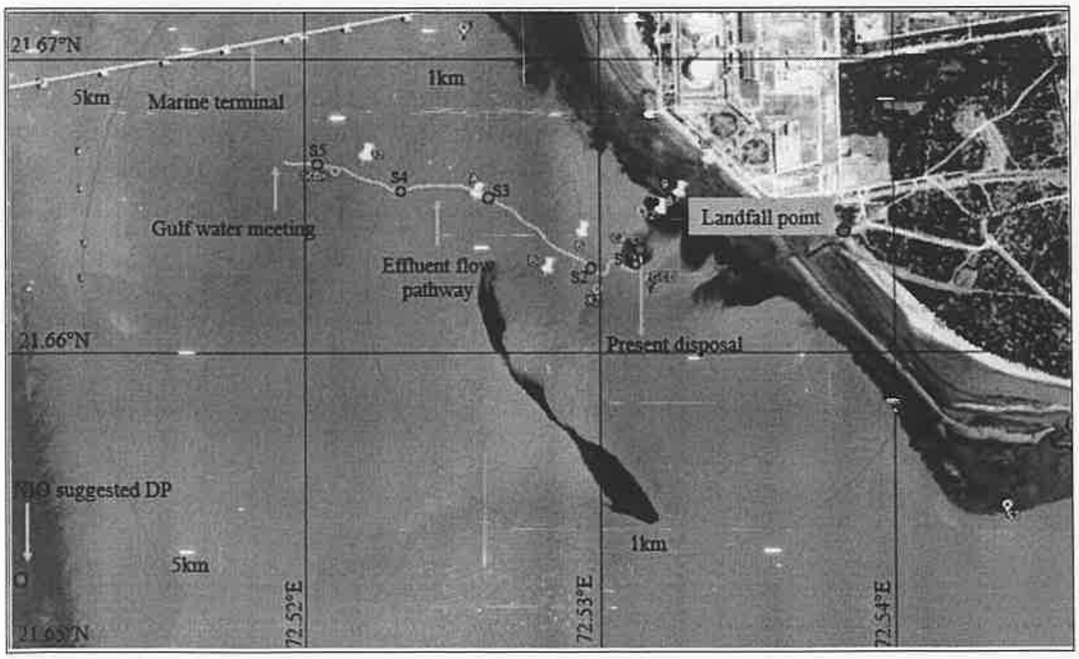

Fig. 2: Effluent discharge pathway in the intertidal region off Luvara during high tide.

3. PROJECT DOMAIN

3.1 General information

The land fall point for combined discharges from GIDC CETP and other industries is located near the village of Luvara, and the onshore pipeline network spreads across Dahej and Lakhigam. The area is a small town, Dahej, with a few scattered and moderately populated villages. The establishments such as jetties by GMB (Narmada parikrama) and other private companies for their activities are located near the project. The marine terminals that handle various ship-based activities are located in the subtidal region along the northern segment of the region. The GMB port is located in the northern segment of the project site. The estuarine regions of Narmada exist in the southern segment with a small private jetty and Ro-Ro ferry by GMB (Fig. 3). The coastal land in the project vicinity is generally of waste land with low vegetation and covered by silty loam and intertidal region. The land terrain near the coast is generally sandy, flat, and sloping in the direction of the sea towards the west. The sandy coastal stretch of nearly 500 m landward from the HTL reveals a sparse occurrence of salt-tolerant plants like *Acassia.* Alia Bet, in the mouth of the Narmada estuary, has vast stretches of grasslands, while the banks of Dahej have marshy zones with isolated pockets of scrubby mangroves. The coastal terrain around Narmada is flat, and the black soil is highly fertile and cultivable except at the estuarine mouth, mainly devoid of flora.

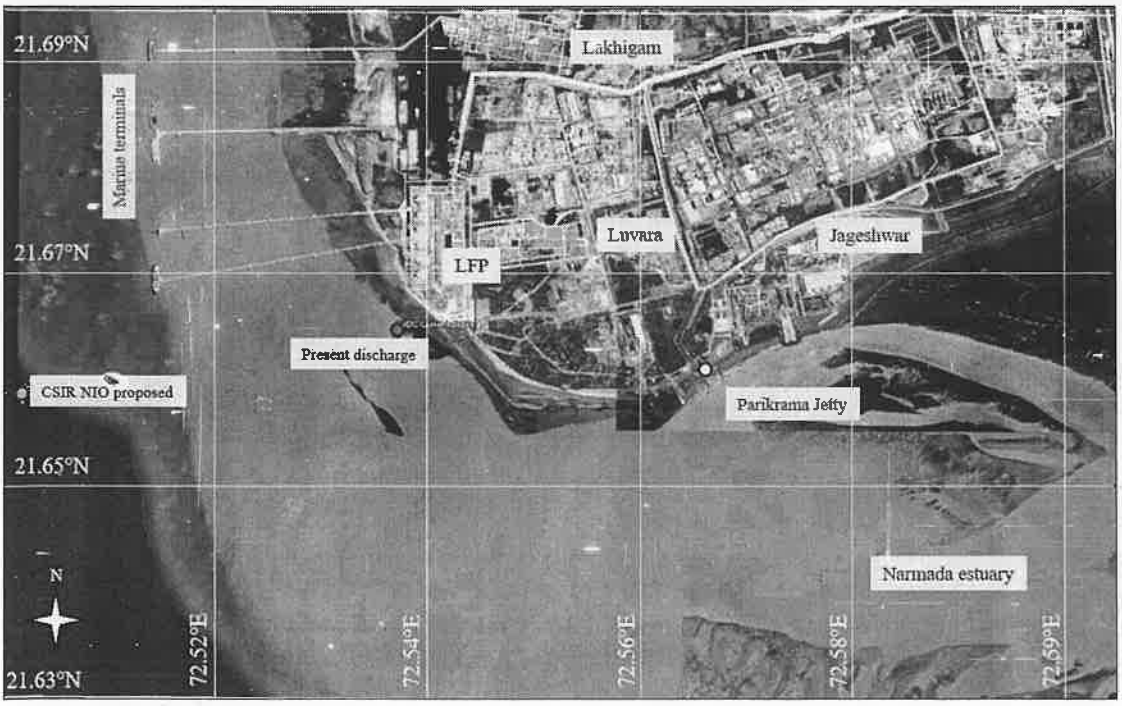

Fig. 3: Marine environmental setting around Dahej, Gujarat.

3.2 Marine environmental condition

The coastal land around the project site mainly holds the sub-bottom pipeline network and is surrounded by the GoKh and Narmada estuary, highly influenced by tidal incursion. The region experiences significant strong tides in the 4.6-8.7 m range (CSIR NIO report). The tides are semidiurnal, with a slack period of about 30 minutes at high water and 25 minutes at low water. The comparison between the predicted tide at Luvara ranges nearly 0.85 m between the high and low tide periods. The currents in the region are bimodal and generally move N-NE during flood and S-SW during ebb tides. The maximum current speed varied between 1.4 m/s during neap and 3.5 m/s during spring, indicating net flow more or less in the southerly direction and promoted by the freshwater inflow. The GoKh lies between the coast of Surat and Bharuch districts eastward and the peninsula of Kathiawar on the western side.

The results of previously observed biogeochemical observations in the region highlighted that the water quality parameters such as temperature, salinity, and SS were primarily constrained by the spatiotemporal changes and affected by the river runoffs in southwest monsoon and high tidal currents during non-monsoon seasons. The waters were oxic, and BOD_3 was within the limit of marine waters due to the highly dynamic condition. The dissolved nutrients concentration remained higher in the GoKh, influenced by the strong interaction of water column and sediment, also from the sewage through rivers. Overall, the water quality was good concerning the open coastal system of the West Coast of India. The organic carbon and PHc content in sediments were low. The variations in sediment metals were mainly related to grain-size distribution. There were minimal sediment chemical parameters variation between the subtidal and intertidal regions.

The phytopigments such as Chlorophyll *a* and phaeophytin and the phytoplankton cell counts around the GoKh waters off Dahej were moderate to low compared to their limits found in the coastal waters of India. *Nitzschia, Skeletonema*, *Coscinodiscus,* and *Thalassiosira* were the common genera recorded in the GoKh. The seasonal and tidal variability in primary production was minor owing to the prevailing high SS. Similarly, the zooplankton standing stock was minor, with lower diversity of zooplankton groups in the region. The zooplankton was mainly dominant, with copepods, decapods, and chaetognaths in the region. The intertidal and subtidal macrobenthos of the GoKh region vary widely and indicate low benthic production in the subtidal region. Polychaetes, crustaceans, and molluscs were the significant components of macrobenthos in the GoKh. This low macrobenthic productivity attributes to high turbidity and unstable bottom conditions associated with strong tidal currents prevailing in the region. The region has no commercial fishing grounds. Shore-based fishing through the bag or hand nets can be seen. The region sustains shallow fishery in terms of catch (0.1 - 10.5 kg/h). The major components of fish caught were clupeids, catfishes, Bombay ducks, mullets, sharks, and shrimps.

4. PROGRAMME OF THIS STUDY

The present study was conducted in Oct-22 to get a detailed scenario of marine environmental characteristics around GoKh water, particularly the effluent disposal sites. The results of this study were compared further with the baseline (pre-project activity period) that includes the study results between 1997 and 2022, available with CSIR NIO. The comparative analysis helped to assess the changes in the present marine ecological condition around Dahej region. Stations were scientifically selected between longitude 72.45°E-72.65°E and latitude 21.60°N-21.75°N, covering approximately 175 km² area.

4.1 Sampling locations

The 10 subtidal locations were selected for sampling have covered the northern (GN1 and GN2), central (GC1 and GC2), southern (GS1, GS2, and GS3) sectors, and Narmada estuary (NE). A reference station (GR) was selected in the northern region, approximately 10 km from the project activity, avoiding anthropogenic activity. The station GCD was near the present disposal location in the intertidal region. The station GC1 was near the subtidal disposal point recommended earlier by CSIR NIO. The sampling locations of this study are presented in Table 1 and displayed in Fig. 4.

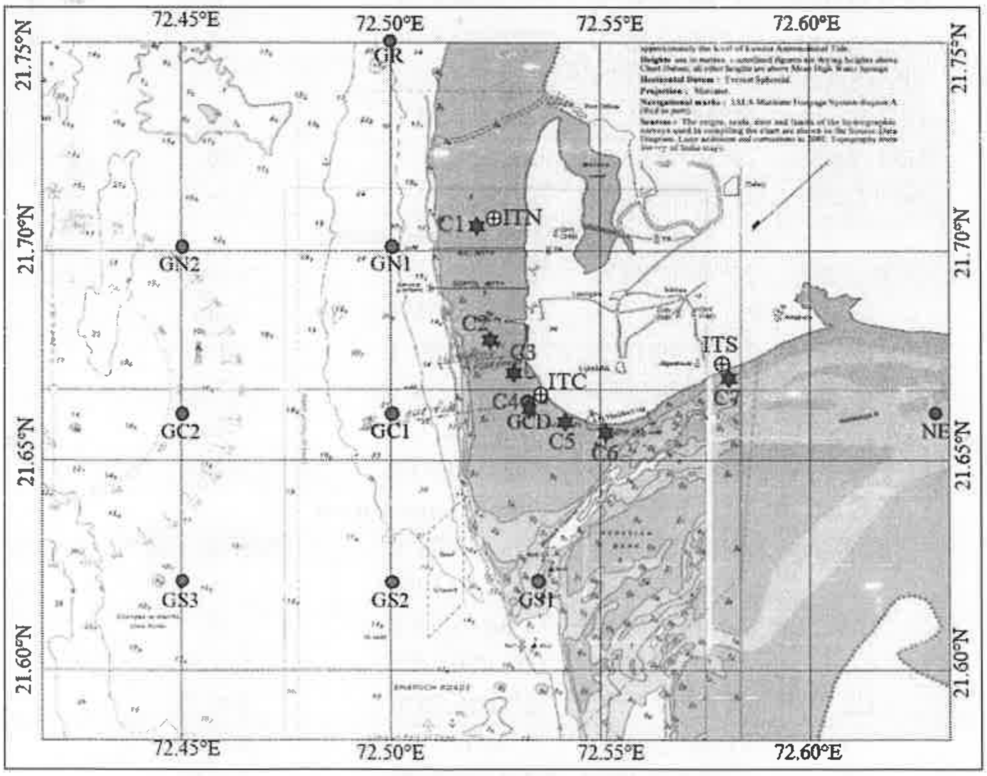

Fig. 4: Sampling locations for marine monitoring off Dahej.

Water and sediment samples were collected from the subtidal stations for physicochemical and biological parameter analysis. Benthic biomass and sediment chemistry studies were conducted at three intertidal locations (ITN, ITC, and ITS). The core samples collected at the seven locations (C1-C7) in the intertidal area were studied to understand the accumulation/enrichment of chemical constituents over the period. The water and sediment samples were collected along the channel (S1-S5) formed between the present disposal point and the GoKh in the intertidal region (Fig. 2). The stations within the nearshore region were monitored during different tidal conditions of the sea, and the stations in the offshore were spot sampled. The stations of this study, which coincided with previously observed stations by CSIR NIO, were selected for comparison. The photographs associated with sampling activities and the intertidal environmental conditions are presented in the Plates (1-5).

Table 1: Geographical location of sampling stations around Dahej.

Station	Latitude	Longitude	Measured depth (m)
Subtidal (water and sediment)			
GR (Tidal)	21°45'00.24"N	72°30'00.55"E	19-24
GN1 (Tidal)	21°42'01.11"N	72°30'00.36"E	20-24
GN2 (Spot)	21°42'00.63"N	72°26'58.61"E	16
GC1 (12hr)	21°39'36.67"N	72°29'59.87"E	27.5-32
GC2 (Spot)	21°38'59.35"N	72°26'59.35"E	18
GS1(Spot)	21°35'57.77"N	72°33'00.18"E	2
GS2 (Spot)	21°35'59.68"N	72°29'59.75"E	19
GS3 (Spot)	21°36'00.18"N	72°26'59.21"E	20
NE (Tidal)	21°38'58.81"N	72°35'59.24"E	2.5-7
Intertidal (water and sediment)			
GCD (12hr)	21°39'47.88"N	72°31'57.13"E	<1m
S1	21°39'49.25"N	72°31'56.56"E	<1m
S2	21°39'49.10"N	72°31'49.20"E	<1m
S3	21°39'54.26"N	72°31'41.58"E	<1m
S4	21°39'57.88"N	72°31'32.50"E	<1m
S5	21°39'59.84"N	72°31'20.90"E	<1m
Intertidal (sediment and cores)			
ITN	21°42'25.92"N	72°31'35.05"E	Surface (S)
ITC	21°39'51.91"N	72°32'10.19"E	S
ITS	21°40'20.88"N	72°34'46.53"E	S
C1	21°42'21.55"N	72°31'16.74"E	S-0.55
C2	21°41'13.12"N	72°31'16.76"E	S-0.55
C3	21°40'13.92"N	72°31'42.78"E	S-0.45
C4	21°39'44.32"N	72°31'58.82"E	S-0.60
C5	21°39'29.09"N	72°32'28.89"E	S-0.75
C6	21°39'22.41"N	72°33'3.88"E	S-0.65

C7	21°40'11.77"N	72°34'49.94"E	S-0.45
5	21°39'50.01"N	72°31'56.05"E	S
6	21°39'51.01"N	72°31'49.60"E	S
8	21°39'53.72"N	72°31'59.31"E	S
9	21°39'55.79"N	72°32'01.58"E	S
10	21°39'59.77"N	72°32'05.14"E	S
12	21°40'00.27"N	72°31'23.23"E	S
A	21°39'55.72"N	72°31'36.76"E	S
B	21°39'46.59"N	72°31'45.30"E	S
X2	21°39'45.24"N	72°31'51.90"E	S-0.30
Y2	21°39'54.70"N	72°31'57.41"E	S-0.30
GCDX	21°39'59.70"N	72°31'19.98"E	S-0.30

S: surface layer

4.2 Sample collection and analysis

The sampling and observations conducted in this study were categorized under different environmental components, such as chemical and biological characteristics. Standard scientific methodologies were adopted to collect and analyze marine samples described below.

4.2.1 Seawater samples

(a) Collection and pre-treatment

Surface and bottom water were collected for desired chemical analyses using a 5L Niskin water sampler, with a closing mechanism through messenger (Plate 5). The surface samples were collected at 0.5 m below the water layer to avoid contamination, and bottom water samples were collected 1 m above the sedimentary bed to prevent the impact of bottom resuspension. Only surface samples were collected for shallow regions (≤ 3 m). The water samples collected were directly from the Niskin sampler through tubing (TYGON) and stored separately in pre-cleaned polypropylene/HDPE bottles for different parameters. In-situ parameters such as water temperature, pH, and turbidity were measured onboard. The samples were stored in an onboard icebox (4 °C) until transport to the shore laboratory. The chemical parameters, such as nutrients, were measured on the same day of sample collection. Dissolved oxygen (DO) samples were fixed using fixing reagents onboard, detailed below.

(b) Analytical methodology

Most water quality parameters were analyzed within 24 h of collection in the shore laboratory. Concentrations of dissolved inorganic nutrients were determined by colorimetric method. The petroleum hydrocarbon (PHc) concentrations in water and sediment were determined by solvent extraction technique.

i) **Temperature:** Temperature was measured immediately after sample collection using the centigrade mercury thermometer with a graduation of 0–50 °C (Precision ±0.05).

ii) **pH:** pH of the water sample was measured onboard using a portable pH meter (Model: Eutech Tutor) with an accuracy of 0.1 pH units. The instrument was first calibrated with standard pH buffers of pH 7.0 and pH 9.0, and then the measurements were made.

iii) **Suspended Solid (SS):** Total Suspended solids of a known volume of water sample were measured by filtration technique (Preston and Summers, 1997). Seawater samples were filtered through pre-weighed membrane filters (pore size, 0.45μm) using vacuum filtration pump. The filter papers were then oven-dried (45°C) and weighed again. The difference of initial and final weights of the filter paper is the SS. Turbidity was measured in a Nephelometer based on the percent transmittance method (Model: Orion AQ4500; Thermo Scientific Ltd.). The US-EPA-approved SDVB primary turbidity standards (0.02-1000 NTU) were used for instrument calibration. TDS was measured using gravimetry method using sensitive anaytical balance to weigh residual dissolved solids from seawater (Grasshoff et al. 1999).

iv) **Salinity:** Salinity was measured using an "Autosal" Laboratory Salinometer (Model: Guideline 8400B; Guideline Instruments Ltd.) based on continuous flow through a conductivity cell at a selectable temperature range technique. International Association for the Physical Sciences of the Oceans (IAPSO) standard seawater (salinity: 34.995; Ocean Scientific International Ltd.) was used to calibrate the instrument. Chloride concentrations were calculated from the salinity-conductivity relationship (Cox et al. 1967). The analytical precision for salinity was 0.001 PSU. The lower salinity values were determined by Mohr-Knudson argentometric titration method (Grasshoff and Wenck, 1972). Using silver nitrate as the titrant and potassium chromate as an indicator.

v) **Sulphate:** The concentration of sulphate (SO_4^{2-}) was determined gravimetrically using Barium Chloride ($BaCl_2$) precipitation technique (Grasshoff et al. 1999), with an analytical precision of ≤5 %.

vi) **DO and BOD_3:** DO concentration in seawater was estimated by Winkler's method (Grasshoff et al., 1999). A known volume of seawater sample was first fixed onboard by adding the Winkler's reagents A (manganous chloride) and B (alkaline potassium iodide) immediately after collection. The formed precipitate was then decomposed with 50% Hydrochloric Acid (HCl), and the released iodine was titrated against $Na_2S_2O_3$. The Endpoint of titration was determined using the starch indicator. The unusual high BOD values were determined by dilution method (APHA, 2000). Concentrations of DO are expressed in mg/L. Samples to determine Biochemical Oxygen Demand (BOD_3) were collected in triplicate. The DO concentration was determined first using one of the triplicate samples. The remaining bottles were incubated in a BOD_3 incubator for three days at 27°C. DO concentration in these samples was determined by Winkler's method after fixing the samples immediately on completion of 3 days incubation period. The difference in the DO concentrations on the 1st and 3rd days yielded the measure of BOD_3 and expressed in mg/L.

vii) Chemical Oxygen Demand (COD): The measurement of COD in samples were made using the method described in Burns and Marshall, 1965, modified in USEPA 410.3, (1979), after the correction of chloride ion (Cl^-) interference. Briefly variable $HgSO_4$: Cl^- ratio used for different samples depending up on the Cl^- content and to mask the excess Cl^-. Mercuric sulphate was added to complex the chloride, and silver sulphate is the oxidation catalyst. The samples are refluxed for 2hr at 150°C in the presence of standard potassium dichromate ($K_2Cr_2O_7$), concentrated H_2SO_4 and silver sulphate ($AgSO_4$). The excess $K_2Cr_2O_7$ present in digested solution was titrated with standard Ferrous Ammonium Sulphate ($(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O$) and the oxidizable matter was calculated in terms of oxygen equivalent. The analytical precision achieved in this methodology was less than 10% during this study.

viii) Phosphate-Phosphorous (PO_4^{3-}-P): Dissolved reactive phosphate was measured by the method of Murphy & Riley (1962), modified by Grasshoff et al., 1999, in which the samples were made to react with acidified molybdate reagent and reduced using ascorbic acid. The absorbance of the resultant blue complex was measured at 882 nm using a UV-Visible spectrophotometer (Model: Shimadzu UV 1240). The instrument performance was evaluated using the international nutrient seawater standard (OSIL, UK).

ix) Nitrite-Nitrogen (NO_2^--N): Nitrite was determined by the method of Grasshoff et al., 1999, wherein the nitrite in the samples was measured after diazotizing it with sulfanilamide and coupling with N (1-Naphthy)-ethylenediamine dihydrochloride. The absorbance of the resultant azo dye was measured at 543 nm using a spectrophotometer.

x) Nitrate-Nitrogen (NO_3^--N): Nitrate in the samples was first reduced to nitrite pa, using each through an amalgamated cadmium reduction column, and the resultant nitrite was determined as above. The measured absorbance was due to the initial nitrite in the sample and the nitrite obtained after nitrate reduction. Therefore, a necessary correction was made for any nitrite initially present in the sample.

xi) Ammonium-Nitrogen (NH_4^+-N): Ammonium -nitrogen was determined by the Indophenol blue method based on the principle that ammonia was allowed to react in a moderately alkaline medium with hypochlorite in the presence of catalytic amounts of nitroprusside to form indophenol blue. The formation of monochloramine requires a pH between 8 and 11.5. The resultant blue complex was measured at 630 nm by spectrophotometer. The total forms of nitrogen and phosphorous in water samples were measured using persulphate oxidation (autoclave) and then determining the nitrate and phosphate as described in Grasshoff et al., 1999.

xii) Petroleum Hydrocarbons (PHc): The PHc in water and fish samples were extracted from in n-hexane and quantified by using a spectrofluorophotometer (Model: Shimadzu RF-5301PC) with excitation at 310 nm and emission at 360 nm (Ehrhardt, M. 1983, IOC-UNESCO 1984). The reference material for quantifying hydrocarbons was Saudi Arabia mixed (SAM) crude oil.

xiii) Phenols: Phenols in water were converted to an orange-colored antipyrine complex by adding 4-amino antipyrine. The complex was extracted in chloroform (25 mL in 500 mL seawater), and the absorbance was measured at 460 nm using phenol as a standard (Carranzo, I.V., 2012).

4.2.2 Sediment samples

(a) Collection and pre-treatment

Surficial sediment was collected using a stainless-steel van-Veen grab (0.04 m^2 area) operated from the boat (Plate 5). After collection, a portion was subsampled from the grab avoiding contamination, and stored in a cleaned polythene bottle. The samples were immediately stored in an icebox (≤ 4°C) until further processing at the CSIR-NIO, RC Mumbai laboratory.

(b) Analytical methodology

i) Texture: Dried sediment (25 g) mixed with deionized water and 10 mL sodium hexametaphosphate (6.2 g/L) was sieved through a 63 µm sieve to retain sand, and the passed material was dispersed in deionized water (1L). The fractions (20 mL) collected at 20 and 10 cm depths immediately and after 2 hr 3 min were considered silt and clay, respectively. Collected sediment fractions were dried separately and weighed. Different fractions of sediment are expressed as percentages (%).

ii) Metals: Sediment samples were brought into solution by treatment with concentrated HF-$HClO_4$-HCl-HNO_3 in the ratio 1:3:5:5: and the metals were estimated on a Perkin Elmer (Optima 7300 DV) Inductively Coupled Plasma-Optical Emission Spectrophotometer (ICP-OES) and selected metals on Inductively Coupled Plasma – Mass Spectrophotometer (ICP-MS, Thermo iCAP-RQ) (Loring and Rantala, 1992). On an Analytical precision and reproducibility were achieved by comparing the measurement of international marine sediment CRM (certified reference materials, NRC Canada) available such as MESS3, MESS4, and PACS4 presented in Table 2. Samples for Hg analysis were digested using an acid mixture (HF-HCl-HNO_3 at 1:1:3) in semienclosed digestion vessel at 120°C for 90min. Post-digestion, the Hg measurement was carried out on a ICP-MS using gold solution (Au) as detailes in Bulska et.al. 2017. Certified and observed values of Hg in CRM (MESS4) using the above method were 3.04±0.20 µg/g and 3.06±0.07 µg/g, respectively. The analytical recovery was more than 95% for Hg in the used method.

Table 2: Certified and observed values of International CRM (Marine sediments).

CRM	MESS 3		MESS 4		PACS 4	
Elements	Certified	Observed	Certified	Observed	Certified	Observed
Co (µg/g)	14.4 ± 2.0	14.0 ± 1.7	13.0 ± 0.8	13.1 ± 0.91	12.1	13.4
Ni (µg/g)	46.9 ± 2.2	43.9 ± 2.7	42.8 ± 1.6	40.7 ± 3.3	39.5 ± 2.2	34.4 ± 3.8
Cu (µg/g)	33.9 ± 1.6	32.9 ± 2.8	32.9 ± 1.8	31.2 ± 3.1	326 ± 10	308 ± 18
Cr (µg/g)	105 ± 4	105.57 ± 8	94.3 ± 1.8	96.3 ± 4.4	90.6 ± 4.0	97.9 ± 7.6
Mn (µg/g)	324 ± 12	312 ± 20.20	298 ± 14	290 ± 15	432 ± 16	405 ± 17
Zn (µg/g)	159 ± 8	152 ± 11	147 ± 6	142 ± 6	376 ± 12	370 ± 25
Al (%)	8.59 ± 0.23	7.98 ± 0.37	7.91 ± 2.0	7.61 ± 0.4	6.58 ± 0.1	6.41 ± 0.5
Fe (%)	4.34 ± 0.11	4.34 ± 0.22	3.79 ± 1.6	4.0 ± 0.3	4.1 ± 0.1	4.4 ± 0.3

iii) PHc: Sediment after refluxing with KOH-methanol mixture was extracted with hexane. After removing excess hexane, the residue was subjected to a clean-up procedure by silica gel column chromatography. The hydrocarbon content was then estimated by measuring the fluorescence described in section 4.2.1 analysis for PHc (IOC-UNESCO 1984).

iv) Organic Carbon (OC): Percentage (%) of OC in the dry sediment was determined by oxidizing organic matter in the sample by chromic acid and estimating excess chromic acid by titrating against ferrous ammonium sulphate with ferroin as an indicator (Walkely and Black et al., 1934).

v) Total Phosphorus: Homogenized sediments were boiled in an acid mixture $HClO_4$, HCl, HNO_3 at 110°C. The clear solution obtained was diluted and made up to a fixed volume to measure phosphate, as described in section 4.2.1 (Grasshoff et al., 1999; Radojevic and Bashkin, 2006).

4.2.3 Flora and fauna

(a) Collection and pre-treatment

Samples for microbiology study was collected in autoclaved PP bottles to avoid contamination and stored in an ice box till their analysis in the shore laboratory. To estimate phytopigments and phytoplankton population (cell count), surface and bottom water samples from Niskin were collected. Samples for enumeration of phytoplankton cell count were fixed with Lugol's iodine onboard, and samples for phytopigments were kept in the icebox and transported to the laboratory. Zooplankton was collected by oblique haul using a Heron Tranter net (mesh size= 0.20 mm, mouth area= 0.25 m²) attached with a calibrated flow meter. All collections were of 5 min duration. Samples were preserved in 5% buffered formaldehyde. Subtidal surficial bed sediment from all locations were collected by a van Veen grab of 0.04 m² area in a quadruplicate for analysis of macrobenthos. The sample after retrieval was transferred to a polyethylene bag and preserved for further analysis. The sediment was sieved through a 0.5 mm mesh sieve, and animals retained were stained with Rose Bengal and kept in 5% buffered formaldehyde.

(b) Analytical methodology

i) Microbes: The fecal coliforms and total coliforms number were determined using a conventional three-tube, three-dilution Most Probable Number (MPN) procedure with minimal modifications to the FDA Bacteriological Analytical Manual (BAM) and American Public Health Association (APHA, 1961) recommended procedures for the examination of sediment, and the water samples. Following homogenization, a 1:10 dilution of homogenate was prepared with 1× phosphate buffered solution (PBS) and 1-g equivalent and was transferred to the three tubes of 10 mL of double-strength Lauryl Tryptose Broth (LTB). One milliliter aliquot (0.1-g equivalent) was also transferred to the three tubes of single strength LTB, while three 1-mL aliquots of a 1:100 dilutions were also transferred to the single-strength LTB. Presumptive positive tubes were confirmed for fecal and total coliforms using EC Medium broth and Brilliant Green Bile broth, respectively. Results are reported in MPN/100 mL (for water) or MPN/100 g (for sediment). Samples were analyzed by serial dilution followed by spread plate techniques for Total Viable Counts (TVC), *Escherichia coli* like organisms (ECLO), and *Streptococcus faecal* like organisms (SFLO). The media employed for growth of bacteria were as follows:

Table 2A: Information on the media used for the bacteria growth.

Serial no	Bacterial type	Culture medium
1	Total Viable Counts	Zobell marine agar
2	Total coliforms (TC) (MPN method)	Lauryl Tryptose Broth Brilliant Green Bile Broth
3	Fecal coliforms (FC (MPN method))	Lauryl Tryptose Broth EC Broth
4	*Escherichia coli* (EC)	M7HrFC Agar
5	*Streptococcus faecal* (SF)	M Enterococcus Agar

ii) Phytoplankton pigments: A known volume of water sample (500 mL) was filtered through a 0.45 µm membrane filter (Millipore), and the planktons retained on the filter paper were extracted in 90% acetone for pigments (Parson et al., 1984). To estimate Chlorophyll *a* and phaeophytin, the fluorescence of the acetone extract was measured using Fluorometer (Turner Design Trilogy) before and after treatment with dilute acid (0.1N HCl). The concentration of phytopigments (Chlorophyll *a* and Phaeophytin) is reported as mg/m^3.

iii) Phytoplankton population: 500 mL of sample was preserved with Lugol's solution and allowed to settle and concentrate to 100 mL. 1 mL of the concentrated sample was transferred into a Sedgewick-Rafter slide for the enumeration and phytoplankton identification and identified and counted under an inverted microscope to the lowest possible taxa (Tomas, 1996). The phytoplankton population density is reported as $\times 10^3$ Cells/L.

iv) Zooplankton: The displacement volume method obtained Biomass and was represented as mL/100m^3 (Harris et al., 2000). A portion of the sample (25-50%) was analyzed under a microscope for faunal composition and population count and reported as $\times 10^3/100m^3$.

v) Macrobenthos: For the macrobenthic study, sediment was sieved through a 0.5 mm mesh sieve, and retained animals were stained with the Rose Bengal and preserved in 5% buffered formaldehyde (Buchanan et al., 1984). The total population was estimated as the number of animals in 1 m^2 area and biomass on a wet weight basis (g/m^2).

5. PREVAILING MARINE ENVIRONMENT

The overall coastal water quality off Dahej would be the net result of the rate at which the anthropogenic contaminants enter the system, are assimilated, and removed from the system. The primary anthropogenic activities in the region are the industrial treated effluent those discharged through several pipeline networks at the pre-designated locations. The other activities that can potentially influence water quality, such as over fishing, agriculture etc. are mainly absent in the region. Ship movement, loading and unloading activities in the marine terminals, leakage of effluents from the broken pipeline, and domestic sewage discharge are the other important sources of contamination in the marine and estuarine environment concerning the localized human activities around GoKh region.

5.1 Existing marine environmental status

The oceanographic observations made during Oct-22 at different stations off Dahej was classified into distinctive segments centering on the project activity region, which was to understand the prevailing environmental and ecological status better. The details of sampling stations corresponding to different segments in the intertidal and subtidal regions are presented in Table 3. The observed water quality results at the subtidal region are presented in Table 4.

Table 3: Sampling stations representing different segments around the project area.

Segments	Stations	Region
Reference	GR	Subtidal
Northern	GN1, GN2	
Central	GC1, GC2	
Southern	GS1, GS2, and GS3	
Estuary	NE	
Disposal area	GCD	Intertidal
Disposal channel	S1, S2, S3, S4, S5	

Diurnal observations made were at the vicinity of the present intertidal disposal area (GCD) and the vicinity of the offshore disposal point suggested earlier by CSIR NIO (GC1) are presented through graphs within the text. The average water quality parameter concentrations observed in the channel across the disposal area and the GoKh water limit (S1-S5) are presented in Table 5, along with the measured water quality in treated effluent from FPS. The water quality, sediment quality, flora, and fauna results are averaged segment-wise and presented in the Table within the text for interpretation.

5.1.1 Measured water quality

5.1.1.1 Temperature

The water temperature generally varies with the prevalent air temperature in shallow coastal areas, primarily alters due to any artificially induced warm water release. The observational water and air temperature ranges in the subtidal region were 27-31.6°C (avg. 28.8°C) and 27-35°C (avg. 30.5 °C), respectively, during Oct-22. The water temperature range at GCD disposal was between 23.2°C and 34.2°C, averaged at 28.6°C, which was in the range of subtidal temperature limits (Tables 4 and 5). The highest temperature, 34.2°C, was during the peak solar insolation at GCD, and the lowest was along the disposal channel (S1-S5). Temperature variation between surface and bottom water in the subtidal region was insignificant due to the well-mixed water column. Due to the Narmada water influence, the southern and estuary segments had lower temperatures than other segments (Table 5A).

Table 5A: Segment-wise temperature distribution around GoKh during Oct-22.

Segments	Water temperature (°C)	Air temperature (°C)
Reference	28.4-29.0 (28.7)	28.5-32.0 (30.3)
Northern	28.9-30.5 (29.4)	29.5-31.0 (30.6)
Central	27.0-31.6 (28.9)	28.0-35.0 (30.6)
Southern	27.5-28.5 (28.1)	28.0-32.0 (30.3)
Estuary	27.0-28.5 (27.5)	27.0-29.5 (28.3)
Disposal area	26.0-34.2 (30.1)	24.6-35.7 (32.4)
Disposal channel	23.2-30.5 (28.3)	32.0

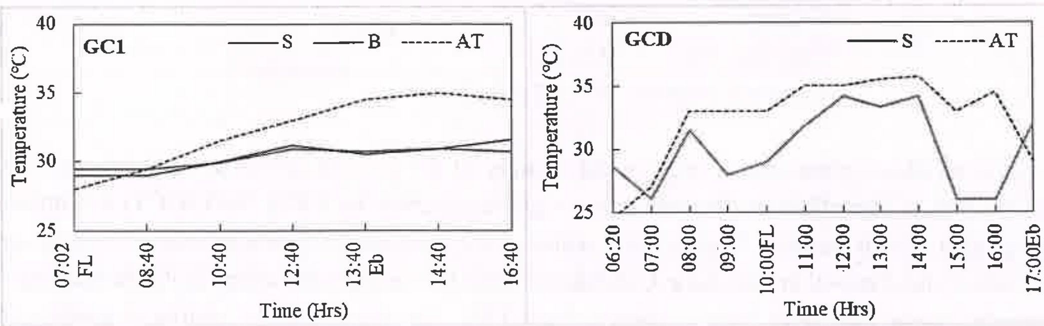

Fig. 5A: Temporal temperature variation at the disposal area off Dahej during Oct-22.

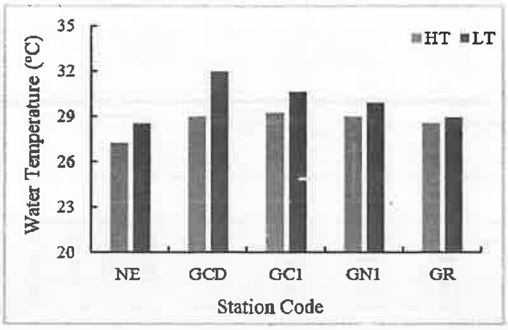

Fig. 5B: Temperature variation during different tides off Dahej during Oct-22.

Fig. 5A depicts the temporal temperature variation at the subtidal (GC1) and intertidal (GCD) disposal points. The water temperature variation during high and low tides were minor and randomly high during low tide due to diurnal temperature change (Fig. 5B). The observational water temperature during the study period was less than 35°C, considered the threshold for tropical aquatic species, therefore, less vulnerable to the aquatic organisms. The water temperature fluctuations at GCD was due to diurnal changes under shallow water column.

5.1.1.2 pH

During this study, the observed pH range was 7.7-8.1 (avg. 7.9). The average pH around the GCD was less than a unit low (7.4) and varied between 7 and 8 (Tables 4 and 5). Surface-to-bottom pH variation was insignificant in the subtidal waters. The average pH variation was minor across all segments, aligning with those generally observed for the nearshore-estuarine waters, which gets randomly influenced by freshwater and acidic/alkaline anthropogenic discharges (Table 5B). The temporal pH changes at GC1 and GCD were marginal and have indicated natural marine waters sustaining low primary productivity (Fig. 5C and 5D).

Table 5B: Segment-wise pH distribution in waters around Dahej during Oct-22.

Segments	pH
Reference	7.9-8.0 (7.9)
Northern	7.7-7.9 (7.8)
Central	7.8-8.1 (7.9)
Southern	7.8-7.9 (7.9)
Estuary	7.8-7.9 (7.9)
Disposal area	7.1-8.0 (7.8)
Disposal channel	7.0-7.6 (7.3)

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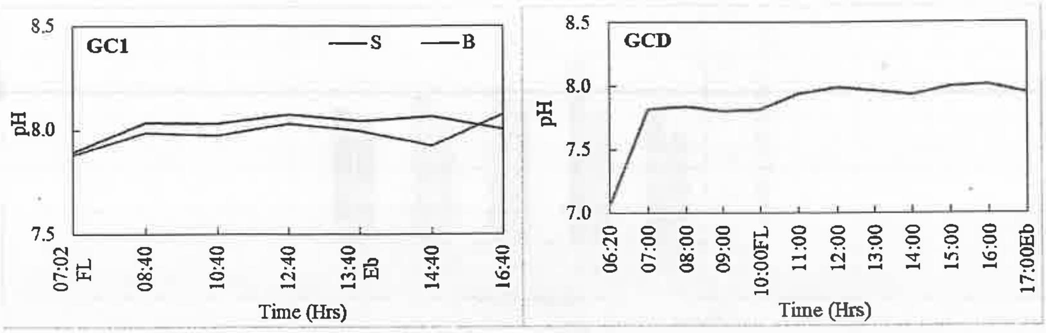


Fig. 5C: Temporal pH variation at the disposal area off Dahej during Oct-22.

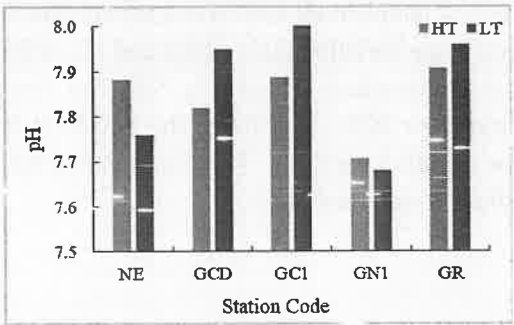


Fig. 5D: pH variation during different tides off Dahej during Oct-22.

The seawater pH range is 7.9-9.0, and it may vary between 7.3 and 9.5 in shallow and biologically active tropical coastal water affected by the diurnal variation. A pH range of 5 to 9 is not directly harmful to aquatic life, but the rapid change in pH can turn common pollutants more toxic in marine waters. The average pH variation in the entire region during this study was less than 1, which seems natural considering the dynamic nature of the water.

5.1.1.3 Salinity

The salinity range was 8.9–24.6 PSU (avg. 20.7 PSU) in the subtidal stations during Oct-22. Salinity near the GCD was 9.9-20.8 (avg. 16.6 PSU) (Tables 4 and 5). Lower salinity averages were at the Narmada estuary, GCD, and stations S1-S5 in the channel were due to the effects of freshwater and treated effluent mixing (Table 5C). Vertically, the salinity values were consistently higher in the bottom in the subtidal region owing to the higher density.

Table 5C: Segment-wise salinity distribution in waters around Dahej during Oct-22.

Segments	Salinity (PSU)
Reference	18.7-20.8 (19.9)
Northern	17.2-23.0 (20.1)
Central	17.7-22.5 (19.6)
Southern	20.2-24.6 (22.4)
Estuary	8.9-20.6 (18.6)
Disposal area	9.9-17.9 (14.1)
Disposal channel	15.1-20.8 (17.0)

The diurnal salinity variation at GC1 was noticeable, with higher values during the flood (FL) as compared to the ebb (Eb) tide (Fig. 5E). The salinity near GCD was higher during Eb than the FL, affected by the seawater incursion (Fig. 5F).

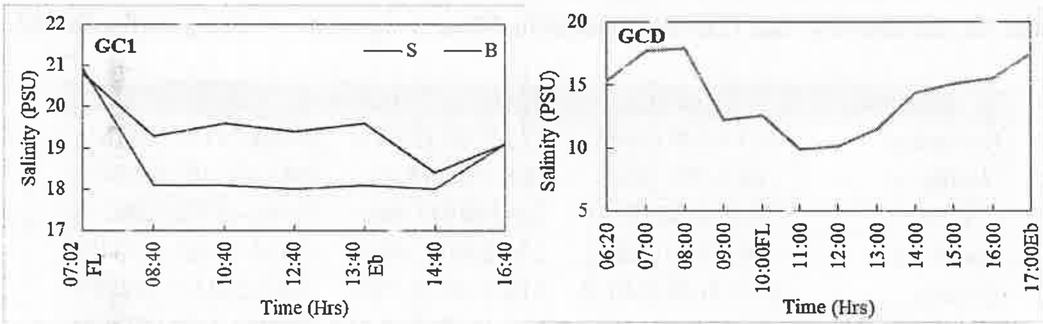


Fig. 5E: Temporal salinity variation at the disposal area off Dahej during Oct-22.

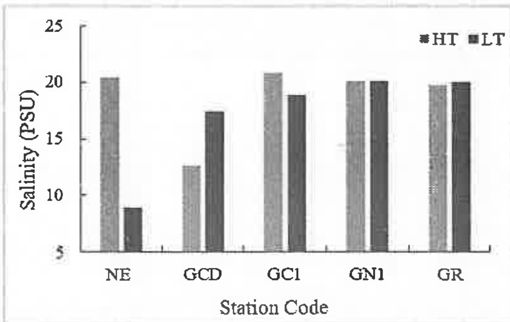


Fig. 5F: Salinity variation during different tides off Dahej during Oct-22.

The higher salinity around GCD during the low tide (LT) was possibly due to the stagnancy and evaporation (Fig. 5F). The seawater salinity levels depend on the balance between evaporation and precipitation, averaged at 35.5 PSU. The marine organisms acclimatize to a specific salinity range; however, considerable salinity variation can affect the lower-order organisms' dominance while higher-order organisms migrate. In coastal and Nearshore waters, abrupt salinity changes are due to the saline effluent discharges from anthropogenic activities. Sudden changes in salinity may cause high biota mortality, including fish. The salinity range during the present study was much lower than 35 PSU, as expected during the post-monsoon, and the impact of treated effluent on salinity rise is not significant.

5.1.1.4 SS, Turbidity, and TDS

The observed SS, turbidity, and TDS ranges during Oct-22 were 24.9-7916 mg/L (avg. 1483 mg/L), 3.9-8688 NTU (avg. 1232 NTU), and 2205-45722 mg/L (avg. 26159 mg/L), respectively. The average SS, turbidity, and TDS values around GCD was 468 mg/L, 113 NTU, and 19698 mg/L, respectively, which were lower than the subtidal averages owing to the less dynamic environment (Tables 4 and 5). The segment-wise variation presented in Table 5D indicated lower SS, turbidity, and TDS in the disposal area and channel owing to the mixture of estuarine water and treated effluent.

Table 5D: SS, turbidity, and TDS distributions in different segments off Dahej during Oct-22.

Segments	SS (mg/L)	Turbidity (NTU)	TDS (mg/L)
Reference	511-6299 (3166)	372-7660 (3670)	22886-29160 (24761)
Northern	26.7-991 (284)	8.8-2900 (516)	20483-37387 (26302)
Central	28.2-5742 (918)	3.9-8688 (1096)	20546-45722 (28621)
Southern	296-7916 (2682)	244-2680 (1095)	13054-29881 (25347)
Estuary	24.9-3058 (1610)	219-2685 (1378)	2205-24441 (18298)
Disposal area	18.5-1839 (468)	24.5-1537 (285.4)	17080-17643 (17362)
Disposal channel	-	61.5-99.2 (78.7)	19206-21895 (20165)

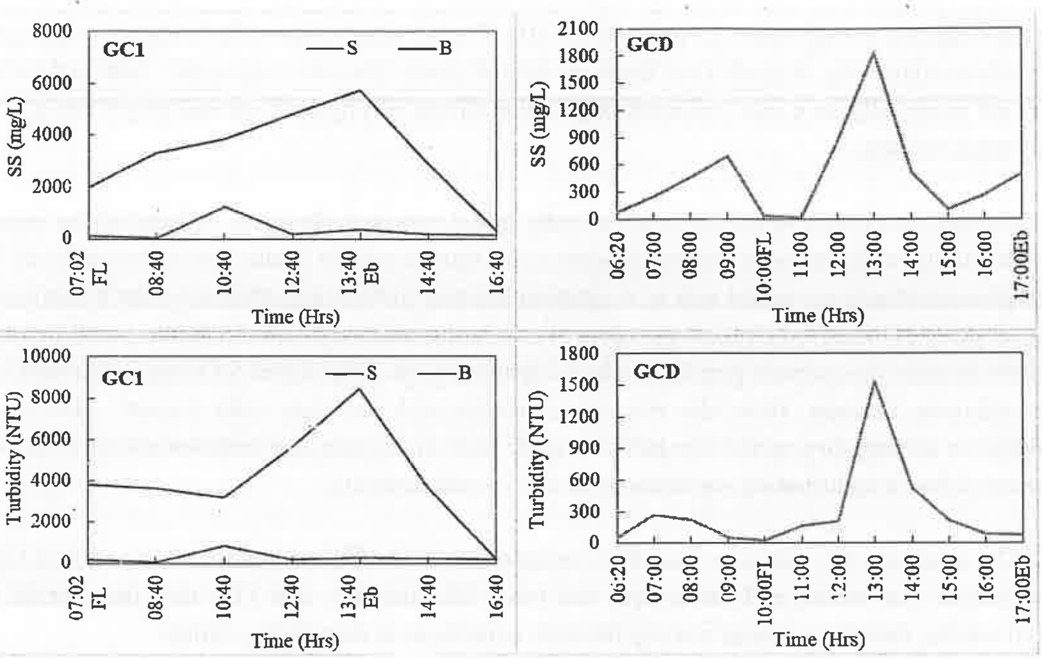


Fig. 5G: Temporal SS and turbidity variation at the disposal area off Dahej during Oct-22.

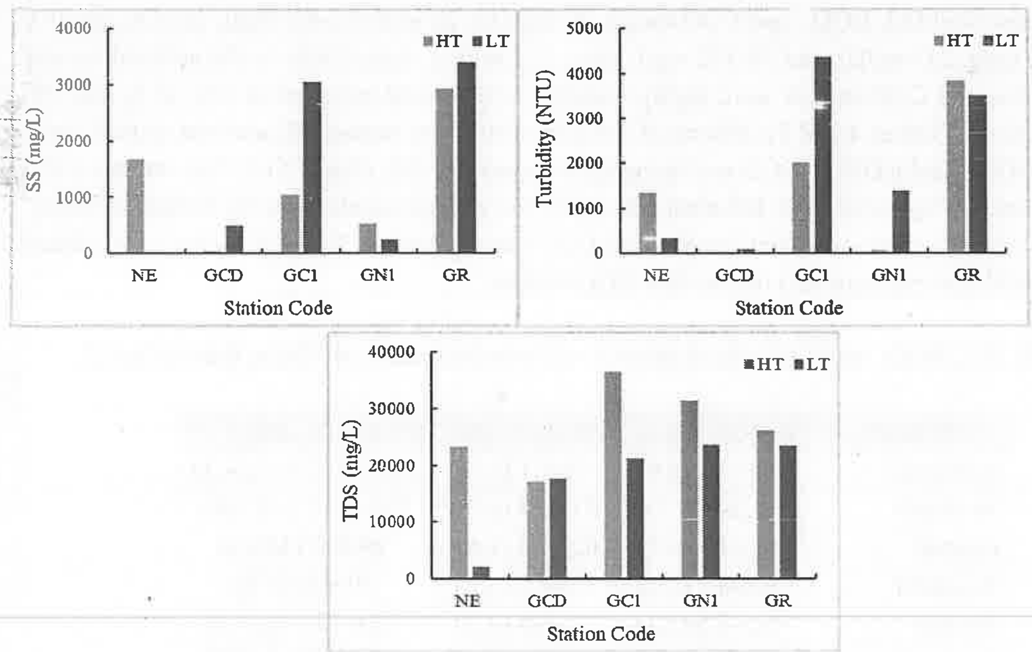


Fig. 5H: SS, turbidity, and TDS variation during different tides off Dahej during Oct-22.

Temporal SS and turbidity variations were significant in the bottom water at GC1, but not at GCD (Fig. 5G). Tidal SS and turbidity variations were random, except for the TDS, which was higher during high tide due to high seawater influx (Fig. 5H). The SS scoured from the inorganic and organic materials, hinterland soils, degraded and fresh residues of plants, plankton, algae, etc., float in the water column and eventually sink into sediment due to the effects of physicochemical properties and the hydrodynamic sorting.

The SS contributes to the turbidity, thereby affect seawater clearness, enhancing the organic matter and humic acids contents, ultimately impact the aquatic animal health and photosynthesis. The reduced photosynthesis can cause loss of vegetation life and initiate degradation by the bacteria with the consumption of dissolved oxygen, therefore deteriorating the ecosystem. SS settling on the bed can damage the benthic invertebrate population, block spawning, etc. The higher SS loads in the GoKh are due to sediment delivery from the riverine networks and the high tidal current. Due to the hydrodynamic sorting, large grain size particles settle and small grain size particles remain suspended in the water column contributing significantly to the SS and turbidity.

The observed SS, turbidity, and TDS variations in this study aligned with the natural GoKh water dynamic. The treated effluent sample had lower SS, turbidity, and TDS than the subtidal and intertidal waters; therefore, it does not significantly contribute to their higher limits.

5.1.1.5 DO, BOD_3, and COD

The observed DO, BOD_3, and COD ranges during Oct-22 were 4.2-8.2 mg/L (avg. 6.7 mg/L), 0.5-4.6 mg/L (avg. 2.0 mg/L), and 59-192 mg/L (avg. 112 mg/L), respectively in the subtidal waters. The DO, BOD_3, and COD ranges were highly variable at GCD and averaged at 4.1, 35.3, and 190 mg/L, respectively (Tables 4 and 5). Mixing of estuarine water and treated effluent had caused lower DO, higher BOD_3, and COD at GCD and along the channel (S1-S5) (Table 5E). The average COD levels in the studied segments were less than 250 mg/L, the general standard for the treated effluents. During this study, the treated effluent samples had COD values close to 300 mg/L, which gets diluted when mixed with the estuarine and marine low COD waters.

Table 5E: DO, BOD_3, and COD distributions in different segments off Dahej during Oct-22.

Segments	DO (mg/L)	BOD_3 (mg/L)	COD (mg/L)
Reference	6.6-7.3 (6.9)	1-1.1 (1)	108.1-137.4 (124.3)
Northern	4.2-7 (6.1)	0.6-2.4 (1.3)	101.4-127.4 (114)
Central	6.2-7.4 (6.7)	0.5-4.6 (1.8)	99-192 (150.9)
Southern	6.8-8.2 (7.3)	1.9-4.4 (3.2)	59-97 (72.8)
Estuary	6.5-7.5 (7.1)	2.2-3.8 (3.2)	78.6-131.1 (113)
Disposal area	0-8.1 (5.4)	1.3-27.6 (9.1)	112.2-287.4 (158)
Disposal channel	1.2-7 (3.8)	25.7-70 (40.5)	128.1-259.9 (196.8)

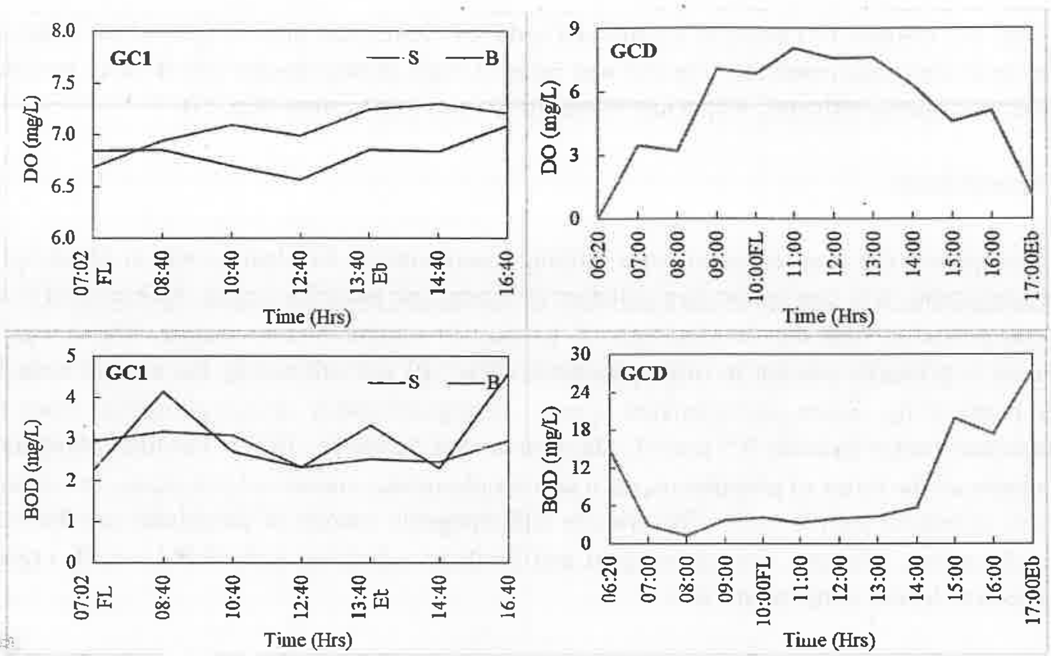


Fig. 5I: Temporal DO and BOD_3 variation at the disposal area off Dahej during Oct-22.

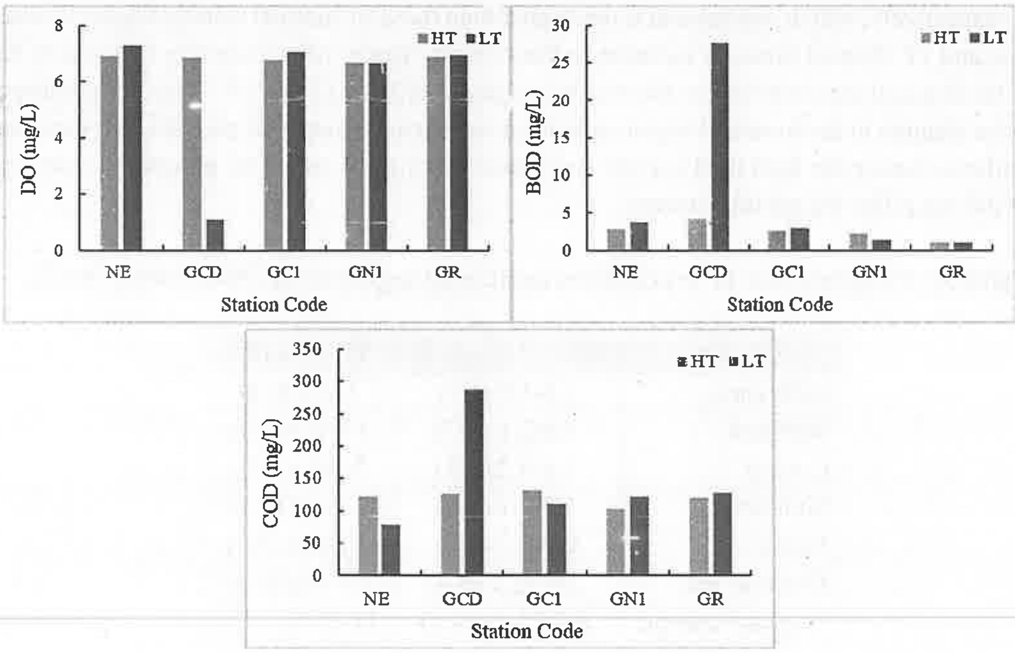


Fig. 5J: DO, BOD_3 and COD variation during different tides off Dahej during Oct-22.

The low DO and high BOD_3 conditions were prevalent during the ebb tide around GCD. Such conditions arose possibly due to inefficient flushing/mixing of the subtidal and estuarine waters in the region (Fig. 5I). Overall, DO levels in the subtidal and GCD were more than 2 mg/L, which indicated the absence of a hypoxic condition. The DO was below 2 mg/L during the ebb tide at GCD, resulting from mixing of anoxic effluents, which had higher BOD_3 and COD values (Fig. 5J).

5.1.1.6 Phosphorous

Phosphorus (P) is an essential but a limiting macronutrient for algal growth in oligotrophic aquatic ecosystems. It is also known as a pollutant in coastal and estuarine waters. An excess of P can cause eutrophication and the development of blooms in natural marine waters. The inorganic phosphorus is primarily present in ortho-phosphate (PO_4^{3-}-P) and utilized by the marine biota for primary productivity. Some phytoplankton species disproportionately absorb phosphate when the ambient concentration exceeds 0.5 µmol/L (Jayaraman and Seshappa, 1957). The total phosphorus (TP) includes all the forms of phosphorus, such as orthophosphate, condensed phosphate, and organic phosphate, in natural marine water. The primary anthropogenic sources of phosphates are domestic sewage, detergents, effluents from agro-based and fertilizer industries, agricultural runoff, organic detritus such as leaves, cattle waste, etc.

The phosphate and TP concentrations in the subtidal waters of this study were 0.9-3.2 µmol/L (avg. 1.9 µmol/L) and 1.7-3.3 µmol/L (avg. 2.4 µmol/L), respectively, with minimal variations between surface and bottom (Tables 4 and 5). The phosphate and TP averages around GCD were 13.2 and 15.9 µmol/L, respectively, which was several times higher than those of subtidal waters. Segment-wise, the phosphate and TP showed minimal variation in the subtidal region, whereas nearly three times higher levels at the disposal area were due to the mixing of treated effluent (Table 5F). The effluent dispersed through the channel in the intertidal region upholds a significant quantity of phosphorous compounds. Due to dilution under the high tidal current and robust mixing, the intertidal phosphorus enrichment possibly did not affect the subtidal waters.

Table 5F: Phosphate and TP distributions in different segments off Dahej during Oct-22.

Segments	PO_4^{3-}-P (µmol/L)	TP (µmol/L)
Reference	1.6-1.9 (1.7)	1.7-2.4 (2)
Northern	1.4-2.1 (1.7)	1.9-2.7 (2.4)
Central	1.5-3.2 (2.1)	2.3-3.1(2.6)
Southern	1.3-2.1 (1.9)	1.8-3.3 (2.5)
Estuary	0.9-2.1 (1.7)	1.8-2.9 (2.5)
Disposal area	2.1-33.7 (6.4)	3.1-10.6 (6.9)
Disposal channel	8.8-26.1 (14.6)	11-27.5 (17.7)

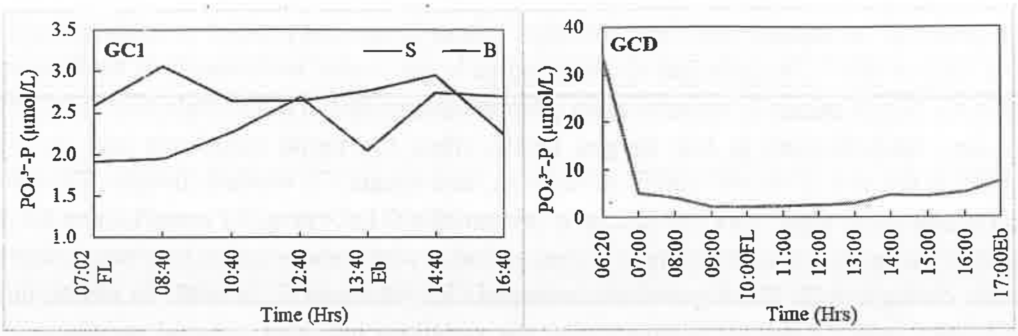


Fig. 5K: Temporal phosphate and TP variation at the disposal area off Dahej during Oct-22.

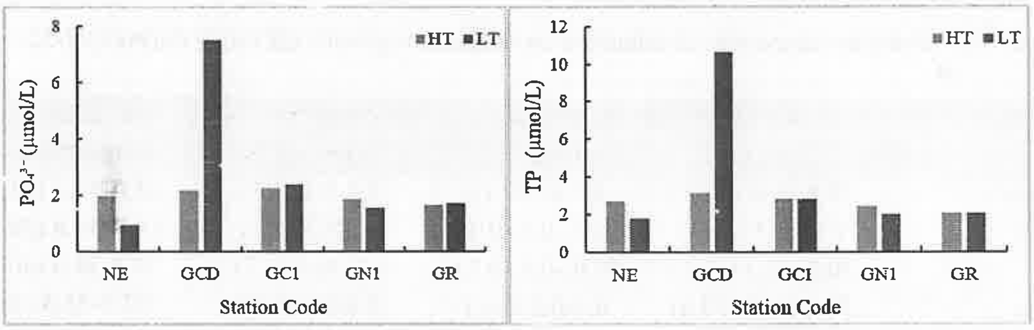


Fig. 5L: Phosphate and TP variation during different tides off Dahej during Oct-22.

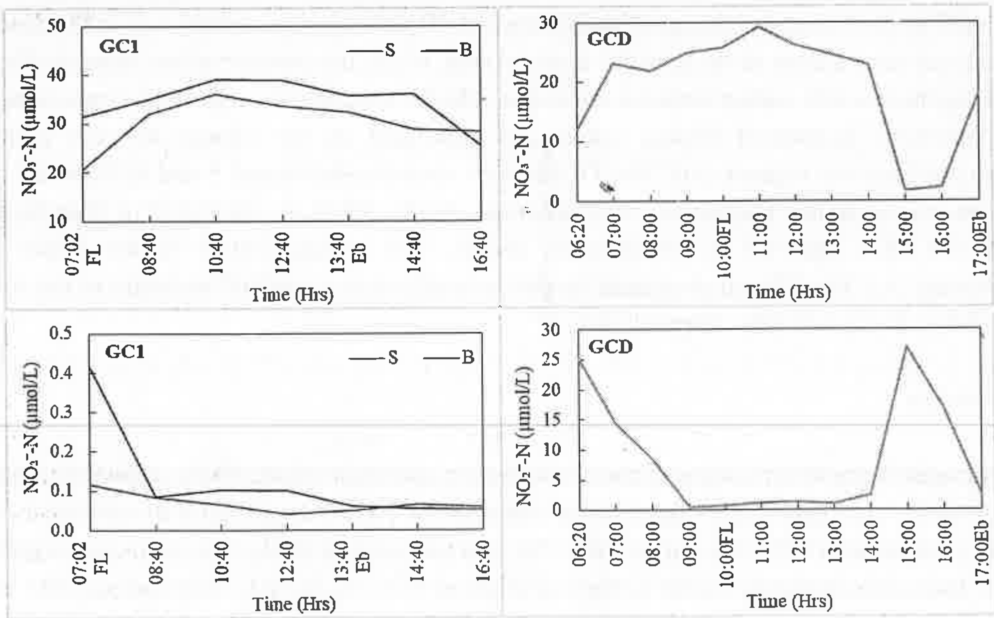
The phosphate and TP variation across the tides was minimal at the subtidal and disposal area (Fig. 5K and Fig. 5L). Also, the change of phosphate and TP between high and low tide at the nearshore region were not seen, except at the intertidal disposal area, where the concentrations were significantly higher during the low tide, owing to the accumulation. The TP concentrations generally have noticeable regional variations in tropical inshore waters and dependent on the balance between biological production and bacterial regeneration. The TP generally remained between 1.5 and 12.8 µmol/L in the Arabian sea coastal waters (Jayaraman and Seshappa, 1957). Similarly, the range of phosphate was extensive (<0.1-8.4 µmol/L) in the beaches, creeks, and coastal waters of the Indian coast (Supplementary A). The TP and phosphate levels have indicated a minimal variation in the subtidal waters enriched in the intertidal disposal area.

5.1.1.7 Nitrogen

Nitrogen is present in estuarine and coastal water, mainly in nitrate (NO_3^-; oxidation state +5), ammonium (NH_4^+; oxidation state -3), and other compounds. The dominant forms of nitrogen that exist in seawater are nitrate (NO_3^--N), nitrite (NO_2^--N), and ammonium (NH_4^+-N). Ammonium produced during the oxidation of organic matter further oxidized to NO_3^--N via NO_2^--N in the presence of DO. The nitrogen cycle involving elementary dissolved nitrogen, oxides: NO_3^-, NO_2^-, and NH_4^+, has significant potential for aquatic biota sustainability. Nitrate is the end product of oxidation and the most stable form at pH 7. The principal nitrogen source in the marine environment is the fixation of atmospheric N_2. Nitrite occurs in seawater as an intermediate product of nitrate reduction in microbial processes, i.e., denitrification at low oxygen levels, when the nitrite transforms into N_2. Total nitrogen (TN) is the sum of nitrate, nitrite, ammonium, and organically bonded nitrogen. The nitrate, nitrite, and ammonium ranges were 7.6-60.1 (avg. 36 µmol/L), 0.1-0.4 (avg. 0.1 µmol/L), and 0.1-16.4 (avg. 4 µmol/L), respectively in the subtidal waters of Dahej, with some variation between surface and bottom water during Oct-22. The disposal area averaged 13.1, 48.9, and 113 µmol/L for nitrate, nitrite, and ammonium (Tables 4 and 5). Segment-wise, the variations indicated minimal variations in the subtidal region; exceptional was for the estuary segment, where the nitrate and TN were higher, possibly due to riverine nitrogen load (Table 5G). The disposal channel had higher levels of all the constituents affected by the treated effluent.

Table 5G: Nitrogen compounds distributions in different segments off Dahej during Oct-22.

Segments	NO_3^--N (µmol/L)	NO_2^--N (µmol/L)	NH_4^+-N (µmol/L)	TN (µmol/L)
Reference	25.8-44.6 (32.8)	0.1-0.2 0.1)	3.5-7.4 (5.5)	33.0-54.2 (43.9)
Northern	7.6-41.5 (30.1)	BDL-0.2 (0.1)	2.3-6.5 (4.1)	19.7-55.8 (38.7)
Central	20.2-43.0 (37.1)	BDL-0.4 (0.1)	1.6-16.4 (6.3)	37.9-58.9 (46.5)
Southern	30.5-54.7 (39.6)	0.1-0.2 (0.1)	0.2-2.0 (1.3)	33.7-55.3 (44)
Estuary	34.0-60.1(42.6)	0.1-0.4 (0.2)	0.1-2.4 (1.4)	36.0-69.8 (52.7)
Disposal area	1.5-29.4 (19.4)	0.5-27 (8.5)	3.3-125.5 (32.1)	46.4-58.2 (52.3)
Disposal channel	1.6-24.1 (11.8)	10.9-110 (57)	111-149 (129)	150-213 (188)



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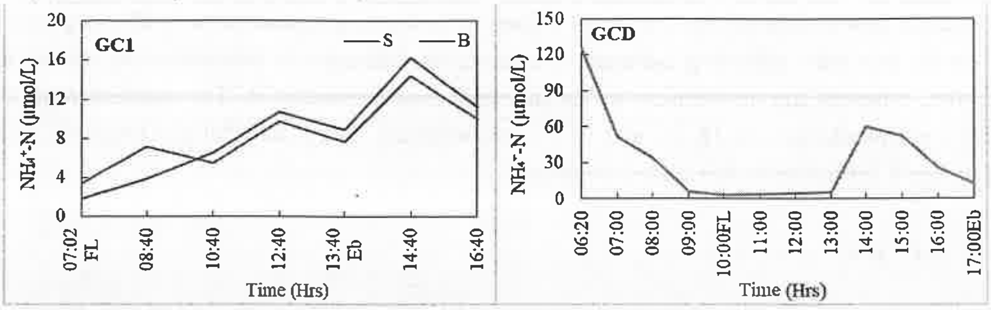

Fig. 5M: Temporal variation in nitrogen at the disposal area off Dahej during Oct-22.

There were random nitrite, nitrate, and ammonium concentration changes between the flood and ebb tide at the subtidal and intertidal locations. The random increase of these constituents between the tidal epochs was related to the disproportional addition by the treated effluents in the intertidal region (Fig. 5M).

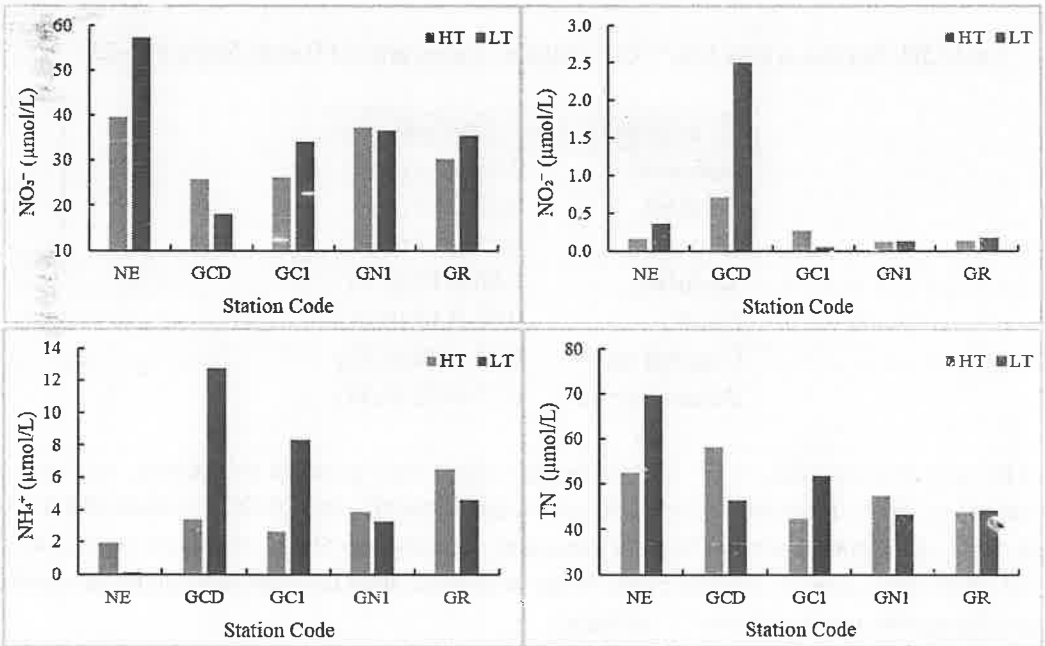

Fig. 5N: Nitrogen compounds variation during different tides off Dahej during Oct-22.

The estuarine nitrate was higher in low tide due to the riverine and anthropogenic supply. The nitrate-rich waters dispersed during high tide in the intertidal region, thereby increasing the nitrate levels at the disposal. The high nitrite and ammonium resulted from the effects of low oxygen that inhibited nitrite oxidation at the disposal area. The changes in TN among the tides were random and dependent on the variation in the inorganic constituents. The subtidal water nitrate, nitrite, and ammonium constituents were within limits in Indian coastal water (Supplementary A). However, the low oxygen condition provoked the enhanced values of ammonium and nitrite in the disposal area, especially in the low tide, affecting nitrogen accumulation. Nitrogen is dominated by nitrate in the subtidal region, whereas the ammonium in the disposal area dominates it. The nutrient ratio (N:P), essential for phytoplankton, was 18.2:1 and 10.3:1, respectively, in the subtidal and intertidal regions, indicating minor P limitation in the former region.

5.1.1.8 SO_4^{2-}:Cl^- ratio

Sulphate (SO_4^{2-}) is one of the conservative elements, which co-varies with chlorinity in seawater with a constant SO_4^{2-}: Cl^- ratio of 0.14 (Morris and Riley 1966). The principal source of sulphur in the coastal marine environment could be from the sea salts during rain and continental and anthropogenic transports (Kroopnick, 1977). The SO_4^{2-}: Cl^- ratio may vary with the addition or removal of SO_4^{2-}. The addition of SO_4^{2-} rich substances can enhance the ratio, and the removal or dilution of SO_4^{2-} salts can lower the ratio. The SO_4^{2-}: Cl^- ratio was between 0.02 and 0.17 (avg. 0.13) in the subtidal region. The disposal area water had a higher ratio of 0.25 and 0.93 (avg. 0.54), indicating enrichment of SO_4^{2-} rich substances (Tables 4 and 5).

Table 5H: Segment-wise SO_4^{2-}: Cl^- ratios in waters around Dahej during Oct-22.

Segments	SO_4^{2-}: Cl^-
Reference	0.13-0.14 (0.13)
Northern	0.13-0.14 (0.13)
Central	0.13-0.17 (0.15)
Southern	0.06-0.15 (0.15)
Estuary	0.02-0.13 (0.11)
Disposal area	0.13-0.46 (0.33)
Disposal channel	0.25-0.93 (0.54)

The segment-wise SO_4^{2-}: Cl^- have indicated minor fluctuation in the central, southern, and estuary segments, with higher values in the disposal area caused due to high SO_4^{2-} values of the treated effluents dispersed in the region (Table 5H). Seawater typically has SO_4^{2-} concentration of 2.65 g/kg and Cl^- of 18.98 g/kg. The Cl^- content in the region was lower than the seawater due to the combined influence of estuarine water and low Cl^- effluents.

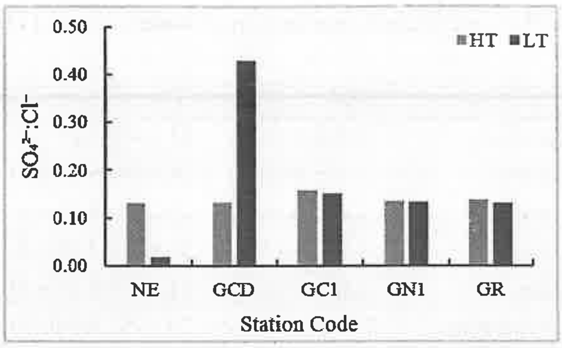

Fig. 5O: SO_4^{2-}: Cl^- ratio variation during different tides off Dahej during Oct-22.

The SO_4^{2-}: Cl^- ratio was close to the ratio of seawater during high tide in selected tidal stations (Fig. 5O). The low tide maxima at the disposal area were due to sulfate enrichment concerning Cl^-. Alternatively, the lower SO_4^{2-}: Cl^- ratio of Narmada estuary water was due to low SO_4^{2-} and Cl^- content (Tables 4 and 5).

5.1.1.9 PHc and Phenols

Naturally occurring hydrocarbons in the aquatic environment are in trace amounts of simple forms microbes produce. Crude oil and its products are added to the marine environment by anthropogenic activities such as production and handling related spillages, ship traffic, etc., substantially contributing to PHc levels. Primary land-based sources are domestic and industrial effluents, atmospheric fallout of fuel combustion products, condensed vapors, etc. PHc can cause severe damage to aquatic life when there are sudden discharges in large quantities during accidents such as tanker collisions, pipeline ruptures, fires, etc. The observed PHc and phenols range during Oct-22 were 3.8-6.4 µg/L (avg. 5.1 µg/L) and 24.8-80.9 µg/L (avg. 54.5 µg/L), respectively, in Dahej subtidal waters (Tables 4 and 5). The waters around the treated effluent disposal area in the intertidal region have PHc and phenols average of 9.6 and 40.8 µg/L, respectively, which were in the line of subtidal waters and therefore indicated no significant contents of oil residues in the treated effluent. Segment-wise PHc and phenol levels indicated minor variation among different regions and no significant enrichment (Table 5I). The tidal variation of PHc and phenols was consistent at the nearshore station, except in the disposal area and the Narmada estuary (Fig. 5P). Overall, the values were lower than the recommended water quality criteria (0.1 mg/L in terms of oil and grease) by CPCB.

Table 5I: Segment-wise PHc and phenol distribution in waters around Dahej during Oct-22.

Segments	PHc (µg/L)	Phenol (µg/L)
Reference	5.0-6.4 (5.7)	41.7-49.8 (45.8)
Northern	5.1-5.8 (5.4)	24.8-80.9 (46.9)
Central	3.8-6.3 (4.9)	40.7-80.8 (56.9)
Southern	3.8-5.5 (4.7)	56.6-63.1 (60.8)
Estuary	4.0-5.7 (4.9)	31.6-59.1 (45.3)
Disposal area	7.3-12.0 (9.6)	29.1-52.4 (40.8)
Disposal channel	-	-

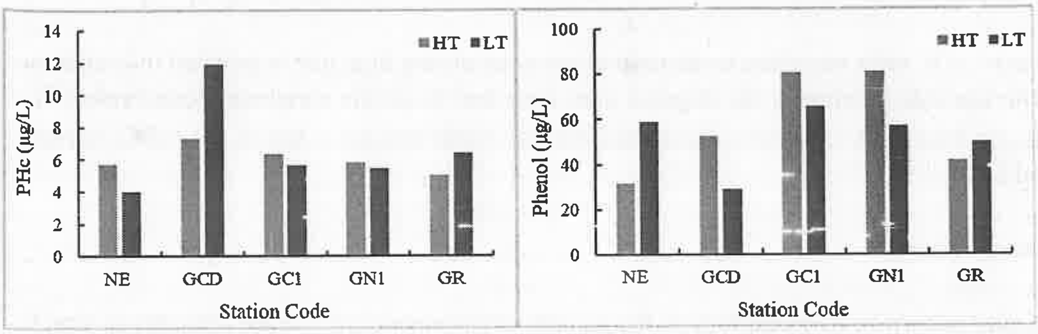

Fig. 5P: PHc and phenol variation during different tides off Dahej during Oct-22.

5.1.1.10 Treated FPS effluent

The average chemical constituents observed during Oct-22 in the treated effluent, collected at the FPS (Final Pumping Station) before its discharge and mixing with the seawater near the intertidal disposal area, and the subtidal seawater are presented in Table 5J.

Table 5J: Comparative water quality at critical locations of Dahej during Oct-22.

Parameter (unit)	FPS effluent	Disposal area	Subtidal water
Temperature (°C)	33.4	28.6	28.6
pH	7.3	7.4	7.9
Turbidity (NTU)	23.3	113.2	1313.7
TDS (mg/L)	16826	19698	25442
SS (mg/L)	171.2	467.6	1575.6
DO (mg/L)	0.0	4.1	6.8
BOD (mg/L)	201.2	35.3	2.2
COD (mg/L)	297.0	190.3	112.2
Salinity (PSU)	11.9	16.6	20.5
SO_4^{2-}: Cl^-	0.95	0.51	0.13

PO_4^{3-}-P (µmol/L)	19.7	13.2	1.8
NO_3^--N (µmol/L)	1.9	13.1	36.4
NO_2^--N (µmol/L)	1.8	48.9	0.1
NH_4^+-N (µmol/L)	184.1	113.0	3.7
TP (µmol/L)	20.6	15.9	2.4
TN (µmol/L)	209.9	165.2	44.4
PHc (µg/L)	30.6	9.6	5.0
Phenol (µg/L)	105.4	40.8	53.5

The average subtidal water quality parameter limits were much lower than those in the disposal area, indicating efficient dilution of chemical constituents in the GoKh water. However, the water quality near the disposal area is primarily affected by the enriched limits of the chemical constituents in effluent samples. Nevertheless, the input from the estuarine region, which includes the effluent disposal and Narmada river water, appeared to be considerable, especially in the low tide.

5.1.2 Surficial sediment quality

The sedimentary bed in coastal aquatic systems acts as an eventual sink of suspended solids, which carry significant amounts of chemical substances (metals, organic carbon (OC), and pollutants) from its source region transported through the water column and interacts through various physicochemical and biological processes. The concentrations of metals, OC. and other pollutants increase over time in sediment depending on their input, accumulation, and removal rates. The accumulated concentrations of these constituents indicate the sediment quality, which impacts the sustainability of a healthy benthic ecosystem. The observational data on texture, metals, PHc, OC, phosphorous etc., in the sediment samples collected from the Dahej subtidal and intertidal region during Oct-22 are presented in Table 6.

5.1.2.1 Texture

The measured sand, silt, and clay contents in subtidal sediments were 5.2-97% (69.2%), 2.8-87.2 % (27.9%), and 0.2-7.6 % (2.9%), respectively, during Oct-22. The intertidal sediments exhibited sediment composition with sand, silt, and clay ranges from 0.5-89.2% (38.2%), 9.6-94.5% (58.4%), and 1.2-5% (3.4%), respectively during Oct-22 (Table 6). The overall texture pattern has indicated that the sand content was higher in subtidal sediments. In contrast, the silt content was higher in the intertidal sediments during the study period, related to the differential hydrodynamic sorting process in the two regions. During the study, the sediments from the different segments and at the disposal area were predominantly sand, with minimal clay contents (Table 6A).

Table 6A: Average sediment texture in different segments off Dahej during Oct-22.

Segments	Sand (%)	Silt (%)	Clay (%)
Reference	93.6	5.0	1.4
Northern	71.8	24.7	3.5
Central	55.6	40.9	3.5
Southern	62.6	34.3	3.1
Estuary	65.2	32.0	2.8
Disposal area	90.6	7.8	1.6
Disposal channel	73.0	23.2	3.8

5.1.2.2 Metals

The metal derived from the source rock remain dominant in the nearshore coastal sediment. Heavy discharge of metal-rich industrial effluents scavenged by the SS and deposited in the bottom sediment. Metal forms such as hydroxides, sulfides, and carbonates associated with organic substances get influenced by several factors that determine their residence time in the thermo-dynamically metastable phase. The sediment metal in the nearshore environment largely varies with the texture. The metal concentrations in the subtidal and intertidal sediments of Dahej are presented in Table 6.

Table 6B: Average sediment metals in different segments off Dahej during Oct-22.

Segments	Al	Fe	Co	Cr	Cu	Mn	Ni	Zn	As	Cd	Pb
	in %		in µg/g dry sediment								
Reference	2.8	2.9	16.0	67.0	33.0	766	27.0	51.0	3.5	0.07	10.0
Northern	5.8	5.8	25.0	86.0	65.0	827	46.5	81.0	5.4	0.10	12.5
Central	5.0	6.0	26.0	98.5	70.5	947	48.5	98.5	5.0	0.10	12.0
Southern	3.0	3.6	26.3	95.0	68.7	963	48.3	85.3	6.8	0.09	12.0
Estuary	4.2	5.5	29.0	111.0	74.0	942	50.0	80.0	4.8	0.10	12.0
Disposal area	6.1	7.7	46.1	153.5	93.1	1028	53.5	126.0	7.4	0.2	13.2
Disposal channel	4.7	10.0	65.3	189.9	104.5	1376	52.5	134.1	10.9	0.1	16.2

The metal concentrations were random at different stations, generally higher than those observed in the reference station. The intertidal and disposal area sediments have higher levels of most metals than those in subtidal sediment (Tables 6 and 6B). The compositional metal limits of this study are comparable with the metal levels found in the coastal water bodies along the Indian coast (Supplementary A).

5.1.2.3 Petroleum Hydrocarbon (PHc)

The observational PHc ranges in the subtidal and intertidal sediments were 0.1-0.4 µg/g (0.2 µg/g) and 0.1-0.1 µg/g (0.1 µg/g), respectively, during Oct-22. The PHc levels of this study were low compared to the general limits found on the west coast of India therefore not highlighting any oil contamination in the region (Table 6). The segment-wise PHc distribution indicated comparable average limits between the disposal area sediment and subtidal sediment, highlighting minimal sediment contamination due to oil compounds in the intertidal disposal region (Table 6C).

Table 6C: Average sediment PHc in different segments off Dahej during Oct-22.

Segments	PHc (µg/g)
Reference	0.1
Northern	0.3
Central	0.3
Southern	0.2
Estuary	0.1
Disposal area	0.3
Disposal channel	0.1

5.1.2.4 Organic Carbon (OC)

Organic matter in nearshore and coastal sediments is mainly sourced from terrestrial runoff. Anthropogenic organic matter inputs can be reflected through abnormal increases in OC, affecting benthic ecology. Heterotrophic microorganisms decompose a fraction of OC in the presence of DO. Hence, DO in sediment-interstitial water is continuously consumed, and anoxic conditions develop if the organic matter is more than that can be oxidized through oxygen as an oxidant. Such anoxic conditions are harmful to benthic fauna.

The OC ranges in subtidal and intertidal sediments were 0.1-0.5% (0.3%) and 0.2-0.4% (0.3%), respectively, during Oct-22 in the Dahej area (Table 6). The OC around the region is lower than 1%, which is low compared to the general sediment OC found along the west coast of India sediment. Segment-wise, the OC distribution is random and has a minimal variation (Table 6D).

Table 6D: Average sediment OC in different segments off Dahej during Oct-22.

Segments	OC (%)
Reference	0.4
Northern	0.3
Central	0.4
Southern	0.2
Estuary	0.5
Disposal area	0.2
Disposal channel	0.3

The OC contents in sediment generally varied negatively with texture, which may be a region of lower OC in the disposal area, which coincides with higher sand content. The sediment OC often corresponds to the nature and origin; however, the content may not represent any specific source. The OC levels do not highlight any organic contamination in the region.

5.1.2.5 Sediment Phosphorous (P)

Lithogenic phosphorus in nearshore marine sediments is mainly derived from geological sources through the river, while anthropogenic phosphorus results from sewage and industrial discharges, agricultural runoff, etc. The phosphorous ranges of in subtidal and intertidal sediments of Dahej were 341-442 µg/g (401.7 µg/g) and 378-458 µg/g (427 µg/g), respectively, during Oct-22. The average phosphorous concentrations in different segments were comparable, indicating no enrichment (Table 6E).

Table 6E: Average sediment P in different segments off Dahej during Oct-22.

Segments	P (µg/g)
Reference	341.0
Northern	399.5
Central	393.0
Southern	436.7
Estuary	385.0
Disposal area	396.0
Disposal channel	408.5

5.1.3 Downcore sediment characteristics

The sediment cores collected during this study were in the intertidal region, broadly covering the present disposal area, the meeting point of the channel and GoKh water, northern segments of the intertidal region, southern segments, i.e., towards the Narmada estuary, points before the disposal and after the disposal area. The downcore variability generally highlights the contaminant accumulation (if any) due to rapid sedimentation in the intertidal region. The bottom sediment represents the previously deposited constituents and the surface sediments as the recent deposits. The disturbance of the surficial layer due to the tide and wave action and the anthropogenic dredging is possible due to the dynamic nature of the GoKh and existing anthropogenic settings. However, the downcore study would fairly represent the characteristics of sediment quality in the previously deposited sediment affected by any anthropogenic dumping, irrespective of their quantitative deposition.

The downcore sediment texture indicated that the sediment columns in the northern and southern segments were unaffected by significant texture change, except at C6 (Narmada estuary) (Fig. 6A). The inner estuary sediment core was dominated by silt loading. In contrast, other region cores were dominated by sand without any significant changes across the depth, indicating minimal disturbance. The disposal area has nearly similar proportions of sand and silts up to a depth of 35 cm. The sea limit of the channel area showed uniform sand dominance vertically without any significant change. The proportional mixing of sand and silt in the disposal area and before was primarily due to the combined effects of weak hydrodynamic sorting of effluent SS and the SS in tidally advected seawater in the region.

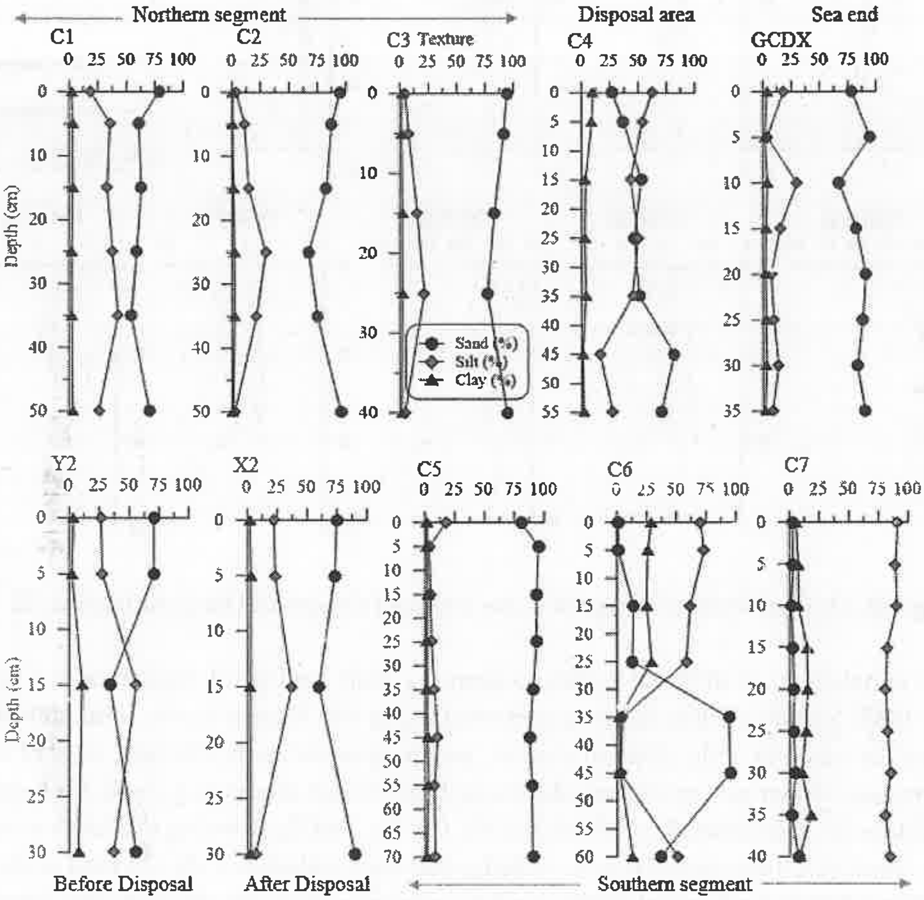

Fig. 6A: Downcore sediment texture in the intertidal regions of Dahej during Oct-22.

Sediment metals in the down core varied randomly in all the segments, except for a few metals in cores from the disposal area, the sea limit of the disposal channel, and the regions before the disposal area (Fig. 6B). Most of the metals were higher in the bottom (approximately 50 cm below the surface), consistent with lower Al, which indicated accumulation in the disposal area. The sea limit of the disposal channel and area before disposal showed higher metal in the upper layer, e.g., 20 cm and 10 cm of, respectively, were contributed by the disposal. The sediments in these layers were contributed from the disposal area and affected by the periodic tidal removal. The sediment metals in the disposal area have accumulated in the bottom due to the rapid settling.

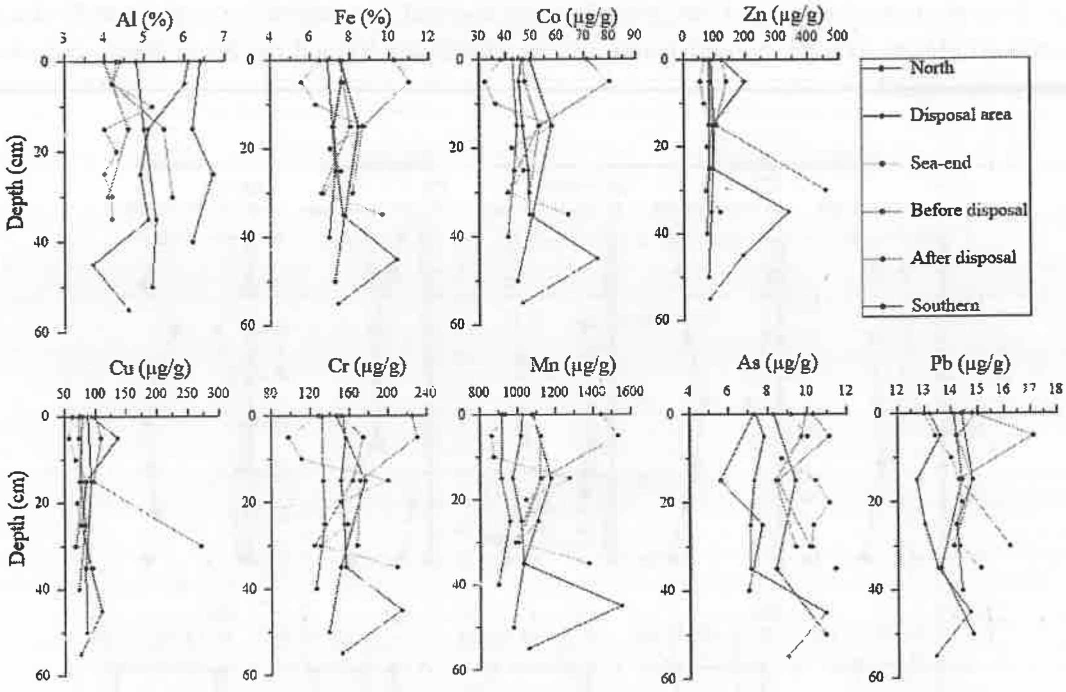

Fig. 6B: Downcore metal variation in the intertidal regions of Dahej during Oct-22.

The enrichment of different metals concerning their geological backgrounds (Taylor and McLennan, 1985; Savenko, 2006) has been presented in Fig. 6C. Except for the cores collected in the disposal area, the sea limit of the disposal channel, and the area before the disposal, most of the metals in other cores have shown no enrichment (depleted). Due to rapid scavenging, the bottom sediment in the disposal area has accumulated metals such as Fe, Co, Cu, and Zn, showing moderate to significant enrichment. Similarly, these metals were enriched in the cores collected at the sea limit of the disposal channel and area before the disposal, indicating the contribution from the disposal area. Metal such as Pb was not enriched in any studied segments around Dahej. The sediment metals enrichment is a slow process and conducive to dumping sediment and a less disturbed environment, mainly related to the grain size of the sediment. The sediment texture around Dahej intertidal area was dominated by silt and sand, possibly hindering the metal accumulation. The high tidal current swifts the upper sediment bed, therefore, causes no metal enrichment in the upper sediment.

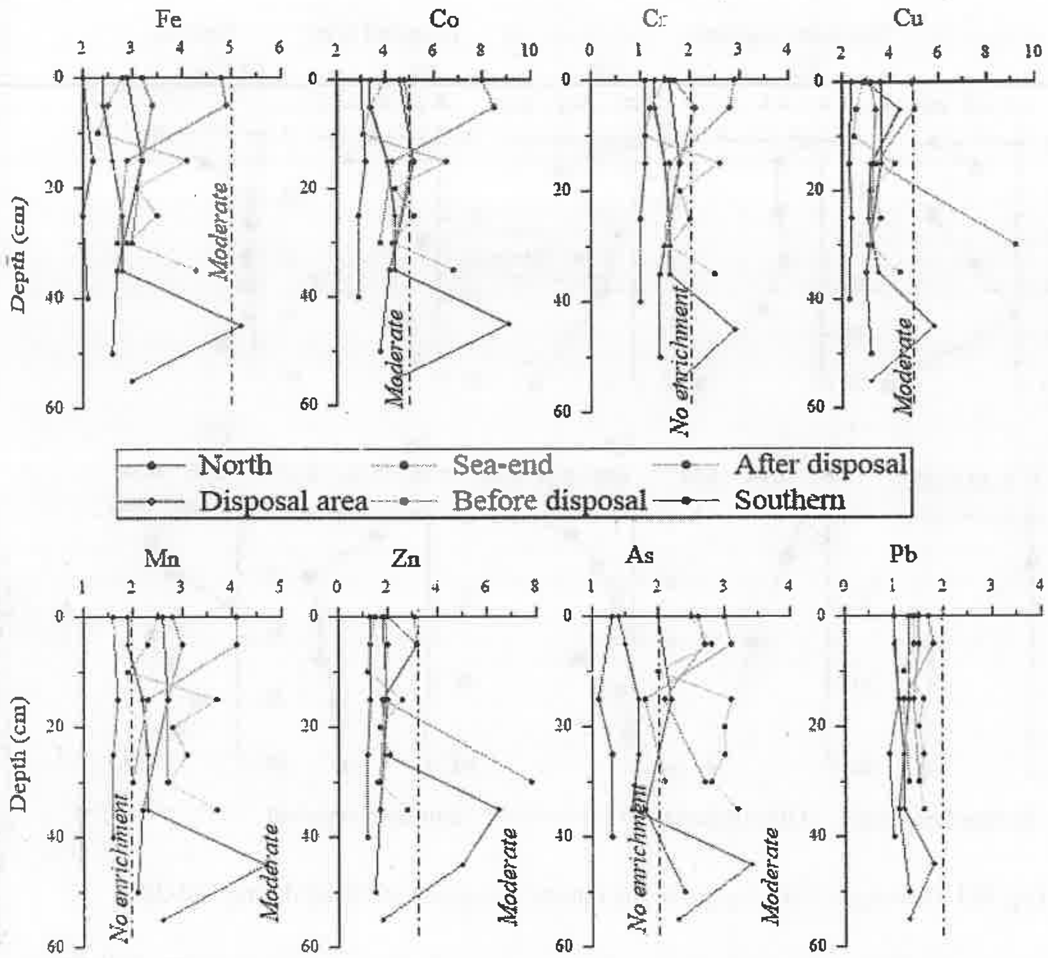

Fig. 6C: Downcore metal enrichment in the intertidal regions of Dahej during Oct-22.

The observational PHc ranges in the cores were minimal as compared to the sediment PHc affected by the oil contamination (Fig. 6D). The sediment PHc variation in downcore sections was less than 1 µg/g wet wt., which is much lower than the CPCB prescribed limits for oil and grease levels in the water. The PHc accumulation in downcore sediments was minimal due to larger grain size (sand/silt); those have a lower tendency to adsorb oil compounds than clay. The similar proportions of silt and sand in the bottom sediment layer of the core collected before the disposal area have accumulated higher PHc, possibly due to the localized dumping and minimal interaction with seawater.

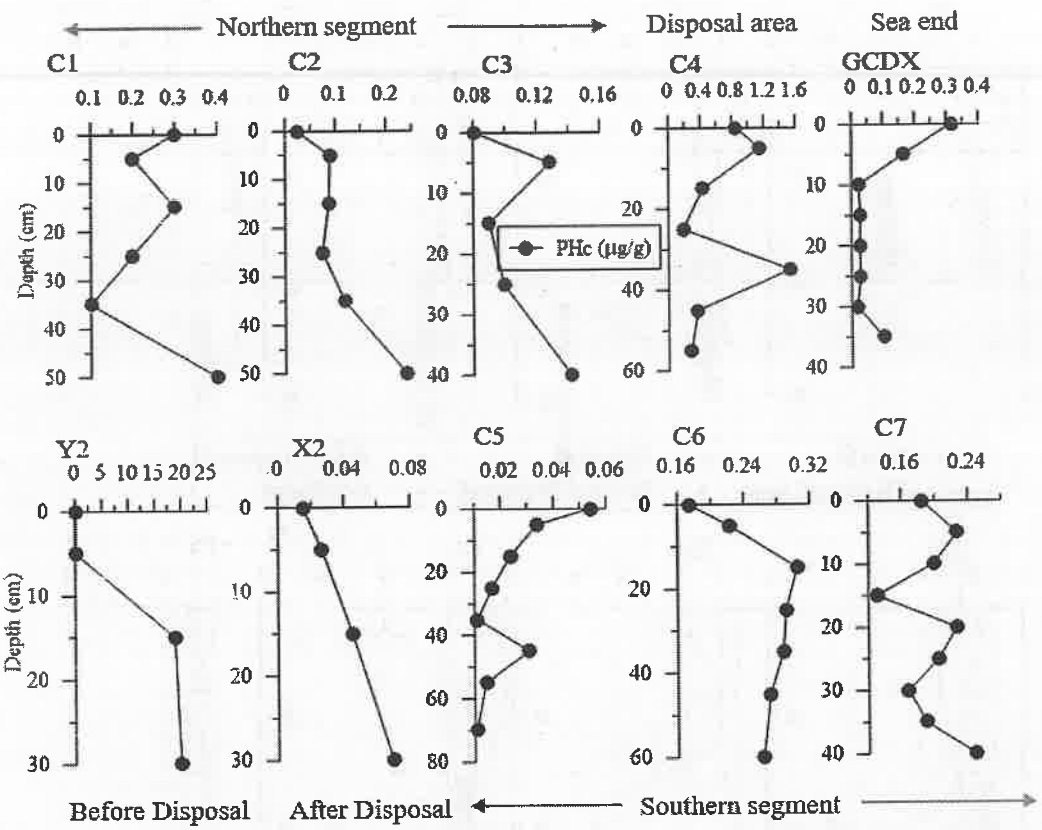

Fig. 6D: Downcore PHc change in the intertidal regions of Dahej during Oct-22.

The sediment OC was less than 1% in all the cores, indicating no organic matter pollution in the region. The contents of OC broadly vary with sediment grain size, and possibly the larger grain size has caused lower OC absorption or storage in the region (Fig. 6E). A higher OC value (close to 2%) was in the bottom sediment (30cm) of the region before disposal was due to storage and minimal interaction with tidal seawater.

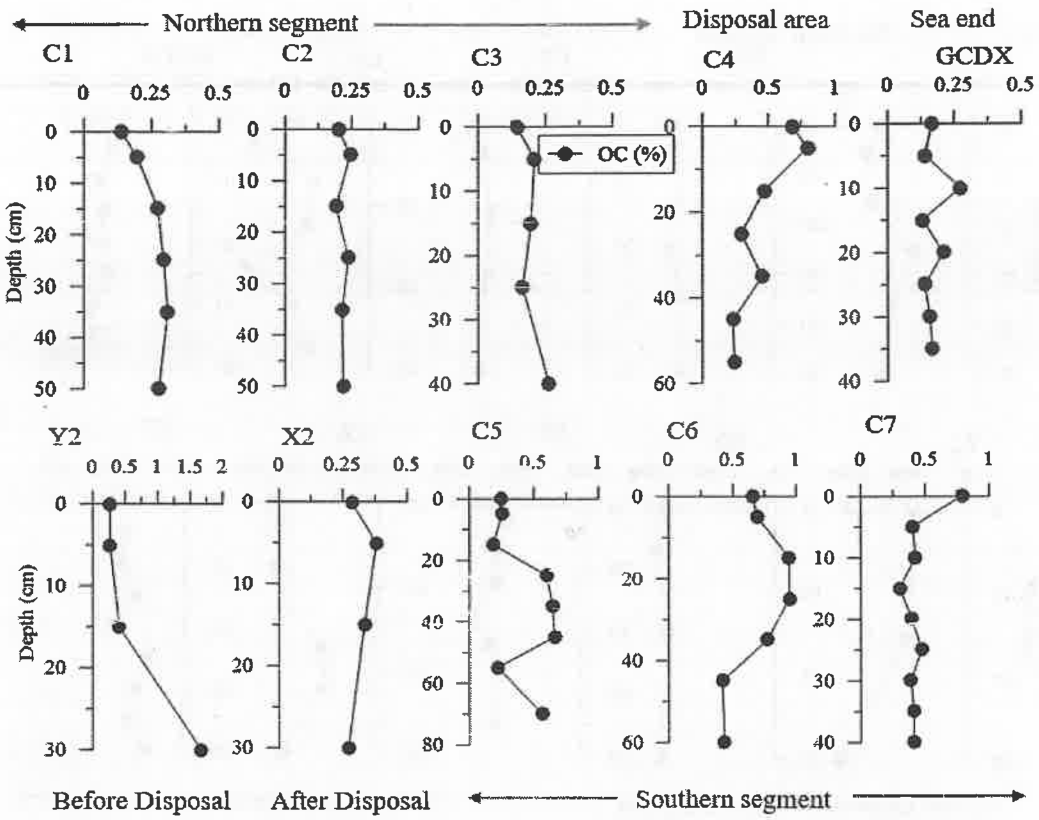

Fig. 6E: Downcore OC (%) variation in the intertidal regions of Dahej during Oct-22

The downcore sediment P variability was consistent in the intertidal region, without any noticeable P accumulation in the disposal area and the sea end of the effluent channel. Likewise, in OC and PHc, the P accumulation was observed in the bottom sediment before the disposal area due to a less dynamic environment (Fig. 6F). The sediment P range observed in the down cores did not indicate any significant enrichment. The geological P in the upper continental crust is approximately 655 µg/g (Rudnick et al., 2003). Anthropogenic contamination can increase this level, and on the northwest coast, it varies widely from 471-4127 µg/g (NIO Report-COMAPS).

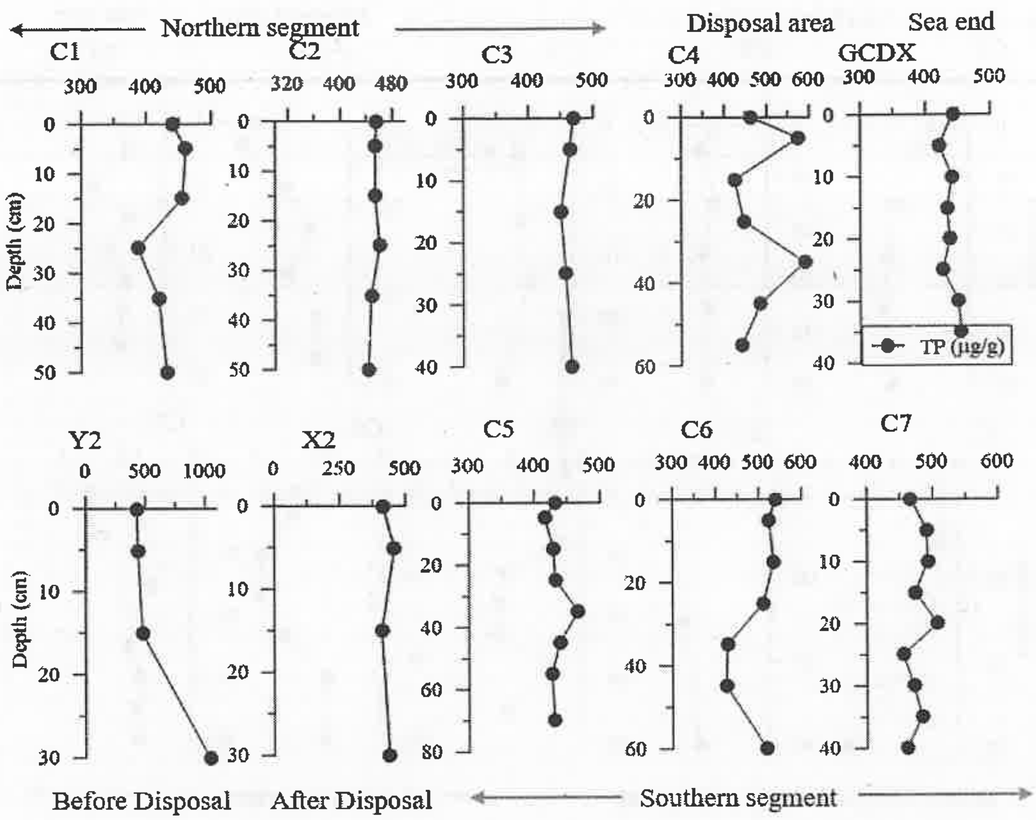

Fig. 6F: Downcore TP variation in the intertidal regions of Dahej during Oct-22.

5.1.4 Flora and Fauna

Marine ecosystems host a large amount of life and are a diverse source of plants, animals, microorganisms and molecules biodiversity. Assessing the effects of both current and projected activities in the coastal zone requires a thorough understanding of the biological state of marine ecosystems. Identification of habitat type, representative communities, predator-prey relationships, and exploitable living resources are all part of the biological characterization of an ecosystem.

An essential component of an ecological evaluation is the research of an ecosystem, particularly its communities. This can be accomplished by choosing a small number of trustworthy parameters from a complicated community structure. Natural stress experienced by marine organisms varies in intensity and frequency depending on changes in the physicochemical properties of the water mass, and the pollutants' long-term effects may eventually impact biological components. The biological parameters considered for the present study are bacterial counts; phytoplankton pigments, cell counts, and generic diversity; zooplankton biomass, density, and group diversity; macrobenthic and meiobenthic biomass, density, and group diversity; and fisheries data collected during Oct-22. The first three represent the primary and secondary levels of water column productivity. As stationary creatures connected to the seabed, benthic organisms offer information on the combined impacts of stress, if any, and are thus reliable indicators for possible damage.

5.1.4.1 Microbiology

The role played by marine microorganisms in the general stability, continuity, and regular operation of marine ecological systems is significant. Marine microorganisms are much more significant despite their modest size because they are involved in processes that affect the water column and sediment (benthic). The base of the food chain is made up of marine microorganisms, which also provide food for many big zooplankton, protozoa, and invertebrate larvae. They also replenish dissolved nutrients needed for marine photosynthesis and the creation of newer organic biomass. Various biological and non-biological events in the waters are strongly correlated with bacteria. Our understanding of the marine ecosystem is changing due to our growing knowledge of the diversity of microbes and the activities they are involved in, and the importance of microbes to marine resilience and resource management is undisputed. The sheer number of microorganism act as sentinels for health status within marine ecosystems and their vast diversity and different functions has led to the realization of threats from emerging pathogens. The abundance and distribution of marine bacteria must be evaluated to highlight the significance of these organisms at the base of the food chain. Along with oceanic processes, anthropogenic activities can impact the microbial diversity of coastal waters.

Apart from potable water, bacterial contamination occurs in surface waters such as those used for fisheries and recreational uses. Though 90% of intestinal bacteria die out within two days in natural waters, the remaining 10% decline much more slowly. Coliform bacteria such as *Escherichia coli* and fecal *Streptococcus* sp. are the two most important groups of non-pathogenic bacteria found in sewage. Because of the number of problems associated with determining individual pathogens, non-pathogenic bacteria (such as coliforms) are used as indicators of water pollution. Untreated domestic waste water has about 3 million coliforms per 100 mL. For water used for swimming and recreation, the standard 200/100 mL of Fecal Coliform (FC) and 1000/100 mL of Total Coliform (TC) (EPA US, 1986; SW-II, CPCB).

The total viable bacterial populations in the water samples ranged widely from 12 to 28×10^3 CFU/mL (Table 7.1). As a general trend, the outer stations showed a lower count than the nearshore stations. A similar result was observed for the TC and FC populations. Other parameters like *Escherichia coli* like organisms (ECLO) and *Streptococcus faecalis* like organism (SFLO) were absent at most stations. The segment wise values of microbial counts are presented in Table 7A.

Table 7A: Microbial counts in subtidal waters segments off Dahej during Oct-22.

Segments	TVC ($\times10^3$ CFU/mL)	TC (MPN/100mL)	FC (MPN/100mL)	ECLO (CFU/mL)	SFLO (CFU/mL)
Reference	27	75	23	NG	NG
Northern	12 – 23 (17)	9 – 19 (14)	6 – 12 (10)	0 – 3 (2)	0 – 1 (1)
Central	15 – 28 (21)	11 – 19 (15)	3 – 14 (8)	1 – 2 (1)	0 – 1 (0.3)
Southern	12 – 26 (20)	19 – 42 (32)	12 – 27 (20)	0 – 1 (1)	NG
Estuary	15 – 19 (17)	44 – 75 (60)	15 – 36 (26)	0 – 1 (1)	NG

NG - indicates No growth

In all segments, the ECLO and SFLO were either absent or, if present, in very low numbers. TVC and TC values were higher at the Reference segments than other areas. Except for estuary, all of the segments had much lower values of FC than the Reference segment. Overall, the TC and FC values of this study were much lower than the prescribed Central Pollution Control Board (CPCB) limits (USEPA, 1986; SW-II (swimming and recreation), CPCB) indicating minimal microbial contamination.

Like in, seawater, the total viable bacterial populations in the sediment samples ranged widely from 19 to 56 $\times10^4$ CFU/g (Table 7.1). The lowest counts were recorded at stations GC2 and GN1 and the highest counts were at stations GS1 and GS2. A high number of TC and FC were observed at stations NE, GS1, GS2 and GR sediments. *Escherichia coli* like organisms (ECLO) and *Streptococcus faecalis* like organisms (SFLO) were absent at all stations except GC1. Segment-wise bacterial counts in sediment have indicated lower or comparable to the Reference segments. Table 7B given below shows the segment wise variation of TVC, TC, FC, ECLO and SFLO in sediments.

Table 7B: Microbial counts in sediments of different segments off Dahej during Oct-22.

Segment	TVC ($\times 10^4$ CFU/g)	TC (MPN/100g)	FC (MPN/100g)	ECLO (CFU/g)	SFLO (CFU/g)
Reference	48	16	11	NG	NG
Northern	20 – 37 (29)	3 – 6 (5)	≤ 3	NG	NG
Central	19 – 32 (26)	9 – 13 (11)	3 – 9 (6)	0 – 2 (1)	0 – 2 (1)
Southern	29 – 56 (46)	15 – 16 (16)	3 – 9 (6)	NG	NG
Estuary	33	20	11	NG	NG

NG - indicates No growth

Water quality criteria set by the CPCB, specifies that the counts of FC to be ≤100 MPN/I00 mL for SW-II Waters. The counts expressed in the present study were within the said range. Comparing the results obtained for microbiological quality of water at studied locations with the standard laid by CPCB for primary water quality criteria for sea waters, it was found that the counts of FC in all stations were low, indicating that the study area was primarily free from fecal pollution.

5.1.4.2 Phytoplankton

Phytoplankton are mostly microscopic, single-celled photosynthetic organisms that live suspended in water. Phytoplankton are the foundation of the aquatic food web, the primary producers, feeding everything from microscopic, animal-like zooplankton to multi-ton whales. In short, they make most other ocean life possible. Through photosynthesis these organisms transform inorganic carbon in the atmosphere and in seawater into organic compounds, making them an essential part of Earth's carbon cycle. Phytoplankton have been used as indicators of water quality. Because of their short life cycles, plankton respond quickly to environmental changes. Hence their standing crop in terms of biomass, cell counts and species composition are more likely to indicate the quality of the water mass in which they are found.

In general, studies of phytoplankton standing crops focus on the biomass component by calculating chlorophyll *a* and primary productivity, while population studies focus on the total number of cells and their general makeup. The grazing activities of zooplankton and the consequent breakdown of phytoplankton cells result in the formation of phaeophytin in natural waters. It is commonly acknowledged that when nutrients are deficient, chlorophyll is changed into phaeophytin. The ratio of chlorophyll to phaeophytin is regarded as a sign of environmental stress. Ratios >1 denote a healthy ecosystem, while ratios <1 denote a stressed one.

a) Phytopigments

During Oct-22, the distribution of chlorophyll *a* in the study area ranged in a narrow range (0.1 – 2.7 mg/m³; avg. 0.4 mg/m³) with maximum concentration being recorded at station NE (Table 7.2). The average values of chlorophyll *a* in the surface (avg. 0.6 mg/m³) and bottom (avg. 0.4 mg/m³) were comparable. The segment-wise variations in chlorophyll *a* concentration during Oct-22 is given in Table 7C.

Table 7C: Segment-wise chlorophyll *a* and Phaeophytin in Dahej waters during Oct-22.

Segment	Level	Chlorophyll *a* (mg/m³)	Phaeophytin (mg/m³)
Reference	S	0.3 – 0.4 (0.4)	0.1 – 0.7 (0.4)
	B	1.0 – 0.7 (0.8)	3.0 – 3.4 (3.2)
Northern	S	0.4 - 0.6 (0.5)	0.2*
	B	0.2 – 0.3 (0.3)	0.1 – 1.0 (0.4)
Central	S	0.1 – 0.5 (0.3)	0.0 – 0.2 (0.2)
	B	0.1 – 0.4 (0.2)	0.0 – 0.5 (0.3)
Southern	S	0.1 – 0.8 (0.3)	0.0 – 0.7 (0.3)
	B	0.2 – 0.7 (0.3)	0.3 – 2.4 (0.7)
Estuary	S	0.1 – 2.7 (1.4)	0.2 - 0.3 (0.3)
	B	0.5*	0.7*
Disposal area	S	0.3 – 1.0 (0.7)	0.0 – 1.0 (0.5)

* All replicates indicate similar value

The above Table indicated that the chlorophyll *a* in the study area was generally low. Chlorophyll *a* values were less than 1.0 mg/m³, except in the estuary. Except the estuarine zone other areas had comparable values with the Reference segment. In the current study, phaeophytin values ranged from 0 – 3.4 mg/m³ (avg. 0.7 mg/m³), with the maximum at station GR (Table 7.2). The phaeophytin in the various segments of the study area was lower or comparable than that of the reference segment (Table 7C). Diurnal observations at station GC1 during Oct-22 indicated low and comparable values of phytopigments during different tidal phases. The phytopigments were observed to be higher during the ebb phase of the tide (Fig. 7A).

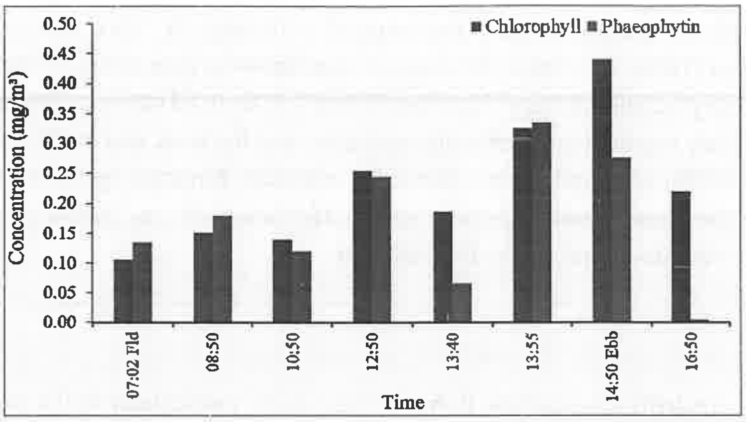

Fig. 7A: Diurnal variation of phytopigments at the subtidal location off Dahej during Oct-22.

b) Phytoplankton population and genera

The density of phytoplankton ranged between 0.2 – 50 × 10^3 cells/L. The maximum cell count was at GN1, and the least was at GR station (Table 6.4). The segment-wise data for phytoplankton cell count and genera in Oct-22 is given in Table 7D. The cell count was much higher in all segments than in the Reference segment. Density of phytoplankton was maximum in the surface waters of the Northern segment.

Table 7D: Segment-wise phytoplankton characteristics in Dahej water during Oct-22.

Segment	Level	Cell count (no × 10^3 Cells/ L)	Genera (no)
Reference	S	0.1 – 0.2 (0.2)	5 – 7 (6)
	B	0.4 – 1.2 (0.8)	3 – 4 (4)
Northern	S	42– 50 (46)	6 – 8 (7)
	B	0.2 – 8 (2.3)	2 - 3 (3)
Central	S	0.6 – 46 (27.7)	4 – 5 (5)
	B	0.2 – 14 (7.2)	2 – 5 (4)
Southern	S	0.3 – 10 (3.7)	3 – 4 (4)
	B	0.4 – 0.6 (0.5)	3 – 4 (4)
Estuary	S	10 – 15 (12.5)	4 -10 (7)
	B	0.8*	6*
Disposal area	S	26 – 52 (39)	9 – 10 (10)

*All replicates indicate the similar value; Values as range and average in parenthesis

The total number of genera varied in the range of 3–10 (avg. 5). Maximum number of genera was at the disposal area (Table 7.3). Table 7D displays segment-wise data of the phytoplankton genera. Overall, 42 genera of phytoplankton were identified (Table 7.4) from all stations. The number of genera was higher in the Estuary segment and in the disposal area, and the least was in the southern segment. *Mermopedia* sp., *Nitzschia* sp., *Synedra* sp., *Nitzschia acicular, Navicula* sp., *Coscinodcus* sp. were the major species in the Estuary zone. Species such as *Merismopedia sp., Surirella sp., Amphiprora sp. and Amphora sp.* were dominant in the disposal area.

5.1.4.3 Zooplankton

Zooplankton are drifting organisms living in the oceans, particularly in the pelagic and littoral zones. By linking the primary producers to higher trophic levels, zooplankton diversity contributes significantly to the food web and are crucial in the transfer of energy . Due to the abundance of food resources, they are typically located in areas that receive plenty of sunlight and can also be found in deep oceanic regions. Zooplankton can be effectively considered as a bioindicator of water quality. It is considered as the chief index of the utilization of aquatic biotopes at the secondary trophic level. Zooplankton are more diverse. Patchiness, diurnal vertical migration, and seasons are the key determinants of their variability. Their abundance is influenced by pollution, stress and hydrographic conditions working together, in addition to changes in food availability (phytoplankton crop).

Zooplankton biomass varied between 0.1–8.0 mL/100m³ and the population density varied between 0.04–53.8 ×10³/100m³ during Oct-22 (Table 7.5). GS2 station had the highest average value of biomass and population, and GC2 station had the least. Total number of faunal groups varied between 5 – 13 (avg. 9). The zooplankton community structure was dominated by copepods (87.1%). Overall, 18 groups of zooplankton were identified from samples collected during Oct-22 (Table 7.6). Fig. 7B given below shows the diurnal variation in zooplankton biomass, density and total groups at station GC1. The data indicated a gradual increase in the zooplankton values from Fld-Ebb (high tide to low tide) and a decreasing trend from Ebb-Fld (low tide to high tide).

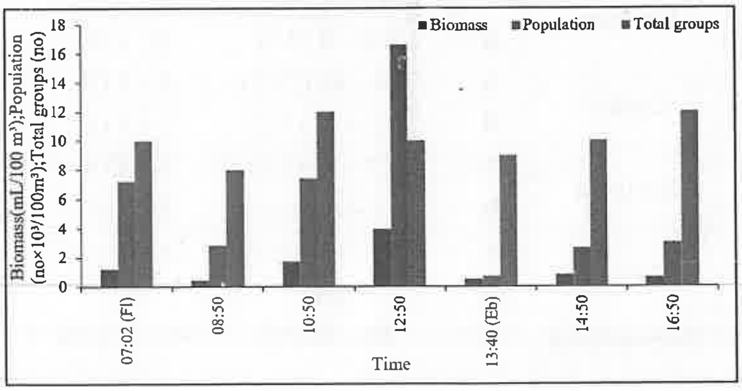

Fig. 7B: Diurnal variation of mesozooplankton biomass, density, and total groups at the subtidal location off Dahej during Oct-22.

Compared to the Reference segment, most of the segments had lower value of zooplankton biomass and population. Variations in average number of faunal groups in studied segments were low (Table 7E).

Table 7E: Segment-wise zooplankton standing stock in Dahej waters during Oct-22.

Segment	Biomass (mL/100m³)	Population (no ×10³/100m³)	Total Groups (no)
Reference	1.7-3.2 (2.5)	5.4-16.9 (11.2)	9-10 (10)
Northern	0.1*	0.1 - 0.2 (0.2)	5-8 (7)
Central	0.1 – 3.9 (0.7)	0.04 – 16.6 (3.0)	5 – 12 (8)
Southern	0.7 – 8.0 (3.7)	4.2 – 53.8 (25.3)	8 – 13 (10)
Estuary	0.7	3.6	11

Values as range and average in parenthesis

5.1.4.4 Benthos

The term benthos refers to organisms that inhabit the substratum and just above the overlaying water column at the bottom of aquatic habitat. Benthos are highly beneficial in converting organic waste from sedimentary storage into dissolved nutrients that can be blended with overlying waters and used to boost primary productivity by rooted plants and algae. Sponges, coelenterates, flatworms, nematodes, roundworms, annelids, molluscs, echinoderms, macro crustaceans, insects etc. are among the macroinvertebrates. Benthic animals are categorized into three groups based on their size: microfauna, meiofauna, and macrofauna.

Because of their constant presence, fairly long lifespans, sluggish habits, and tolerance to diverse types of stress, macrobenthic organisms have been considered as the finest markers of environmental changes brought on by pollution. Benthic animals are vulnerable to physical, chemical, and ecological changes because of their limited mobility. A change in benthic assemblages will occur in areas that are under stress. Unaltered systems are frequently dominated by k-selected species (big body, long lifespan, moderate growth), whereas disturbed communities are characterized by r-selected species (small body size, short lifespan, fast growth).

On the other hand, meiofauna play crucial roles in benthic energetics and are a significant part of the marine benthic population. Meiofauna abundance and biomass can vary significantly depending on the season, latitude, water depth, etc. Specific taxa are limited to certain types of sediment. The vertical distribution of meiofauna has a high degree of variation. Generally, the density decreases with increasing depth in the sediment.

(i) Intertidal macrofauna

Intertidal macrofauna were studied along the three transects, ITC, ITS and ITN. The values of biomass, population and faunal groups are represented in Table 7.7.

Transect ITC in the vicinity of disposal area had the highest average population and faunal group diversity (Table 7.7). ITN had the highest average macrobenthic biomass whereas ITS had the least values for all the parameters. The major faunal components were polychaetes (76.5 %). Overall, 9 faunal groups were recorded from all the stations.

(ii) Subtidal macrofauna

During Oct-22, the average subtidal macrobenthic standing stock varied in terms of biomass and population from 0 – 1.3 g/m² and 0 – 75/m² respectively (Table 7.9). Only polychaetes were found in the study area (Table 7.10). Comparatively, GS2 station had the maximum number of organisms and biomass. Spatial variation of macrobenthos is given in Table 7F below. The macrobenthic population was very minimal across all segments in the study area.

Table 7F: Segment-wise subtidal macrobenthosat Dahej during Oct-22.

Segment	Biomass (Wet wt.; g/m²)	Population (no/m²)	Faunal Group (no)
Reference	NIL		
Northern	0 – 1.3 (0.2)	0 – 50 (9)	0 – 1 (1)
Central	0 – 0.2 (0.07)	0 – 50 (17)	0 – 1 (1)
Southern	0 – 1.1 (0.3)	0 – 75 (20)	0 – 1 (1)
Estuary	NIL		
Disposal area	NIL		

Values as range and average in parenthesis

(iii) Intertidal meiofauna

Transect wise data of biomass, population and number of faunal groups of meiobenthos during Oct-22 is given in Table 7G below.

Table 7G: Meiobenthos in the intertidal regions of Dahej during Oct-22.

Station	Biomass (µg/ 10 cm²)	Population (no/ 10 cm²)	Faunal Group (no)
ITC	4.4 – 567.8 (178.9)	65 – 1304 (499)	3 – 6 (5)
ITS1	0.2 – 78.3 (18.8)	7 – 937 (357)	1 – 4 (3)
ITN1	0 – 197.1 (42.9)	0 – 253 (79)	0 – 5 (3)
Average	0 – 567.8 (80.2)	0 – 1304 (311)	0 – 6 (4)

Values as range and average in parenthesis

In the current study period (Oct-22), the intertidal meiofaunal biomass and population varied from 0 to 567.8 µg/ 10 cm² and 0 to 1304 no/ 10 cm² respectively (Table 7.11). The number of meiofaunal groups in the study area varied from 0 to 6. The mid water level of ITC had the highest average values of biomass (avg. 304.07 µg/ 10 cm²), population (avg. 1184 no/ 10 cm²) and number of faunal groups (avg. 6 nos). The major faunal group was Nematoda (Table 7.12).

(iv) Subtidal meiofauna

During Oct-22, the population, biomass and number of faunal groups were comparable across the various segments. Comparatively, Station GN2 had exceptionally higher biomass (avg. 36.2 µg/ 10 cm²) and station GS1 had higher population (avg. 25 Ind/ 10 cm²) (Table 7.13). The major faunal group was Nematoda at all the subtidal stations of Dahej except GCD, where a similar percentage (25%) of Amphipoda, Copepoda and Polychaeta were found with a lower (13%) of Nematoda group (Table 7.14). Segment wise data of meiobenthos in subtidal waters are given in Table 7H below.

Table 7H: Segment-wise subtidal meiobenthos at Dahej during Oct-22.

Segment	Biomass (µg/10 cm²)	Population (ind/10 cm²)	Faunal Group (no)
Reference	1.4 – 1.6 (1.5)	1 – 8 (4)	1 – 2 (1)
Northern	0 – 108.4 (18.2)	0 – 8 (4)	0 – 4 (2)
Central	0 – 1.9 (0.51)	0 – 6 (2)	0 – 3 (1)
Southern	0 – 1.6 (0.43)	0 – 34 (9)	0 – 4 (2)
Estuary	0 – 0.3 (0.2)	0 – 4 (2)	0 – 1 (1)
Disposal area	0 – 12.9 (4.4)	0 – 6 (4)	0 – 3 (2)

Values as range and average in parenthesis

The biomass and population of meiobenthic community were random in all the segments. Highest average of meiobenthic biomass was at the norther segment, followed by the disposal area. The meiobenthic population was higher in southern segment, with similar averages at the reference, northern and disposal area. The meiobenthic faunal groups were low, with almost similar averages in all the segments (Table 7I).

5.1.4.5 Fishery

The general pattern of fishing season of different fisheries in the Saurashtra and South Gujarat is given in Table 7I.

Table 7I: General pattern of fisheries in Saurashtra and South Gujarat.

Fishery	Fishing season	
	Saurashtra	South Gujarat
Bombay duck	October-February	October-April
Pomfret	October-April	October-April
Jew fish	October-April	October-April
Prawn	October-April	October-April
Hilsa	October-April	July-September

High tidal amplitude and high turbidity coupled with strong tidal currents make trawling or gill netting for fish, difficult and risky in the GoKh. The results of experimental gillnet fishing carried out by NIO during Oct-22 resulted very poor catch during the periods (i) high to low tide (1 kg) and (ii) low to high tide (0.5 kg), off Narmada (5-15m) water depths. Evidently, no active commercial fishing exists in the study region except limited shore–based fishing by common bag-nets or other traditional gears. Enquiries with the local fishermen and the Department of State Fisheries, Ghogha also confirm that the trawlers generally do not operate in the coastal waters in the GoKh segment between Dhadhar and Luvara and in the estuarine segment of Narmada, which are close to the current disposal site.

The fishing season is very much inter-related to the climatic conditions. By and large the fishing operations are confined to the period from mid-September to mid-May. From mid-May onwards the sea becomes very rough and hence fishing remains suspended. The district Bharuch, where Dahej is located accounted for low fisheries (barely 0.2 to 0.94% of the total landings of the state), in the GoKh. The marine fish landing at Bharuch district have showed comparatively increased values after 2005 and thereby random increase and decrease from 2010 (Fig. 7C).

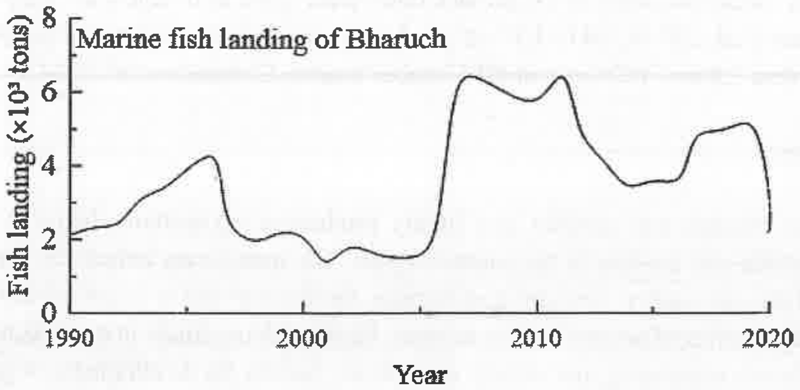

Fig. 7C: Long-term marine fish landing in Bharuch district. (Source: Department of State Fisheries, Bhavnagar and Bharuch)

The present marine fish landing of Bharuch district is more or less comparable with the landing during pre-industrialization (1990). The fish landing data of Bharuch District for 2020-2021 indicated that the Bombay Duck, shrimps and mullet were the major catches. Bharuch District has 9 major fish landing centres which include Malpur, Kavi, Nada, Katyajal, Luvara, Lakhigam, Zamdi, Tankari and Sarod. The landing centers Luvara and Lakhigam have showed declined fisheries as compared to their landing during 2006-07 (Fig. 7D).

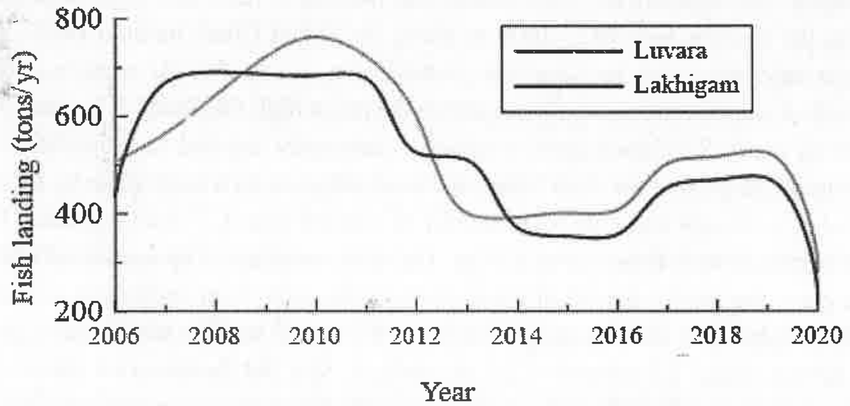

Fig. 7D: Long-term marine fish landing in Luvara and Lakhigam landing centre. (Source: Department of State Fisheries, Bhavnagar and Bharuch)

The fishes caught in the gillnet and collected from the shore-based fishing methods are listed in Table 7.15. Overall, the study region revealed low fishery potential which could be related to high turbidity associated with strong currents and the low biological potential at different trophic level. The chemical constituents such as PHc is vital considering the operation of ships in the region. The PHc levels in the fish gills and muscles tissue were ranged from 0.1 to 5.2, µg/g wet. wt. (av. at 1 µg/g wet.

Wt). The range of values observed in the present study were close to 0.52 to 2.05 μg/g in Tamilnadu coast (Veerasingam et al., 2011), 0.47– 3.77 μg/g in North and Central Arabian Sea (Gupta and Qasim, 2001) and lower than 1.8 and 10.8 μg/g in off Mumbai waters (Chouksey et al. 2004).

5.1.4.6 Mangroves

Mangrove swamps are complex and highly productive ecosystems, helps in the shoreline stabilisation, prevents soil erosion in the coastal region. The mangroves enrich the coastal water by adding dissolved organic matter, nutrients and detritus, besides serving as breeding and nursery areas for the larvae and juveniles of several marine animals. High tidal amplitude in the GoKh of Khambhat, low rainfall, extreme temperature, and salinity are limiting factors for development of good quality of mangroves in Gujarat. Mangroves on Saurashtra coast from Dwarka to Khambhat are confined to limited mudflats and creeks. These mangroves are sparse and scrubby and consist of mainly of *Avicennia*. As per FSI 2021 Report, Bharuch District has 45.38 km² of mangrove cover. The marshy domain of the inner regions of the GoKh of Khambhat has extensive growth of mangroves which form a vital component of the ecosystem of the area. Mangrove cover in Dahej indicated major changes in last few decade (Khare and Shah, 2019), improved recently due to their growth on the barren mudflats and salt marsh zone.

About 5 km north of Birla Copper Jetty (Lat 21° 43' 960"N and long 72° 33' 076"E) a dense patch of *Avicennia marina* approximately 4.5 km^2 exists along the open shore, Dhadhar and Dahej creeks. Large extent of tidal zone particularly supralittoral areas in this region, had been reclaimed, mainly for industrial development and agricultural (salt pans) activities. However, intertidal regions of 5 to 20 m along the rivulets and 50 to 1000 m along the Dahej Creek harbour dense growth of *A. marina*. Obligate halophyte such as *Sesuvium portulacastrum* and *Suaeda maritima* are commonly noticed along with *A. marina* in the region just above the mean high tide level. *S. maritima* is dominant at the supralittoral zone. *Salvodora persica* appears commonly beyond the supralittoral zone. The mangrove regions are exploited for shell fishes and mud skippers on a large scale by local fishermen. The coast of Dahej is muddy and composed mostly of clay of recent alluvial deposits. The intertidal expanse varied approximately from 0.8 to 2.5 km. The open mudflats of approximately 800 to 1000 m wide along the coast are totally devoid of natural mangrove vegetation, indicating unstable nature of substratum. The height of *A. marina* ranged between 0.2 to 1.6 m. The plants were generally short (avg. 0.6 m) with occasional tall ones of ~1.2-1.6 m height. Alia Bet the estuarine island situated at the mouth of Narmada Estuary abounds in the mangrove grass *Porteresia coarctata* which is used by the large camel population inhabiting on the island. A patch of *Avicennia* is observed in west south part of the Alia Bet.

5.2 Comparison with previous study results

The average water quality limits at different marine zones, such as estuary, nearshore, and offshore regions of Dahej observed during Oct-22, were compared with results from previous studies (1993 onwards) established by CSIR NIO in the same region, to see any noticeable changes. The data of post-monsoon periods from October to February are compared with Oct-22 observation. The stations considered for different marine zones are estuary (NE), nearshore (GN1, GC1, and GS2), and offshore (GN2, GC2, and GS3). Stations of earlier studies in the vicinity of the above zones were selected for comparison.

5.2.1 Hydrography

The long-term hydrography changes in different marine zones of Dahej, presented in Fig. 8A, have highlighted that the water temperature, pH, and salinity followed a general marine distribution from nearshore to offshore. The levels of these parameters observed in different zones during Oct-22 have remained comparable with previous limits those found in Oct-93, Oct-95, and Oct-07 (Fig. 8A). The GoKh waters are dynamic and with well-mixed characteristics, which corresponds to the minimal changes in the hydrography parameters in the nearshore and offshore region in a particular season. Estuary zone has lower temperature and salinity levels than marine zones due to freshwater mixing. Unlike the previous results, no abrupt changes were observed in water temperature, pH, and salinity during Oct-22 at any zone.

The SS load in the estuary and nearshore region fluctuated markedly during Jan-12 and Oct-22, noticeably higher than the values of Oct-93 and Oct-07 but much lower than those found during Feb-97. Mixing bottom sediment and SS transport from the rivers enhances the SS concentration in the GoKh water. The SS ranges in the subtidal region, including the reference station, were wide (25-6299 mg/L) but lower than the SS of the disposal area (18.5-1839 mg/L). The observational SS in the treated CETP effluent was avg. 171.2 mg/L. Therefore, SS increase due to effluent load is negligible. The Dahej industrial region was developed in 2006-07. No noticeable hydrography change was observed during Oct-22 compared to 2006 and earlier. The values of DO and BOD_3 were consistent, without any abrupt variation over the period. Overall, the region remained oxic throughout; exceptionally, the higher BOD_3 values in the estuary segment during Jan-12 and Oct-22 were supported with good DO, therefore, did not highlight any intense organic matter oxidation in the estuary.

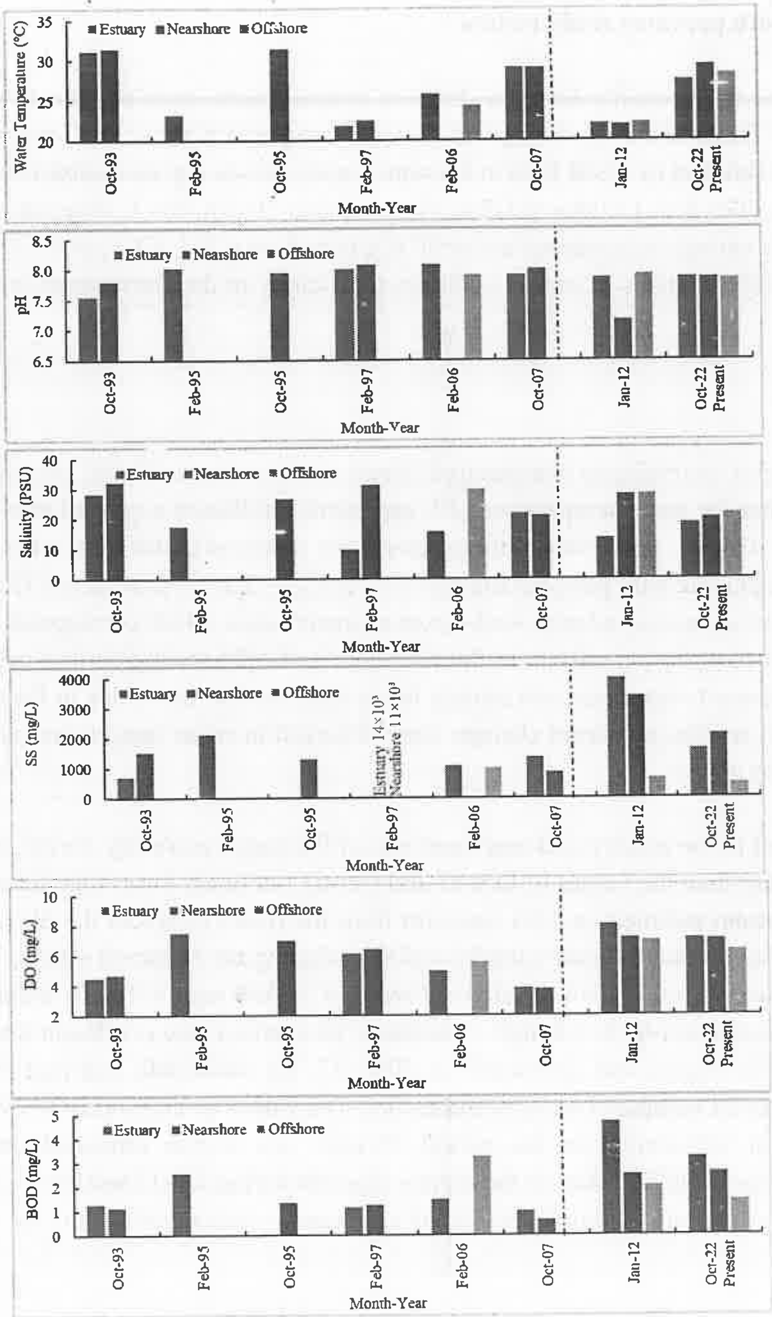

Fig. 8A: Long-term hydrography changes in different marine zones of Dahej (dotted line differentiate the period before and after Dahej Industrialization).

The long-term hydrography conditions at the subtidal disposal location, which CSIR NIO suggested, showed random variation without any abrupt increase in the average levels before and after the industrialization in the Dahej area (Fig. 8B). The average limits of temperature, salinity, DO, and

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BOD, the key hydrography parameters for marine ecology were represented by their seasonal characteristics.

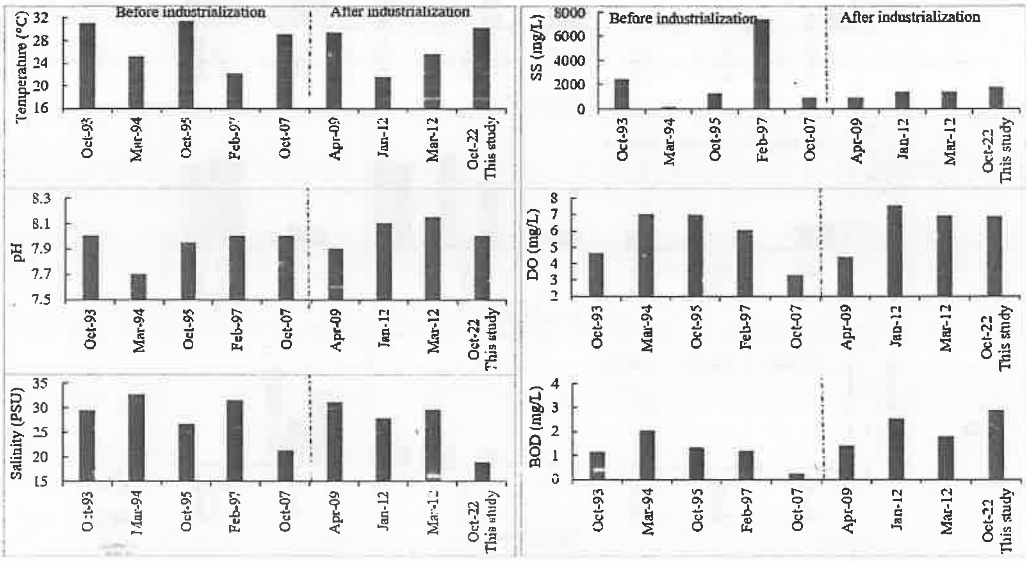

Fig. 8B: Long-term hydrography changes in the subtidal disposal location.

5.2.2 Nutrients

The long-term variation in dissolved nitrogen and phosphorous compounds in Dahej waters is presented in Fig. 8C, which indicates the random variation of these compounds among the three zones. The nutrients such as phosphate, nitrate, and nitrite have increased in recent periods, and mostly, the estuarine waters have relatively higher concentrations as compared to the nearshore and offshore. Exceptionally, the dominance of nitrite in Jan-12 was supported by lower ammonium and nitrate levels during the same period. The average phosphate levels were consistently higher after Feb-97 in all the observations. The nearshore and offshore ammonium values were higher, in line with the nitrate levels during this study. A similar result was seen during the Oct-95 pre-industrial period, which indicated the natural variation of ammonium in the water and estuarine transport.

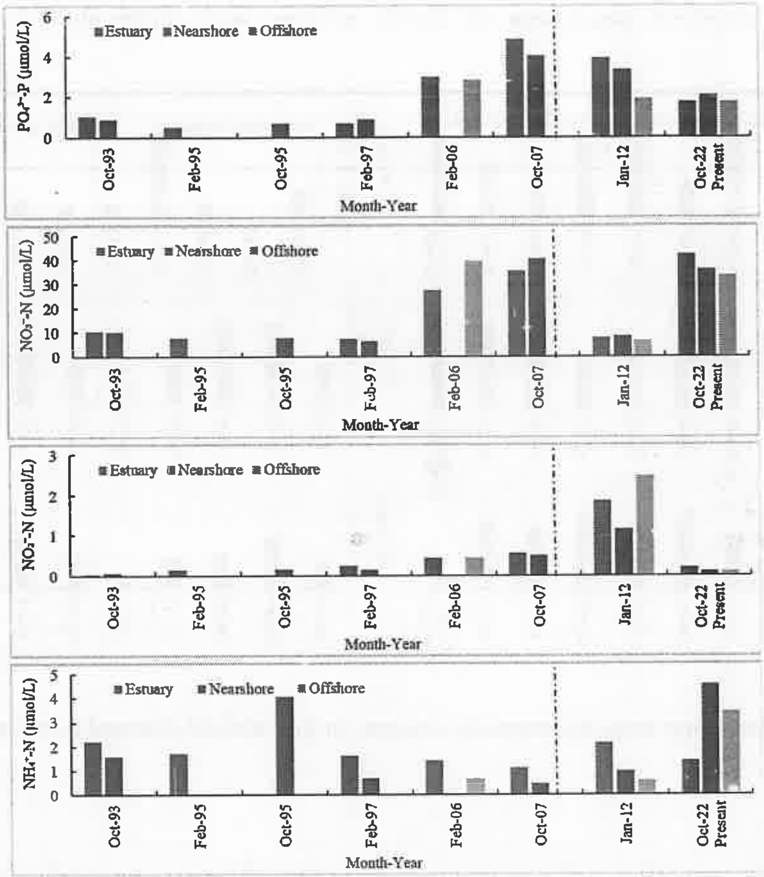

Fig. 8C: Long-term nutrient changes in different marine zones of Dahej (dotted line differentiate the period before and after Dahej Industrialization).

The composition of phosphate, nitrate, nitrite, and ammonium was in the range generally found in west coastal waters. The long-term average nutrient at the subtidal disposal location, which CSIR NIO suggested, showed increased phosphate and nitrate levels during post-industrialization in the Dahej area (Fig. 8D).

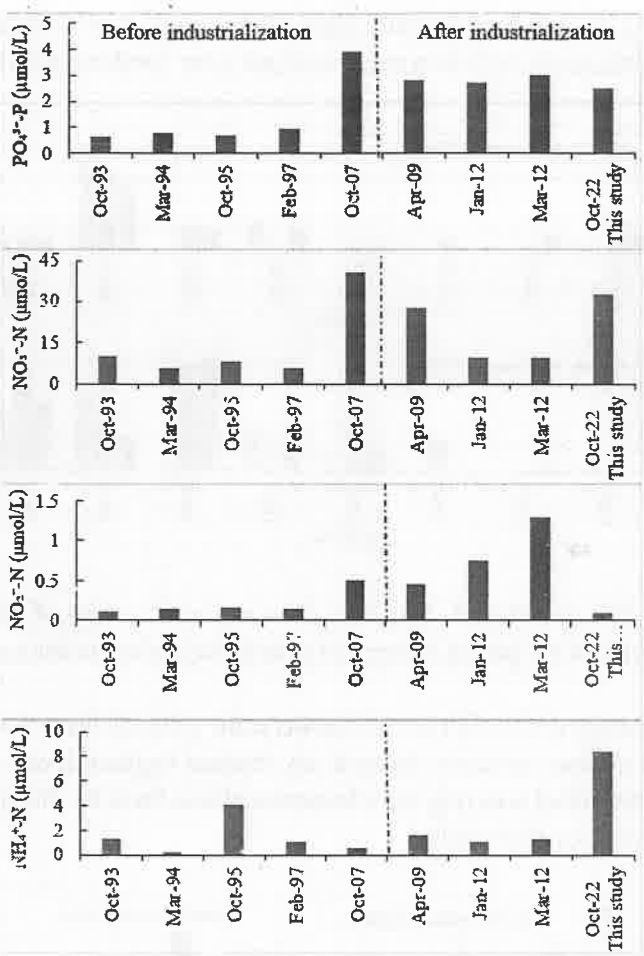

Fig. 8D: Long-term nutrient changes in the subtidal disposal location.

Nitrate and phosphate are prime nutrients for biological activities in marine waters. The disproportional enhancement of nitrate, nitrite, and ammonium in natural marine waters is related to nitrification and denitrification. The proportional limits of these constituents may enhance the stoichiometric imbalance to have particular nutrient species limitations for biological productivity. The enhancement of both the constituents, such as nitrate and phosphate, in Dahej waters after Oct-07 would not change their molar ratio, but the occasional increase of ammonium and nitrite would hamper the ratio and possibly can trigger the phosphate limitation.

5.2.3 PHc and Phenols

The limits of petroleum compounds such as PHc and Phenols at different zones of this study were comparable with previously observed values in similar zones. The distribution of these compound among the estuary, nearshore and offshore were random due to multiple sources (Fig. 8E). The levels of PHc and Phenols were in their range generally found in the west coast waters and do not highlight any oil spill/leakage in the region. Exceptionally higher PHc values in all three zones were recorded during Jan-12, possibly related to heavy ship movement and other localized activities in the region.

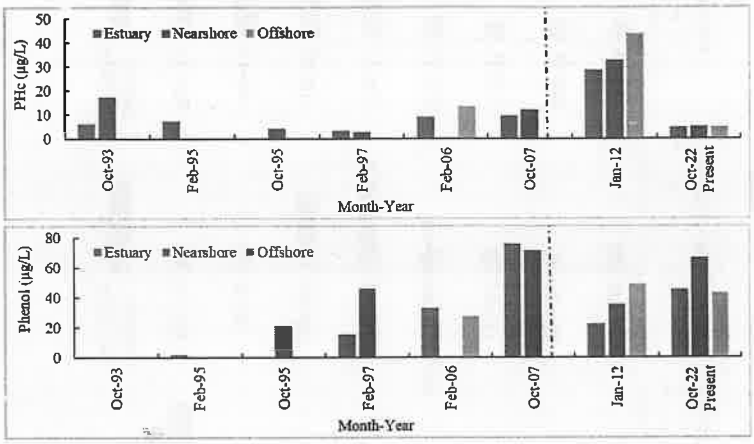

Fig. 8E: Long-term PHc and Phenol changes in different marine zones of Dahej (dotted line differentiate the period before and after Dahej Industrialization).

The long-term average limits of PHc and Phenols at the subtidal disposal location, which CSIR NIO suggested, showed random variation, without any marked increase levels during the period of post industrialization in the Dahej area (Fig. 8F). Exceptional was there for Phenol in Apr-09 and PHc in Jan-12, those were decreased afterwards.

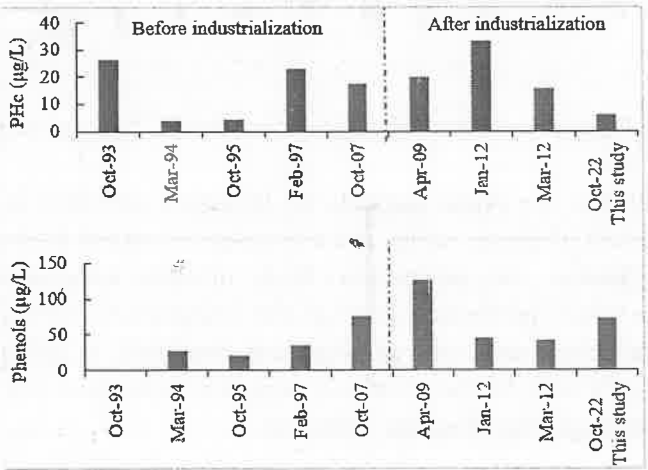

Fig. 8F: Long-term PHc and Phenols changes in the subtidal disposal location.

5.2.4 Sediment quality

The long-term variation of sediment texture in the subtidal and intertidal sediment of the Dahej region was random. Broadly, the sediment of the nearshore region is disproportionately mixed with sand and silt, therefore randomly showing the dominance of either texture. During the present study, the nearshore sediments were similarly composed of sand and silt, whereas the central segment, which is close to the disposal area, was dominant with sand (Fig. 8G). Alternatively, the northern and southern intertidal segments have shown the dominance of silt, which together have indicated a differential hydrodynamic sorting process that controls the sediment texture in the intertidal segments. Further, the dominance of sand in the sediment in the central segment presumably has a lower impact on the accumulation of chemical constituents in the sediment.

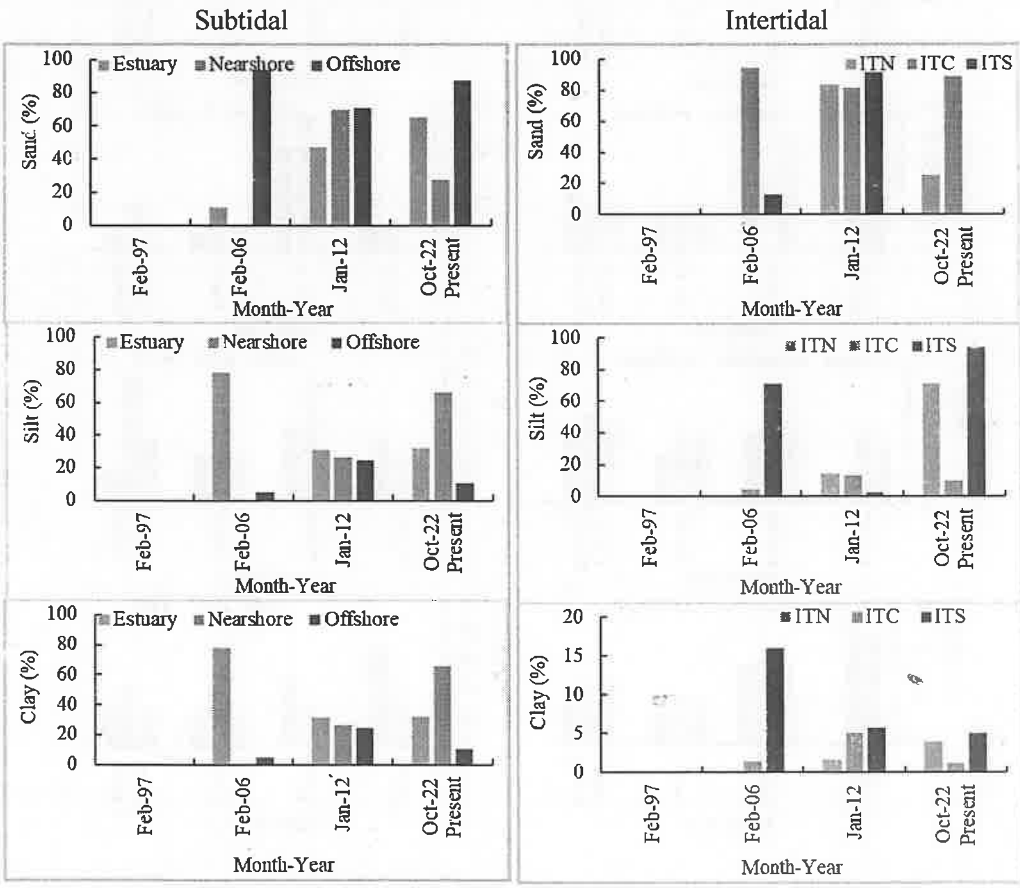

Fig. 8G: Long-term sediment texture changes in different marine zones of Dahej.

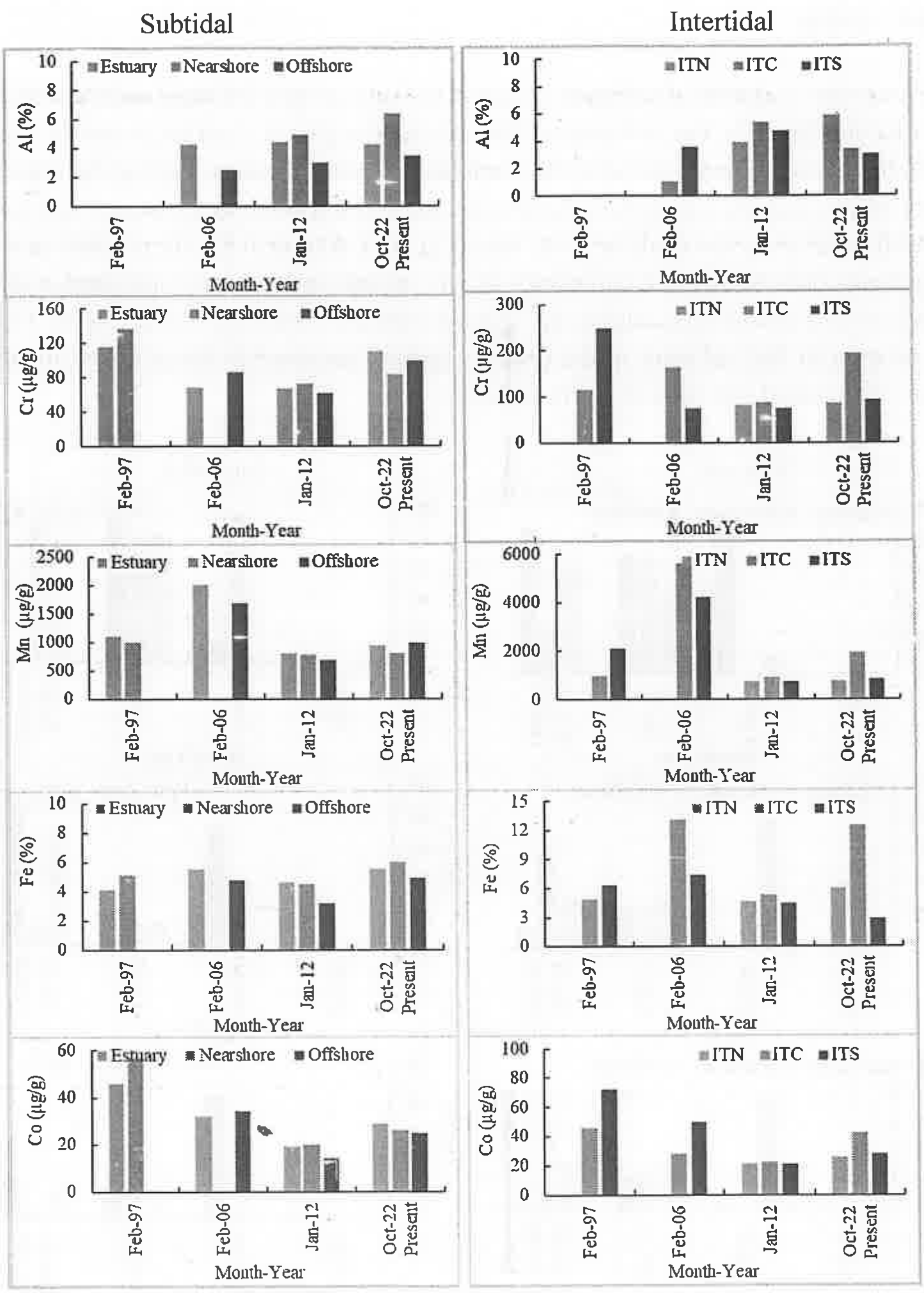

Fig. 8H: Long-term sediment metal changes in different marine zones of Dahej.

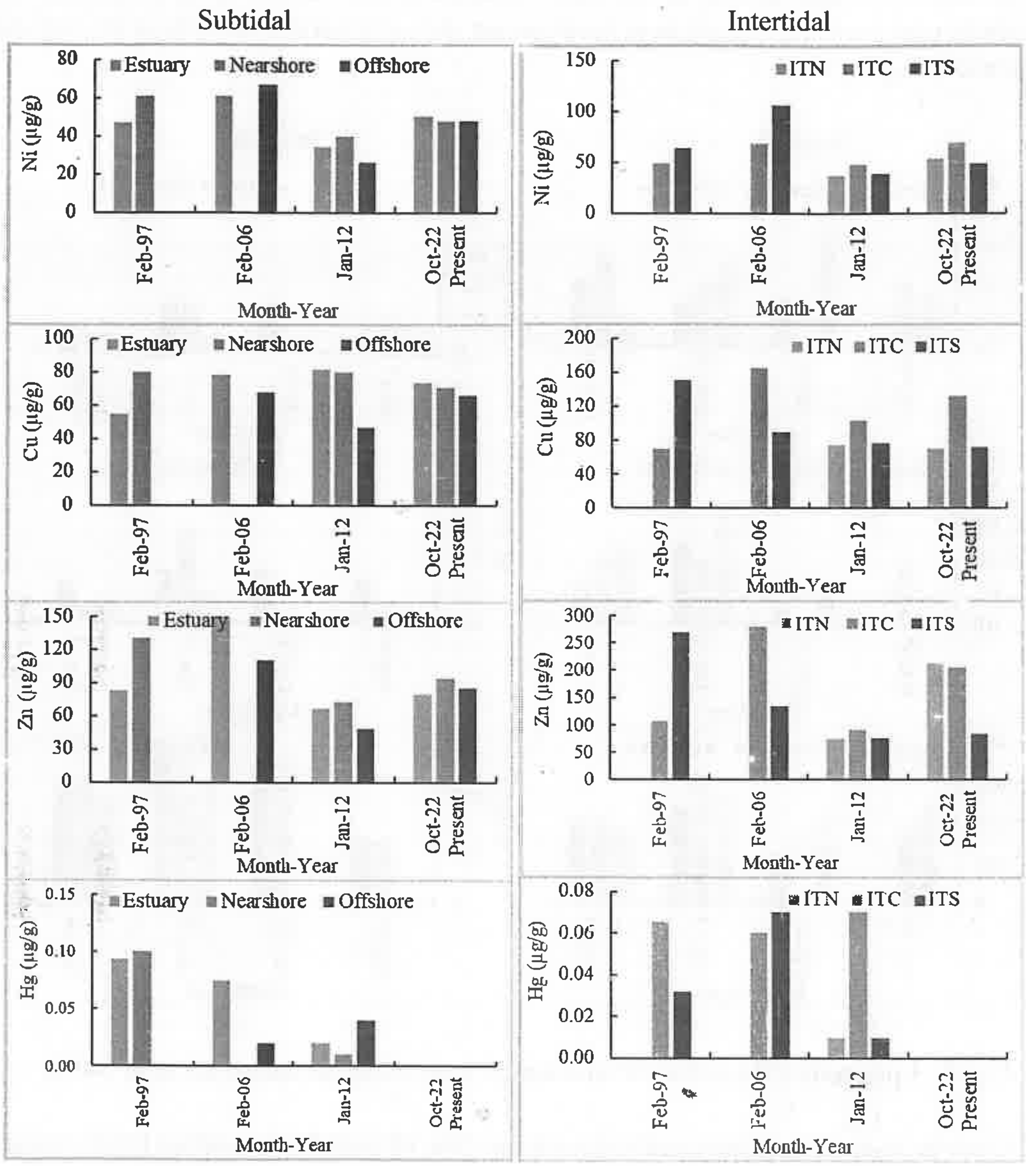

Fig. 8H: Continued…. (Long-term sediment metal).

The long-term metal concentrations in the subtidal and intertidal sediments of Dahej have indicated comparable or lower limits during Oct-22 in general. In contrast, it indicated disproportional metal variation among different segments during different periods. The central zone of the intertidal region (ITC), the vicinity of the disposal area, has shown relatively higher metal levels, except for the Al, compared to the other two (ITN and ITS) regions. The lower Al in this segment was due to higher grain size (Fig. 8H). The ITC sediments had higher concentrations of Cr, Cu, Fe, and Zn than their limits during pre-industrialization or development (Feb-97), indicating their enrichment. The metals in subtidal sediment were random at all the segments. Also, the concentrations during Oct-22 were lower or comparable with pre-industrialization or development (Feb-97) and did not indicate any noticeable metal pollution (Fig. 8H).

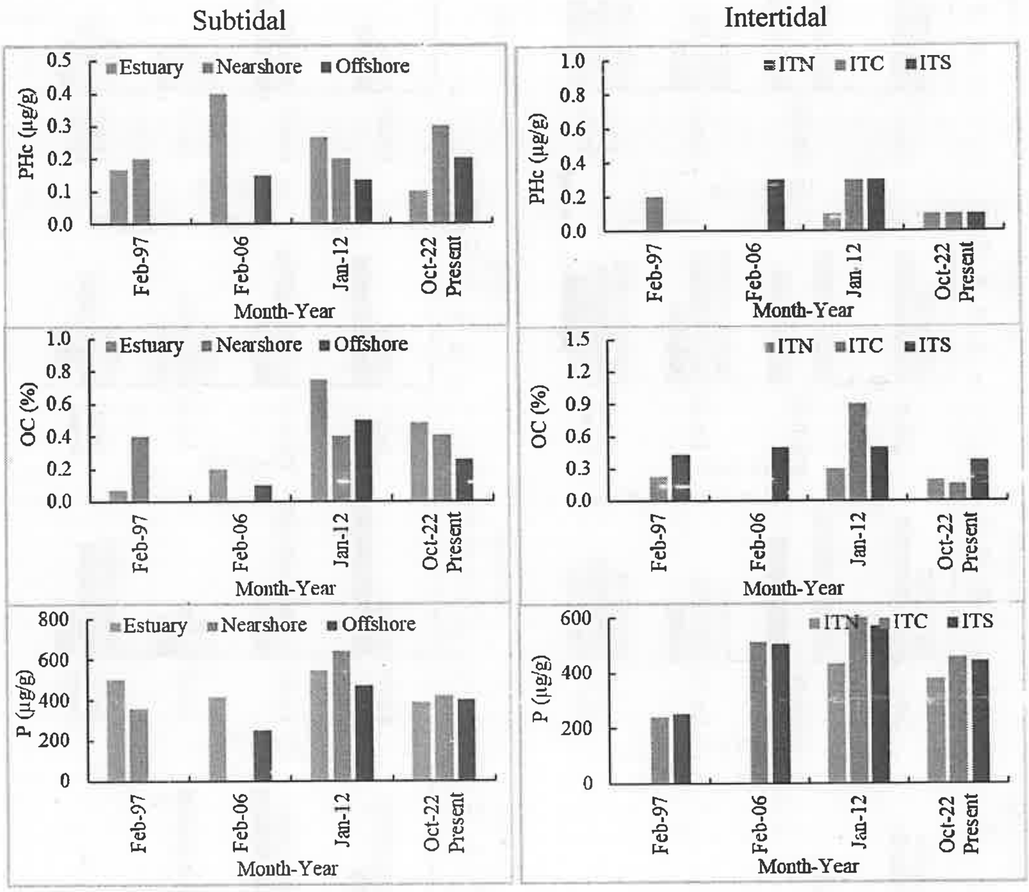

Fig. 8I: Long-term PHc, OC and P in sediment from different marine zones of Dahej.

Likewise, metals, the other constituents such as PHc, OC and P have average limits comparable with pre-development (Feb-97) period limits, with random variation across different zones (Fig. 8I). The intertidal segments have showed increased P values in sediment as compared to the Feb-97 limits, which indicated periodic accumulation in this sediment. The ITC and ITS have higher P than the ITN during this study is consistent with previous results of Jan-12. Overall, the P levels were much lower compared to their geological limit and those generally found in the coastal regions of India.

(a) Metal enrichment in subtidal sediment

The metal enrichment in subtidal sediments from Dahej was random over the periods and varied between moderate and significant enrichment concerning their geological concentrations (Fig. 8J). The metals Cu, Fe, Co, and Mn, were moderately enriched in the estuary and offshore segments during Oct-22, comparable with previous data. Metals such as Co and Mn, were significantly enriched in the offshore segment during Feb-06. Before industrialization (Feb-97), no metal enrichment was found in the subtidal sediments. The anthropogenic enrichment of metals in the estuary and offshore was primarily related to the variation of Al and Fe, which is affected by the regional grain size distribution.

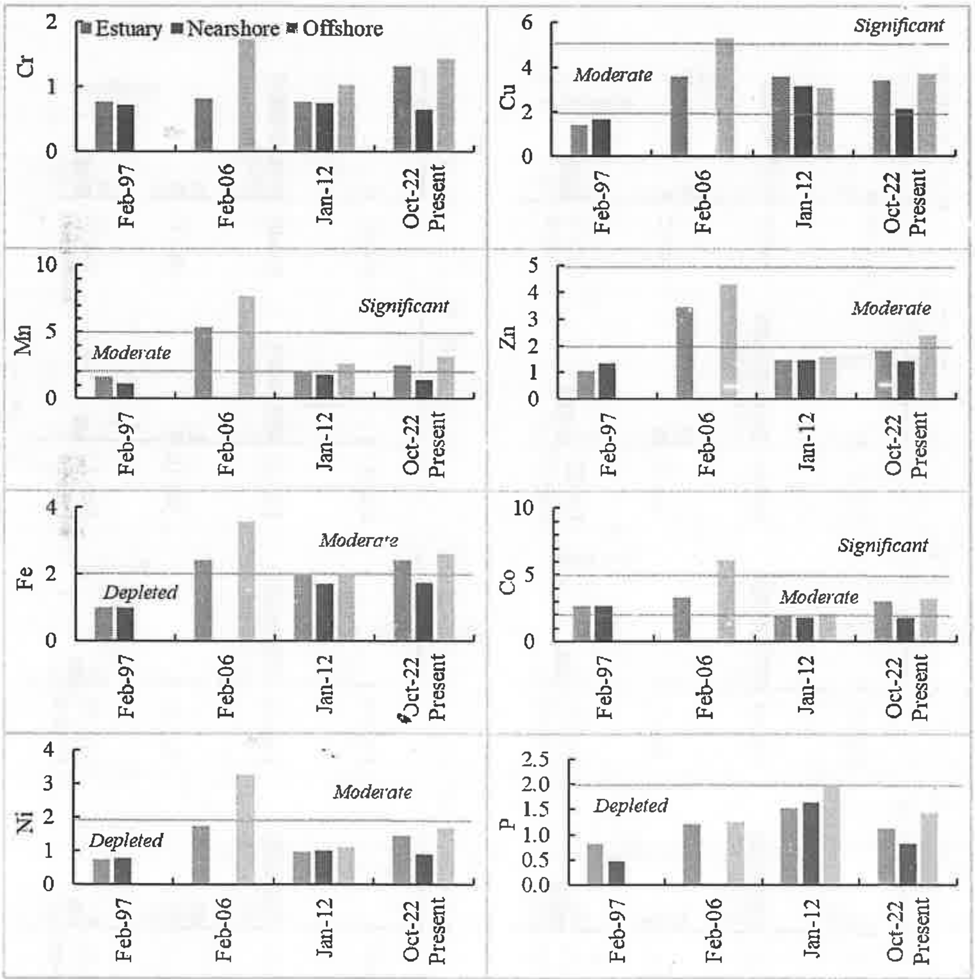

Fig. 8J: Long-term metal enrichment in subtidal sediments from Dahej.

(b) Metal enrichment in intertidal sediment

The metal enrichment in the Dahej intertidal sediments were significant and very high concerning their geological limits. Most of thc studied metals, were significantly enriched in the central segments, i.e., in the region of disposal compared to the southern and northern segments (Fig. 8K). The southern segment near Narmada estuary remained depleted with metal, except for the Cu, Co and Mn, which showed moderate enrichment. Enrichment of these metals in estuarine sediment is common, possibly resulting from multiple sources and discharge in the region. The central segment of the studied intertidal region has showed substantial enrichment of all the metals during Feb-06, which was significantly higher than present observational results and the results of the pre-industrialization period (Feb-97).

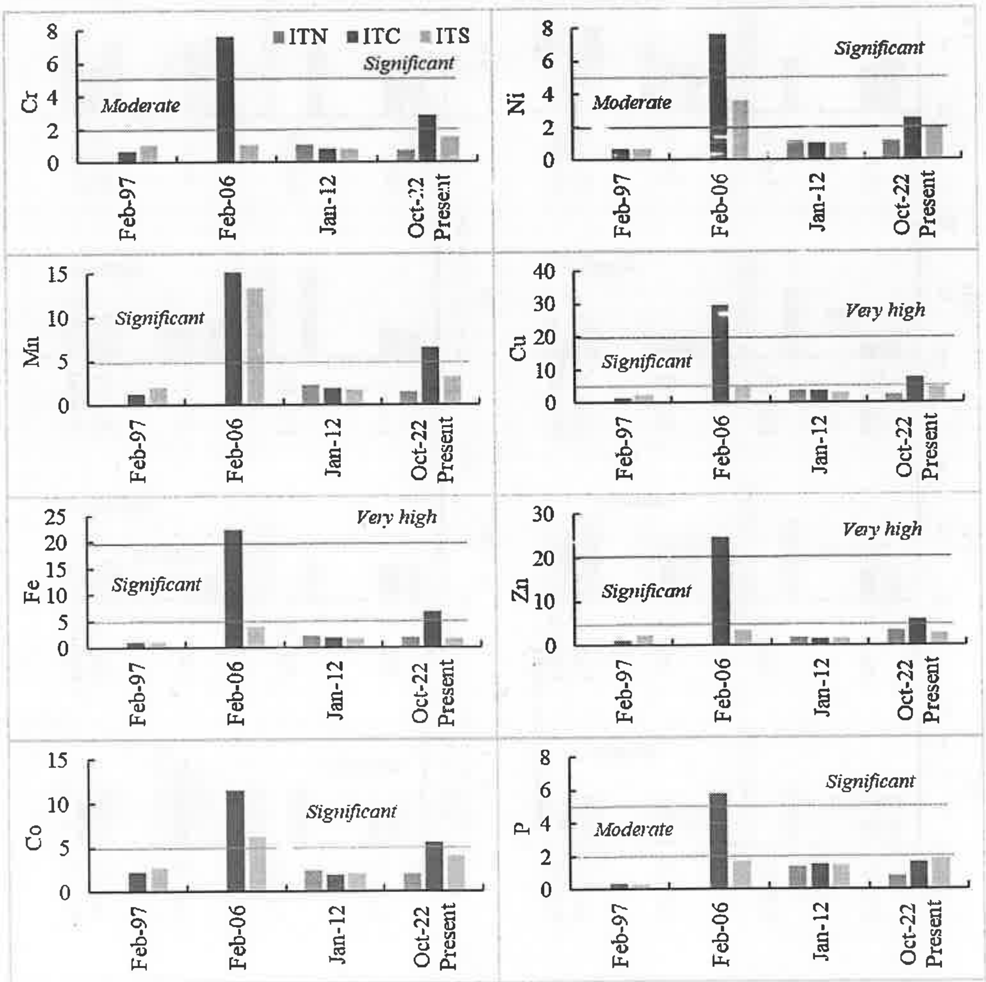

Fig. 8K: Long-term metal enrichment in intertidal sediments from Dahej.

5.2.5 Biological characteristics

Long-term data of Chlorophyll *a*, the prime indicator of primary production in the subtidal waters of Dahej have indicated declined values in the nearshore and offshore segments during recent years as compared to 1993. (Fig. 8L). The highest value (1.8 mg/m^3) during Jan-12, was observed in the estuary segment and with high nutrients. Generally, the region has lower average chlorophyll *a* (<0.5 mg/m^3) since Oct-93, possibly due to high SS. Likewise, the phaeophytin values in Dahej waters were generally low (0.4 to 0.7 mg/m^3) prior to the industrialization (Feb-97). Exceptionally higher value was observed during Jan-12 in all the studied segments.

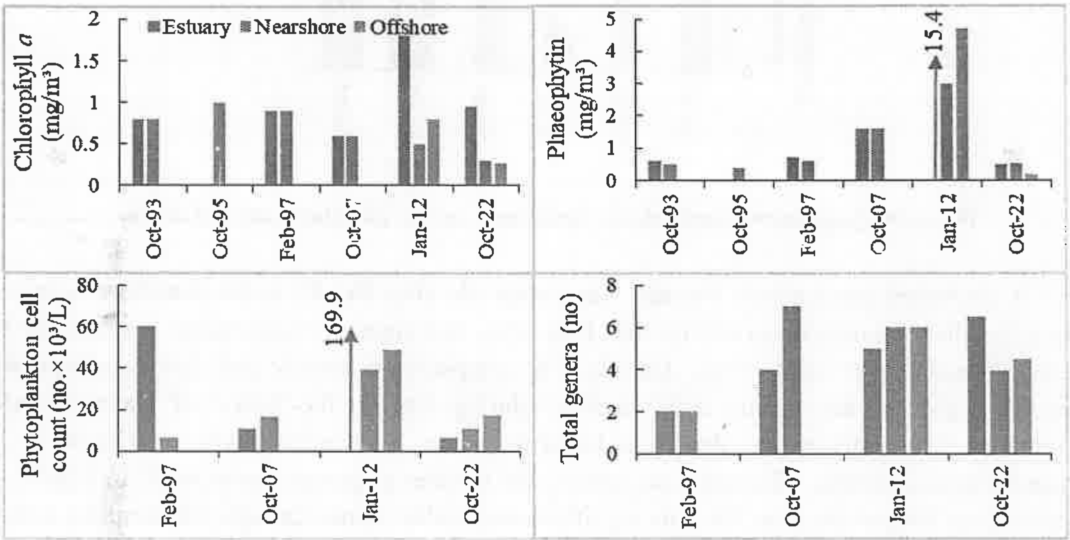

Fig. 8L: Long-term phytoplankton parameters in the subtidal waters of different marine zones off Dahej.

The temporal distribution in phytoplankton cell count and genera were random in the region. Estuarine segment had high cell count 60.6 × 10^3 cells/L during the pre-industrialization, which then declined in the later years, except during Jan-12, . The phytoplankton cell counts were lower during the present study period but comparable with Oct-07. The average number of genera was 2 before the industrialization in the region, but registered an increase at all the segments in recent sampling years (Fig. 8L).

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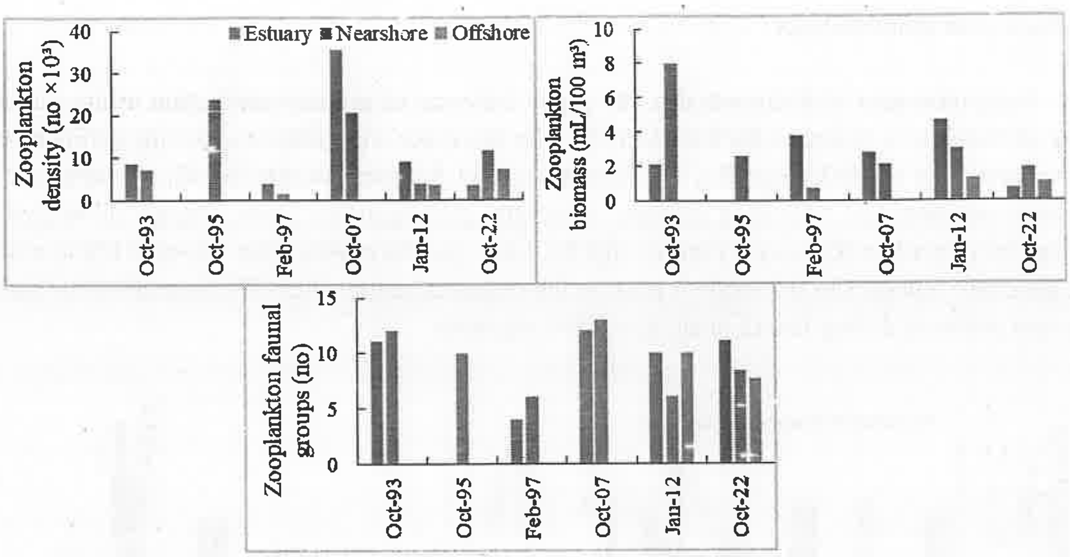

Fig. 8M: Long-term zooplankton parameters in the subtidal waters of Dahej.

A decreased zooplankton biomass was noticeable after Oct-95 in the nearshore waters off Dahej as per the long-term observational data (Fig. 8M). The biomass in the estuary has been random with occasional higher limits (e.g., Jan-12). The zooplankton density and faunal groups were noticeably higher in the estuary and nearshore during Oct-07, the period of Dahej industrial development. The zooplankton density reduced thereafter, the faunal groups were more or less comparable across periods. Though a decrease in the number of groups from Oct-93 to Feb-97 was indicated, post industrialization, the data signified comparable values through the sampling periods, comparable to Oct-93 were observed.

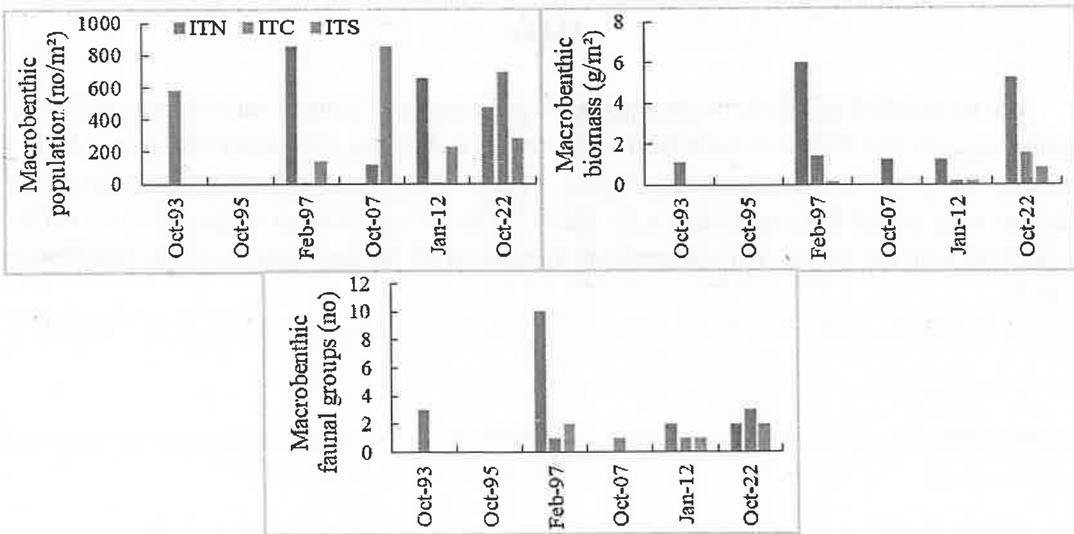

Fig. 8N: Long-term macrobenthic parameters in the intertidal sediment of Dahej.

On analyzing the historical data for microbenthic biomass, the values were found to be low before and after the industrialization. There were variations in population among the transects during different sampling periods, with no particular trends. The population in the central segment i.e., in the area of disposal have showed higher value and comparable with Oct-93. The number of faunal groups were low and their variation was not distinct between the pre and post industrialization phases, except in station ITN, which had an exceptionally higher number of faunal groups during Feb-97. The average macrobenthic biomass and groups in the central segment (ITC) were remained comparable but low in the periods before and after the industrialization in the region (Fig. 8N).

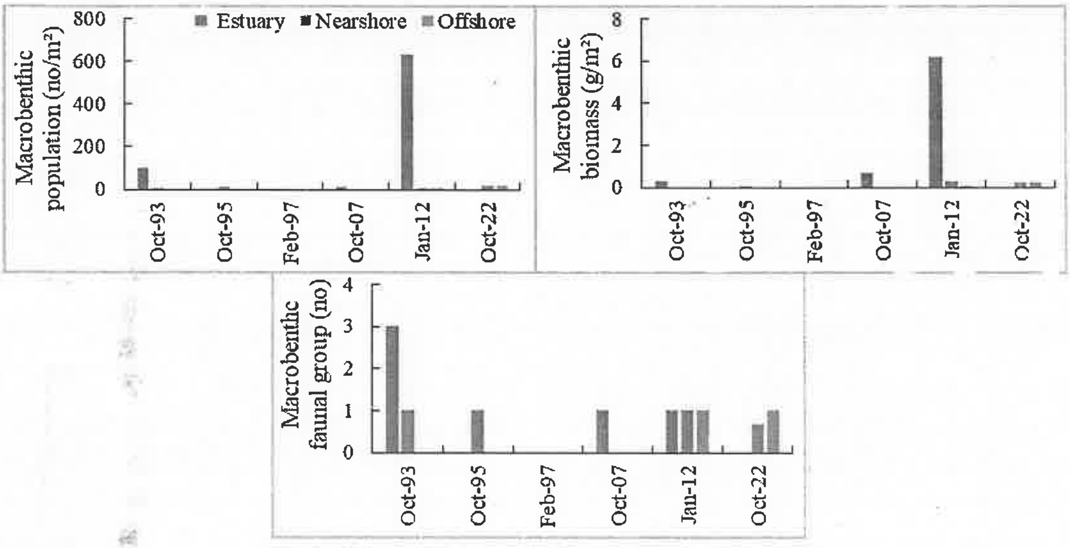

Fig. 8O: Long-term macrobenthic characteristics in the subtidal sediment of Dahej.

The average biomass values were very low in the study area (≤0.6 g/m²) during all the previous study periods except during Jan-12, when the estuarine zone had an average biomass of 6.2 g/m² (Fig. 8O). Poor macrobenthic values were observed as a result of high currents and hard substratum. The average numbers of organisms were very low (≤20/m²), except in Jan-12 and Oct-93, where the estuary segment had 631 and 100 no/m² respectively. Mirroring the macrobenthic biomass, the population indicated very low values at different segments before and after the industrialization. During most of the sampling periods, only one faunal group was found. Exceptions were Oct-93, where three groups were identified in the sample collected. The faunal groups found in the nearshore and offshore areas were comparable before and after the industrialization. Only polychaetes were observed in the area.

6. IMPACTS ON MARINE ECOLOGY AND MITIGATION

The present study has made widespread assessment in the context of multiple driver effects on the marine environmental and biological characteristics around Dahej intertidal and subtidal regions. Spatio-temporal scale sampling and observations were made, which were compared with the past results, to have better understanding of the changes in present ecological conditions.

Potential impacts

1. The combined CETP and other industries treated effluent disposed directly in the intertidal region off Luvara, Dahej, near 0.6 km from the high tide line (HTL). Without a diffuser mechanism, the dumped effluents enrooted through a channel across the low tide line (LTL) for about 2.5km and joined the water limits of the Narmada estuary and GoKh. The channel remains actively visible during the low tide and submerged due to overlying seawater during the high tide. The shoreward transport of the effluent has been affected by the periodic tidal incursion, which has created the low-energy condition in the entire region, and the effluent mixed water spreads between the HTL and GoKh water limit, with a disposal point in the middle. Besides the disposal point, unidentified ruptured pipeline networks were buried across the channel, adding wastewater along this cross-section. The dissolved chemical constituent characteristics of treated effluents closely resemble the overlying intertidal waters spread within a cross-section of nearly 3 km between HTL and LTL. The subtidal waters in nearshore and offshore have much lower concentrations than the intertidal waters, getting minimal influence.

2. The direct disposal of effluents and restricted dispersion in the intertidal region have a strong potential for accumulating constituents, such as heavy metals that are scavenged from the water column by SS, eventually sinking and enriching in the sediment. The accumulation of metals and organics is vulnerable to the ecological destruction of the area. Removal of chemical constituents by the effects of tidal currents (slow process) and the monsoon flood (fast) has significant potential for their distal transport and impact on the nearshore marine environment.

3. The enrichments of chemical constituents in the effluent mixed seawater in the intertidal region possibly caused acute toxicity to flora and fauna that may be momentarily trapped in the wastewater plume. The exposure of biota to such concentration of pollutants is short-term, and bio-accumulation needs to be envisaged.

Present condition

1. The constituent chemical levels of FPS effluents, when mixed with the tide-borne seawater in the intertidal region, get lowered, as observed in this study. The observational samples collected at a location less than 50 m from the dumping indicated decrease of BOD_3 and COD by 5.6 and 1.5 times, respectively, after being mixed with seawater and without any significant fluctuations throughout 12 hr during the study. The DO values were naturally achieved to more than 4 mg/L,

from the value zero (anoxic) in the effluent. Similarly, the temperature reduced from 33.4 to 28.6 when mixed with seawater. The contaminants such as PHc and Phenols were reduced by more than two times their levels in the effluent (Section 5.1.1j). The water quality even showed recovering values in the region of sea limit and healthier in the nearshore subtidal region (Tables 4 and 5).

2. The metals in the surficial sediments near the disposal area and in the intertidal region vicinity, have exhibited higher levels than those found in the subtidal sediment and studied intertidal regions in the north and south. A further detailed study indicated that the metals have moderately enriched in the bottom layers (about 50 cm below the surface), indicating their dumping was scavenged by SS. Nevertheless, periodic removal of the metals by the tidal current action have caused dispersion and disproportional sorting in the upper sediment layer (10 to 20 cm) across the region between HTL and LTL. The accumulation indicated moderate enrichment and sporadic, owing to the natural sand and silt dominance, which have a lower potential for their distal transport. The subtidal sediments were not indicated any significant metal enrichment during the study (Section 5.2 iii).

3. The flora and faunal communities those are potential to get affected by the enriched metals and nutrients present in the dumped effluent, have revealed changes in the biomass and genera during this study. The intertidal region near disposal remained low in chlorophyll *a* (< 1 mg/m^3), similar to the GoKh, but had higher average cell counts and genera; those remained comparable with the central and northern subtidal regions of Dahej. The intertidal region near the disposal area has shown the highest average population and faunal group diversity, dominated by Polychaeta. The disposal area has no macrobenthic biomass. Also, the meiofauna has poor density and group diversity, indicating that the area was not conducive for benthic organisms.

Mitigation

1. The present mode and area of disposal of the FPS effluents must be changed immediately by following the norms and guidelines from the appropriate authorities. The disposal of effluents should be into the deep seawater, where the appropriate dilution and dispersion of the released effluent to meet ambient seawater quality.

2. The present condition of the diffuser located in the deep sea at the location suggested by CSIR NIO must be checked for suitability. The exposed pipeline in the intertidal region must be buried to avoid ecological damage.

3. As suggested earlier, implanting a properly functioning diffuser to discharge effluents in the deep sea is suggested, which would dilute the concentrated effluents by 100 to 200 times and achieve the ambient condition in the region.

4. It is always important to take periodic measurements at the deep-sea disposal location to evaluate diffuser performance. A diffuser's efficiency might decrease over time due to the settlement of biofoulers at the port openings, entry of sediment into the diffuser, etc. Hence, the efficiency of the diffuser shall be checked periodically (once in 2 y). If necessary, the diffusers must be cleaned to confirm the dilution ascertained through initial tracer studies. Such precautions may avoid damage to the laid pipeline due to overpressure and imbalance flow pattern of the effluents from the source to the deep-sea disposal.

5. The broken pipeline network buried in the intertidal region must be identified and repaired. Periodic monitoring of the pipeline route in the intertidal and subtidal region to identify any leakage through the holes will help to take in-time action for damage repair and minimal impact on the intertidal and subtidal marine ecology.

6. The biological productivity of the GoKh at different trophic levels varies from poor to moderate as compared to other coastal segments of the west coast. Hence, it shall be ensured that the effluent released into the GoKh always meets the prescribed GPCB criteria. Under normal operational conditions, strictly following the GPCB norms and releasing the treated effluent through the appropriate deep-sea disposal is expected to minimize the adverse impact, if any, on marine ecology off Luvara.

7. SUMMARY AND CONCLUSION

The water and sediment quality in the intertidal and subtidal regions off Dahej was monitored during Oct-22 to highlight the potential impacts of disposals in the intertidal region on the nearshore marine ecology. The observational results obtained on the prevailing marine environment and biological parameters were primarily assessed based on the comparison with the data available with CSIR NIO for the same region and the coastal waters of India and elsewhere. Diurnal observation of water quality was undertaken near the disposal point and at the offshore reference point. The sediment cores were collected along the intertidal region to evaluate pollutant enrichment (if any) in the bottom sediment over time. The chemical constituents in the released effluents were studied and compared with nearby intertidal and subtidal water limits. The overall assessment based on the observational and historical data of marine environment and biological parameters helped better understand the area's ecological status and provide necessary mitigation measures.

The organic and inorganic pollutants get scavenged by the SS and eventually settle in the sediment. Hence, sediments indicate the integrated impact of several contaminants, particularly trace metals, PHc, and organics. Some of these pollutants can leach into overlying water under changing redox conditions coupled with their re-suspension by tidal movements and waves. Disturbance of bed sediment can also lead to the release of nutrients and microbes into the water column. Based on the monitoring during Oct-22 and comparison of results with the historical data and published information for the coastal waters of India and elsewhere, the following conclusions have emerged.

i. The pipeline carrying effluent from the CETP to FPS combined with other industries treated effluents and released at location Lat: 21°39'50.010"N Long: 72°31'56.690"E in the intertidal region off Luvara. The pipeline was exposed towards the HTL, approximately 100m along with other pipelines laying parallelly in the region. The snaky channel with approximate width 1-5m carrying effluent was noticeable during low tide and submerged during high tide flow and joined the GoKh water at Lat: 21°39'59.464"N Long: 72°31'20.568"E. Waters were bubbling from the bottom, found to be from the broken pipeline at a point near S3 (Lat: 21°39'50.803"N Long: 72°31'49.663"E) within the channel between the point of disposal and the GoKh.

ii. The observational intertidal water temperature during Oct-22 was wide compared to the subtidal water temperature, primarily related to diurnal temperature variation due to the shallow water column. The overall water temperature was less than 35°C in intertidal and subtidal waters. Therefore, it may not significantly impact the tropical aquatic species. The observational water temperature remained broadly comparable with the historical limits in the estuary, nearshore, and offshore region of Dahej.

iii. The temporal pH changes at the intertidal and subtidal disposal locations were marginal and aligned with the natural marine waters sustaining low primary productivity. The pH changes in the seawater from different subtidal zones were comparable. The salinity range of this study was much lower than 35 PSU, as expected during the post-monsoon, and the impact of treated effluent on salinity rise was not observed.

iv. The natural SS variability was significantly higher in the bottom water of the subtidal region than in the intertidal region, and their tidal variation was random during this study. The treated effluent sample has lower SS, turbidity, and TDS than subtidal and intertidal waters.

v. The average DO levels indicated oxic water around the subtidal region. Due to anoxic effluent mixing, the disposal area and channel waters had DO below 2 mg/L during ebb tide. The subtidal waters had average COD values between 72.8 and 150.9 mg/L, much lower than the general standard for the treated effluents prescribed by CPCB (250 mg/L). The ranges of COD and BOD_3 in the intertidal region were much higher, aligned with the values of treated effluents disposed of in the region. The subtidal waters were not evidenced with any random increase of BOD_3 and COD, indicating minimal organic contamination. The levels of BOD_3 and COD are of the order reported for other coastal regions of India. The temporal enrichment of these constituents in the intertidal region was possibly due to inefficient flushing/mixing of the subtidal and estuarine waters in the region.

vi. The nutrients such as phosphate, nitrate, and ammonium were randomly higher in the intertidal region, with minimal variations in the Dahej subtidal water. The total phosphorous was found to be several times higher in the intertidal waters due to the effects of effluent, and the nitrogen compounds have been increased in the estuary compared to nearshore and offshore over some time. Low oxygen condition in the intertidal region has provoked the enhanced values of ammonium and nitrite. The proportional increase in nitrate and phosphate, prime nutrients for plankton, have caused minimal changes in their molar ratio.

vii. The other constituents, such as sulphate, were higher in the intertidal region due to their enrichment in the dispersed effluent. No marked PHc and phenol variation was recorded in the sampling area, indicating no oil contamination. However, these constituents were randomly varied in Dahej waters during post-industrialization.

viii. The chemical constituents such as PHc, organic carbon, and total phosphorous have been markedly lower in this study's intertidal and subtidal segments, owing to larger grain size and lower adsorption capacity. The metals such as Cr, Cu, Fe, and Zn have shown enrichment compared to the pre-industrialization or development period in the intertidal region, specifically the central segment dominant with the industrial network in Dahej. No enrichment of metals was found in the subtidal region.

ix. Surprisingly, the downcore sediments have enriched metal contents randomly distributed across the intertidal region, especially in the vicinity of effluent disposal. Due to differential hydrodynamic sorting, the scavenged metals get enriched and accumulate in the deeper sediment near the disposal area. Periodic disturbances due to the tidal action have caused sediment removal from the surface. Therefore, the metals have shown enrichment in the upper sediment layers before the disposal.

x. The microbial counts observed in the water and sediments of the present study were lower in the study area than in the reference site. Also, comparing the results obtained for the microbiological quality of water at studied locations with the standard specified by the CPCB for primary water quality criteria for seawater indicated that the counts of fecal coliforms at all stations were low, signifying that the study area was primarily free from fecal pollution.

xi. The chlorophyll *a* content was generally low in the study area (< 1 mg/m^3) throughout all past and present sampling periods. However, the chlorophyll *a* recorded was low (<0.5 mg/m^3) during post-industrialization in the region. Phytoplankton abundance indicated a decreasing trend in recent sampling periods. Though phytoplankton generic diversity was generally poor throughout all sampling periods, the post-industrialization periods indicated a higher average number of genera.

xii. The historical data of zooplankton biomass indicated a decreasing trend from the first to the present observations in the nearshore environment. However, higher biomass values were visualized in the estuary during the post-industrialization period. The zooplankton group diversity was consistent during post-industrialization.

xiii. Macrobenthic biomass, population, and faunal group diversity in the intertidal zone were very low before and after industrialization. Similarly, the subtidal macrobenthic parameters were also low during all periods. This low macrobenthic productivity can be attributed to high turbidity and unstable bottom conditions associated with strong tidal currents prevailing in the GoKh of Khambhat. However, after the effluent discharge had commenced, only one macrobenthic group (Polychaeta) was observed in the area. The meiofauna also displayed poor density and group diversity, indicating that the area was not conducive for benthic organisms.

The present assessment results have indicated an apparent increase in chemical constituents and their enrichment, concerning the geological limits, near the disposal area, which gets diluted across their transport. No enrichment of chemical constituents was in the subtidal region. Historical data have indicated enriched nutrients in recent periods compared to the pre-industrialization period in Dahej without any significant impact on their molar ratios. The dissolved chemical constituents enriched were near the disposal area, which dispersed in the subtidal waters owing to the strong hydrodynamic condition of the GoKh. However, the sediment chemical constituents significantly enriched were restricted to the vicinity of the intertidal region due to the combined effects of hydrodynamic sorting and natural grain size distribution. The GoKh waters have witnessed lower biological mass owing to strong tidal currents and turbidity. Post-industrialization, there have been some changes in the phytoplankton and zooplankton group diversity, with minimal effect on the genera, especially in the nearshore waters. The Narmada estuary waters have higher biomass than the nearshore and offshore. Lower macrobenthic productivity and dominance of a single group were attributed to the region's high tidal current and anthropogenic activities. The present study has widely assessed multiple driver effects on the marine environmental and biological characteristics around Dahej intertidal and subtidal regions. Overall results have highlighted significant impacts o the water and sediment quality due to disposal at the intertidal region.

Nevertheless, the activity's effects are significant to the nearby region, but the impacts were not seen in the offshore region. Necessary mitigations to relocate the disposal point in the offshore region have been suggested, and repairing broken pipeline networks buried in the intertidal region is recommended to minimize the unaccounted other discharge. Reducing pollution and eutrophication are relatively straightforward to restore the damaged intertidal communities to bring them into a more natural and healthy state. Once the effluent influx intc the intertidal ecosystems has stopped, the original state can be gradually expected.

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Table 4: Water quality at the subtidal stations off Dahej during October 2022.

Observation Parameter (unit)	Level	Tidal GR Min.	Max.	Avg.	Tidal GN1 Min.	Max.	Avg.	Spot GN2 *Avg.	Diurnal GC1 Min.	Max.	Avg.
Temperature (°C)	S	28.6	29.0	28.8	29.0	30.5	29.8	29.8	29.5	30.9	30.3
	B	28.4	28.8	28.6	28.9	29.3	29.1	29.0	29.0	31.6	30.3
	AT	28.5	32.0	30.3	29.5	31.0	30.3	31.0	28.0	35.0	32.3
pH	S	7.9	8.0	7.9	7.7	7.7	7.7	7.9	7.9	8.1	8.0
	B	7.9	8.0	8.0	7.7	7.7	7.7	7.9	7.9	8.1	8.0
Turbidity (NTU)	S	372.0	579.0	468.0	13.4	19.0	16.7	8.8	47.6	840	275.2
	B	6235	7660	6871	135.0	2900	1461	578.0	183.0	8688	4072
TDS (mg/L)	S	22886	23026	22956	20483	25401	22942	24385	20546	27324	23935
	B	23971	29160	26565	26850	37387	32119	25763	21752	45722	33737
SS (mg/L)	S	510.8	599.1	555.0	30.4	65.5	48.0	26.7	51.5	1248.1	323.0
	B	5254	6299	5776	466.4	991.0	728.7	332.2	288.4	5741.5	3265.8
DO (mg/L)	S	7.2	7.3	7.3	6.9	7.0	6.9	6.7	6.6	7.4	7.1
	B	6.6	6.6	6.6	6.4	6.4	6.4	4.2	6.5	7.2	6.8
BOD (mg/L)	S	1.0	1.0	1.0	1.5	2.4	2.0	0.6	2.3	3.2	2.8
	B	1.0	1.1	1.0	1.2	1.9	1.5	1.1	2.3	4.6	3.1
COD (mg/L)	S	108.1	118.6	113.4	101.4	114.6	108.0	112.2	99.0	152.5	124.6
	B	133.1	137.4	135.3	105.0	127.4	116.2	119.4	121.1	146.8	131.7
Salinity (PSU)	S	18.7	19.6	19.2	17.2	17.5	17.4	19.5	18.0	20.9	18.6
	B	20.4	20.8	20.6	22.8	23.0	22.9	20.8	18.4	20.8	19.5
SO_4^{2-}: Cl^-	S	0.13	0.14	0.13	0.13	0.14	0.14	0.13	0.15	0.17	0.16
	B	0.13	0.14	0.14	0.13	0.14	0.13	0.13	0.15	0.17	0.16
PO_4^{3-}-P (µmol/L)	S	1.7	1.9	1.8	1.4	2.1	1.8	1.6	1.6	2.9	2.3
	B	1.6	1.7	1.6	1.6	1.8	1.7	1.8	2.2	3.2	2.7
NO_3^--N (µmol/L)	S	32.0	44.6	38.3	38.9	41.5	40.1	39.1	20.2	36.6	30.3
	B	25.8	28.8	27.4	31.5	35.9	33.7	7.6	25.1	40.2	34.5
NO_2^--N (µmol/L)	S	0.1	0.2	0.1	0.2	0.2	0.2	0.1	BDL	0.1	0.1
	B	0.1	0.2	0.2	BDL	0.1	0.1	BDL	BDL	0.4	0.1
NH_4^+-N (µmol/L)	S	5.2	7.4	6.3	2.3	4.4	3.3	3.0	3.1	15.5	8.3
	B	3.5	5.7	4.8	3.1	4.2	3.8	6.5	1.6	16.4	8.5
TP (µmol/L)	S	1.7	2.3	2.0	2.1	2.3	2.2	2.4	2.6	3.1	2.8
	B	1.7	2.4	2.0	1.9	2.6	2.2	2.7	2.6	3.0	2.8
TN (µmol/L)	S	53.6	54.2	53.9	47.3	55.8	51.6	44.5	46.4	58.9	52.6
	B	33.0	34.8	33.9	38.6	39.0	38.8	19.7	37.9	45.0	41.5
PHc (µg/L)	1m	5.0	6.4	5.7	5.5	5.8	5.7	5.1	5.6	6.3	6.0
Phenol (µg/L)	S	41.7	49.8	45.8	57.0	80.9	69.0	24.8	65.5	80.8	73.2

[*Avg. average of two readings for spot station; AT: air temperature in °C; BDL: Below detection limit]

Table 4: Water quality (*continued*)

Parameter (unit)	Level	Spot GC2 *Avg.	Spot GS1 *Avg.	Spot GS2 *Avg.	Spot GS3 *Avg.	Tidal NE Min.	Tidal NE Max.	Tidal NE Avg.
Temperature (°C)	S	28.0	28.5	28.5	28.2	27.5	28.5	28.0
	B	27.0	-	28.0	27.5	27.0	27.0	27.0
	AT	29.0	32.0	31.0	28.0	27.0	29.5	28.3
pH	S	7.8	7.8	7.9	7.9	7.8	7.9	7.8
	B	7.8	-	7.9	7.9	7.9	7.9	7.9
Turbidity (NTU)	S	3.9	244	417.5	299	219	345	283.5
	B	33.9	-	2680	1056	2260	2685	2473
TDS (mg/L)	S	25502	13054	25354	26951	2205	22103	12154
	B	31311	-	29881	27935	24441	24441	24441
SS (mg/L)	S	28.2	296.4	437.9	398.0	24.9	297.6	161.3
	B	55.0	-	7915.5	2056	3058.4	3058.4	3058.4
DO (mg/L)	S	6.7	7.2	6.8	6.9	6.5	7.5	7.0
	B	6.2	-	8.2	7.1	7.1	7.3	7.2
BOD (mg/L)	S	0.7	3.7	1.9	2.6	2.2	3.8	3.0
	B	0.5	-	4.4	3.2	3.4	3.4	3.4
COD (mg/L)	S	192.0	66.4	75.3	97.0	78.6	111.3	95.0
	B	155.2	-	59.0	72.9	131.1	131.1	131.1
Salinity (PSU)	S	17.7	20.2	20.4	24.4	8.9	20.6	16.7
	B	22.5	-	21.8	24.6	20.4	20.4	20.4
SO_4^{2-}: Cl^-	S	0.16	0.06	0.13	0.12	0.02	0.13	0.09
	B	0.13	-	0.13	0.13	0.13	0.13	0.13
PO_4^{3-}-P (µmol/L)	S	1.5	1.3	1.9	2.0	0.9	1.9	1.4
	B	1.7	-	2.1	2.0	2.0	2.1	2.0
NO_3^--N (µmol/L)	S	43.0	54.7	46.8	41.7	44.2	60.1	50.9
	B	40.6	-	32.3	30.5	34.0	34.6	34.3
NO_2^--N (µmol/L)	S	0.2	0.2	0.1	0.1	0.2	0.4	0.3
	B	0.1	-	0.1	0.1	0.1	0.1	0.1
NH_4^+-N (µmol/L)	S	4.6	0.2	1.8	2.0	0.1	2.4	1.2
	B	3.8	-	1.9	0.7	1.5	1.7	1.6
TP (µmol/L)	S	2.6	1.8	2.6	2.5	1.8	2.9	2.3
	B	2.3	-	3.3	2.3	2.6	2.6	2.6
TN (µmol/L)	S	46.3	54.3	53.3	55.3	68.7	69.8	69.3
	B	45.4	-	33.7	33.7	36.0	36.2	36.1
PHc (µg/L)	1m	3.8	5.0	3.8	5.5	4.0	5.7	4.9
Phenol (µg/L)	S	40.7	63.1	56.6	62.7	31.6	59.1	45.3

[*Avg. average of two readings for spot station; AT: air temperature in °C; BDL: Below detection limit]

Table 5: Water quality at the intertidal stations (disposal area and channel) during Oct-22.

Observation		Diurnal			Spot				
Parameter (unit)	Level	GCD			S1	S2	S3	S4	S5
		Min.	Max.	Avg.	*Avg.	*Avg.	*Avg.	*Avg.	*Avg.
Temperature (°C)	S	26.0	34.2	30.1	30.5	30.5	28.3	28.8	23.2
	AT	24.6	35.7	32.4	32.0	32.0	32.0	32.0	32.0
pH	S	7.1	8.0	7.8	7.4	7.0	7.2	7.5	7.6
Turbidity (NTU)	S	24.5	1537.0	285.4	64.2	61.5	90.8	99.2	77.8
TDS (mg/L)	S	17080	17643	17362	19835	21895	20539	19206	19350
SS (mg/L)	S	18.5	1839	467.6	-	-	-	-	-
DO (mg/L)	S	0	8.1	5.4	2.4	3.0	1.2	5.3	7.0
BOD (mg/L)	S	1.3	27.6	9.1	70.0	25.7	33.9	42.1	30.7
COD (mg/L)	S	111.2	287.4	158.0	259.9	236.8	192.9	166.2	128.1
Salinity (PSU)	S	9.9	17.9	14.1	15.1	20.8	16.4	16.5	16.4
SO_4^{2-}: Cl^-	S	0.13	0.46	0.33	0.93	0.25	0.53	0.50	0.49
PO_4^{3-}-P (µmol/L)	S	2.1	33.7	6.4	26.1	17.0	11.1	10.0	8.8
NO_3^--N (µmol/L)	S	1.5	29.4	19.4	9.1	18.2	24.1	6.0	1.6
NO_2^--N (µmol/L)	S	0.5	27.0	8.5	19.0	110.0	10.9	41.7	103.4
NH_4^+-N (µmol/L)	S	3.3	125.5	32.1	121.7	146.1	110.6	119.0	148.7
TP (µmol/L)	S	3.1	10.6	6.9	27.5	17.8	11.1	11.0	21.0
TN (µmol/L)	S	46.4	58.2	52.3	150.4	213.1	207.9	167.4	199.8
PHc (µg/L)	1m	7.3	12.0	9.6	-	-	-	-	-
Phenol (µg/L)	S	29.1	52.4	40.8	-	-	-	-	-

[*Avg. Average of two readings for spot station; AT: air temperature in °C]

Table 6: Sediment quality at the subtidal and intertidal stations off Dahej during Oct-22.

Station	Sand (%)	Silt (%)	Clay (%)	Al (%)	Fe (%)	Co (µg/g)	Cr (µg/g)	Cu (µg/g)	Mn (µg/g)	Ni (µg/g)	Zn (µg/g)	As (µg/g)	Cd (µg/g)	Pb (µg/g)	C_{org} (%)	P (µg/g)	PHc* (µg/g)
Subtidal																	
GR	93.6	5.0	1.4	2.8	2.9	15.9	66.7	32.9	766	27.3	50.6	3.5	0.07	9.8	0.4	341	0.1
GN1	57.3	37.9	4.8	7.0	6.2	27.2	86.9	75.0	835	51.0	99.6	5.0	0.08	11.5	0.5	441	0.3
GN2	86.4	11.4	2.2	4.5	5.3	22.8	84.9	55.1	819	41.8	61.6	5.8	0.11	12.6	0.1	358	0.2
GC1	20.4	73.4	6.2	6.3	6.1	26.4	84.0	69.3	808	47.9	93.4	4.4	0.09	11.8	0.3	388	0.3
GC2	90.8	8.4	0.8	3.7	5.9	26.5	112.5	72.2	1086	49.1	103.9	5.5	0.11	12.0	0.4	398	0.3
GS1	97.0	2.8	0.2	0.9	1.7	27.5	107.7	67.1	1097	46.5	75.6	9.1	0.12	11.2	0.1	431	0.1
GS2	5.2	87.2	7.6	5.9	5.7	24.5	79.2	67.9	769	44.7	90.0	4.7	0.05	11.9	0.4	437	0.4
GS3	85.6	12.8	1.6	2.2	3.4	25.9	98.1	71.1	1023	53.3	90.2	6.7	0.11	12.8	0.2	442	0.1
NE	65.2	32.0	2.8	4.2	5.5	28.9	110.9	73.9	942	50.4	80.1	4.8	0.1	12.0	0.5	385	0.1
Avg.	**66.8**	**30.1**	**3.1**	**4.2**	**4.7**	**25.1**	**92.3**	**64.9**	**905.0**	**45.8**	**82.8**	**5.5**	**0.1**	**11.7**	**0.3**	**402.3**	**0.2**
Intertidal																	
ITN	24.9	71.1	4.0	5.9	6.0	25.7	85.7	69.8	773	53.2	212.3	4.4	0.06	11.4	0.2	378	0.1
ITC	89.2	9.6	1.2	3.4	12.5	42.6	192.7	132.5	1959	69.2	206.0	10.9	0.13	15.7	0.2	458	0.1
ITS	0.5	94.5	5.0	3.0	2.9	28.1	92.6	72.9	850	48.7	84.1	4.9	0.06	11.4	0.4	445	0.1
8	81.7	16.5	1.8	3.5	10.4	73.0	228.8	105.0	1557	52.9	132.5	10.6	0.2	15.5	0.3	435	0.03
10	18.6	62.2	19.2	5.9	8.5	50.3	170.7	100.9	1083	54.9	104.6	8.0	0.1	14.9	0.7	474	0.1
12	45.0	48.4	6.6	3.9	15.6	110.3	293.4	149.4	2142	65.4	223.5	13.8	0.3	19.3	0.3	415	0.2
A	92.4	5.8	1.8	4.3	6.9	40.7	130.7	70.0	1001	41.0	74.5	9.9	0.1	14.0	0.2	433	0.02
D	49.1	38.1	12.8	5.8	7.7	44.8	145.5	94.1	984	51.1	104.2	9.0	0.1	15.2	0.4	497	0.2
Avg.	**50.2**	**43.3**	**6.6**	**4.5**	**8.8**	**51.9**	**167.5**	**99.3**	**1293.6**	**54.6**	**142.7**	**8.9**	**0.1**	**14.7**	**0.3**	**441.9**	**0.1**

Table 7: Microbial counts in subtidal surface water of Dahej during Oct-22.

Station	Observation	TVC (× 10³ CFU/mL)	TC (MPN/ 100mL)	FC (MPN/ 100mL)	ECLO (CFU/mL)	SFLO (CFU/mL)
GR	Spot	27	75	23	NG	NG
GN1	Ebb	12	19	11	NG	NG
	Flood	16	15	12	NG	1
GN2	Spot	23	9	6	≤3	1
GC1	Ebb	28	15	6	1	1
	Flood	20	11	3	1	NG
GC2	Spot	15	19	14	2	NG
GS1	Spot	26	42	27	1	NG
GS2	Spot	22	34	21	NG	NG
GS3	Spot	12	19	12	NG	NG
NE	Ebb	15	75	36	1	NG
	Flood	19	44	15	NG	NG

NG: No growth

Table 7.1: Microbial counts in surficial sediments from the subtidal region of Dahej during Oct-22.

Station	TVC (× 10⁴ CFU/g)	TC (MPN/100g)	FC (MPN/100g)	ECLO (CFU/g)	SFLO (CFU/g)
GR	48	16	11	NG	NG
GN1	20	6	3	NG	NG
GN2	37	3	≤3	NG	NG
GC2	19	9	≤3	NG	NG
GC1	32	13	9	2	2
GS1	56	16	9	NG	NG
GS2	53	16	6	NG	NG
GS3	29	15	3	NG	NG
NE	33	20	11	NG	NG

NG: No growth

Table 7.2: Phytopigments range and average in the subtidal waters of Dahej during Oct-22.

Station	Level	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)	Chlorophyll *a* : Phaeophytin ratio
GR	S	0.3 – 0.4 (0.4)	0.1 – 0.7 (0.4)	0.6 – 2.2 (1.4)
	B	1.0 – 0.7 (0.8)	3.0 – 3.4 (3.2)	0.2 – 0.3 (0.3)
GN1	S	0.4 – 0.5 (0.4)	0.2*	1.9 – 3.1 (2.5)
	B	0.2 – 0.3 (0.3)	0.1 – 1.0 (0.5)	0.4 – 2.2 (1.3)
GN2	S	0.6*	0.2*	2.7 – 2.8 (2.7)
	B	0.2 – 0.3 (0.2)	0.1 – 0.2 (0.2)	1.4 – 1.8 (1.6)
GC1	S	0.1-0.5 (0.3)	0 – 0.2 (0.1)	0.6 – 20 (10.3)
	B	0.1 – 0.4 (0.2)	0 – 0.5 (0.3)	0.7 – 1.4 (1.1)
GC2	S	0.2 – 0.3 (0.2)	0.2*	1.1*
	B	0.2*	0.2*	1.0*
GS1	S	0.6 – 0.8 (0.7)	0.1*	7.9 – 12.8 (10.4)
	B	0.2*	0.3*	0.7*
GS2	S	0.1 – 0.2 (0.2)	0.7*	1.4 – 3.3 (2.4)
	B	0.2 – 0.7 (0.4)	0.3 – 2.4 (1.4)	0.3 – 0.6 (0.4)
GS3	S	0.1*	0 – 0.1 (0.1)	2 – 3 (2.5)
	B	0.3*	0.4*	0.9*
NE	S	0.1 – 2.7 (1.4)	0.2 - 0.3 (0.3)	0.2 – 8.0 (4.1)
	B	0.5*	0.7*	0.7*
GCD	S	0.3 – 1.0 (0.7)	0 – 1.0 (0.5)	0.5 – 31.3 (15.9)
	B	ND	ND	ND

*All replicates indicate similar value; Averages are in parenthesis

Table 7.3: Phytoplankton characteristics in the subtidal waters of Dahej during Oct-22.

Station	Cell count (no × 10^3 Cells/ L)		Total genera (no)		Common genera	
	S	B	S	B	S	B
GR	0.1 – 0.2 (0.2)	0.4 – 1.2 (0.8)	5.0 – 7.0 (6)	3.0 – 4.0 (4)	*Synedra sp.* *Tolypothrix sp.* *Gymnodinium sp.* *Nitzschia sp.*	*Cyclotella sp.* *Synedra sp.* *Cymatosira sp.* *Coscinodiscus sp.*
GN1	50*	0.6 – 8.0 (4.3)	6.0 – 7.0 (7)	3*	*Nitzschia acicularis* *Pseudonitzschia sp.* *Synedra sp.* *Biddulphia mobiliensis*	*Nitzschia sp.* *Gymnodinium fuscum* *Navicula distans* *Thalassiosira sp.*
GN2	42	0.2	8	2	*Skeletonema costatum* *Pseudonitzschia sp.* *Oscillatoria sp.* *Coscinodiscus centralis*	*Amphora sp.* *Nitzschia sp.*
GC1	0.6 – 18.0 (9.3)	0.2 – 0.6 (0.4)	4.0 -5.0 (5)	2.0 – 3.0 (3)	*Nitzschia sp.* *Pseudonitzschia sp.* *Surirella sp.* *Synedra ulna*	*Nitzschia sp.* *Amphora sp.* *Synedra ulna* *Navicula distans*
GC2	46	14	5	5	*Merismopedia sp.* *Oscillatoria sp.* *Nitzschia linearis* *Biddulphia sinensis*	*Biddulphia sinensis* *Amphora sp.* *Coscinodiscus centralis* *Nitzschia sp.*
GS1	10	NC	4	NC	*Navicula distans* *Gymnodinium sp.* *Pseudonitzschia sp.* *Synedra ulna*	NC
GS2	0.7	0.6	4	3	*Amphora sp.* *Gymnodinium fuscum* *Nitzschia seriata* *Surirella striatula*	*Navicula distans* *Amphora sp.* *Ceratium furca*
GS3	0.3	0.4	3	4	*Coscinodiscus sp.* *Lepocinclis sp.* *Navicula distans*	*Coscinodiscus sp.* *Navicula sp.* *Rhizosolenia sp.* *Thalassionema nitzschioides*
NE	10.0 – 15.0 (12.5)	0.8*	4.0 -10.0 (7)	6.0*	*Merismopedia sp.* *Nitzschia sp.* *Synedra sp.*	*Navicula sp.* *Nitzschia sp.* *Coscinodiscus sp.*

					Nitzschia acicularis	*Nitzschia acicularis*
GCD	26.0 – 52.0 (39)	NC	9.0 – 10.0 (10)	NC	*Merismopedia sp.* *Surirella sp.* *Amphiprora sp.* *Amphora sp.*	NC

NC: no collection; Averages are in parenthesis

Table 7.4: Composition of phytoplankton population (%) in subtidal waters of Dahej during Oct-22.

Species	GR	GN1	GN2	GC1	GC2	GS1	GS2	GS3	NE	GCD	Avg.
					Diatom						
Amphiprora sp.										5.1	0.5
Amphora sp.			4.3	9.1	3.3		30.8			5.1	5.3
Biddulphia mobiliensis		3.3									0.3
Biddulphia sinensis			4.3	4.5	13.3						2.2
Biddulphia sp.									1.1		0.1
Coscinodiscus centralis			8.7		3.3						1.2
Coscinodiscus sp.	1.9							28.6	2.3		3.3
Cyclotella sp.	20.4										2
Cymatosira sp.	15.5										1.6
Navicula distans		6.7	4.3	9.1		40	23.1	14.3	1.1	5.1	10.4
Navicula sp.	1							14.3	4.5	2.6	2.2
Nitzschia acicularis		41.7							6.8	5.1	5.4
Nitzschia linearis		1.7			6.7						0.8
Nitzschia seriata		3.3					15.4				1.9
Nitzschia sp.	8.7	5	8.7	27.3	3.3				29.5		8.3
Pinnularia sp.	1.9										0.2
Pleurosigma sp.										2.6	0.3
Pseudonitzschia sp.		10	21.7	13.6		20					6.5
Rhizosolenia sp.								14.3	1.1		1.5
Skeletonema costatum			30.4	4.5							3.5
Surirella sp.				9.1					1.1	10.3	2
Surirella striatula					3.3		7.7				1.1
Synedra acus										2.6	0.3
Synedra sp.	30.1	8.3							8	2.6	4.9
Synedra ulna		3.3		18.2		20			4.5		4.6
Thalassionema frauenfeldii		3.3									0.3
Thalassionema nitzschioides				4.5				14.3		5.1	2.4
Thalassionema sp.	1		4.3		3.3						0.9
Thalassiosira sp.		3.3									0.3
Thalassiothrix sp.									1.1		0.1
					Dinoflagellates						
Ceratium furca							7.7				0.8
Gymnodinium fuscum		6.7					15.4				2.2
Gymnodinium sp.	9.7	1.7				20					3.1

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Table 7.4 continued.

Species	GR	GN1	GN2	GC1	GC2	GS1	GS2	GS3	NE	GCD	Avg.
					Chlorophyta						
Closterium sp.		1.7									0.2
Tetraspora sp.										2.6	0.3
					Cyanophytes						
Merismopedia sp.					53.3				36.4	41	13.1
Oscillatoria sp.			13		10				2.3	2.6	2.8
Spirulina sp.										2.6	0.3
Tolypothrix sp.	9.7										1
					Euglenophyta						
Lepocinclis sp.								14.3			1.4
Unknown 1										2.6	0.3
Unknown 2										2.6	0.3

Table 7.5: Zooplankton standing stock in the subtidal waters of Dahej during Oct-22.

Station	Biomass (ml/100m³)	Population (no×10³/100m³)	Total groups (no)	Major groups (%)
GR	1.7-3.2 (2.5)	5.4-16.9 (11.2)	9-10 (10)	Foraminiferans (95.7) Siphonophores (3.0) Medusae (0.8) Ctenophores (0.2) Chaetognaths (0.1) Polychaetes (0.1) Others (0.1)
GN1	0.1*	0.2*	5-6 (6)	Copepods (84.9) Chaetognaths (9.1) Gastropods (3.4) Polychaetes (1.1) Isopods (0.9) Appendicularians (0.3) Decapod larvae (0.2) Others (0.1)
GN2	0.1*	0.1-0.2 (0.2)	5-8 (7)	Copepods (92.0) Chaetognaths (2.7) Gastropods (1.6) Isopods (1.4) Marine Insects (1.0) Decapod larvae (0.6) Fish Eggs (0.4) Fish Larvae (0.2) Others (0.1)
GC1	0.4 – 3.9 (1.3)	0.7-16.6 (5.8)	8-12 (11)	Copepods (78.2) Chaetognaths (13.2) Decapod larvae (7.3) Gastropods (0.5) Fish Larvae (0.4) Mysids (0.2) Others (0.2)
GC2	0.1*	0.04 - 0.2 (0.1)	5*	Copepods (93.2) Chaetognaths (2.9) Isopods (1.5) Decapod larvae (1.1) Fish Larvae (0.9) Fish Eggs (0.3) Others (0.1)

*All replicates indicate similar values; #Indicates single collection; Averages are in parenthesis

Table 7.5 continued.

Station	Biomass (ml/100m³)	Population (no×10³/100m³)	Total groups (no)	Major groups (%)
GS1	No collection			
GS2	0.7-8.0 (4.4)	4.2-53.8 (29.0)	8*	Copepods (85.0) Decapod larvae (9.1) Chaetognaths (5.6) Fish Larvae (0.2) Others (0.1)
GS3	2.7-3.2 (3.0)	9.9-33.0 (21.5)	9-13 (11)	Copepods (87.9) Chaetognaths (9.5) Decapod larvae (2.0) Fish Larvae (0.3) Siphonophores (0.2) Others (0.1)
#NE	0.7	3.6	11	Copepods (84.6) Chaetognaths (13.2) Decapod larvae (0.7) Fish Larvae (0.5) Mysids (0.4) Fish Eggs (0.1) Polychaetes (0.1) Gastropods (0.1) Medusae (0.1) Amphipods (0.1) Others (0.1)
GCD	No collection			

*All replicates indicate similar values; #Indicates single collection; Averages are in parenthesis

Table 7.6: Zooplankton faunal group composition (%) in the subtidal regions of Dahej during Oct-22.

Faunal groups	GR	GN1	GN2	GC1	GC2	GS1	GS2	GS3	NE	GCD	Avg.
Foraminiferans	-	-	-	<0.1	-	No collection	-	-	-	No collection	<0.1
Siphonophores	<0.1	-	-	<0.1	-		<0.1	0.2	-		0.1
Medusae	<0.1	-	-	<0.1	-		<0.1	<0.1	0.1		<0.1
Chaetognaths	3.01	9.1	2.7	13.2	2.9		5.6	9.5	13.2		7.4
Polychaetes	<0.1	1.1	-	<0.1	-		-	<0.1	0.1		<0.1
Ostracods	-	-	-	<0.1	-		–	<0.1	<0.1		<0.1
Copepods	95.8	85.0	92.1	78.2	93.3		85.1	87.97	84.7		87.1
Cumaceans	-	-	-	<0.1	-		-	-	-		<0.1
Amphipods	<0.1	-	-	<0.1	-		-	<0.1	0.1		<0.1
Mysids	0.1	-	-	0.2	-		<0.1	<0.1	0.4		0.1
Decapod larvae	0.8	0.2	0.6	7.3	1.1		9.1	2.0	0.7		5.0
Gastropods	<0.1	3.4	1.6	0.5	-		<0.1	<0.1	0.1		0.1
Lamellibranchs	-	-	-	<0.1	-		-	<0.1	-		<0.1
Appendicularians	-	0.3	-	<0.1	-		-	-	-		<0.1
Fish Eggs	<0.1	-	0.4	<0.1	0.3		<0.1	-	0.1		<0.1
Fish Larvae	0.2	-	0.2	0.4	0.9		0.2	0.3	0.5		0.2
Isopods	0.1	0.9	1.4	<0.1	1.5		<0.1	<0.1	-		<0.1
Marine Insects	-	-	1.0	<0.1	-		-	-	-		<0.1

Table 7.7: Macrobenthos in the intertidal regions of Dahej during Oct-22.

Transect	Biomass (Wet wt.; g/m²)	Population (no./m²)	Faunal group (no.)	Major group
ITN	0.03 – 33.9 (5.2)	25 – 1425 (469)	1 – 5 (2)	Polychaetes, pelecypods
ITC	0.2 – 3.5 (1.5)	275 – 1075 (690)	1 – 6 (3)	Polychaetes, pelecypods, amphipods
ITS	0 – 3.4 (0.8)	0 – 850 (281)	0 – 4 (2)	Polychaetes, gastropods
Overall Avg.	0 – 33.9 (2.5)	0 – 1425 (480)	0 – 6 (2)	Polychaetes, pelecypods

Table 7.8: Macrobenthos group composition (%) in the intertidal regions of Dahej during Oct-22.

Faunal groups	Station									Avg.
	ITN			ITC			ITS			
	HW	MW	LW	HW	MW	LW	HW	MW	LW	
Phylum Sipuncula										
Sipunculids						2.1			4.5	0.4
Phylum Mollusca										
Gastropods								26.1		0.9
Pelecypods	32	25			4.8	22.8				13.6
Phylum Annelida										
Polychaetes	68	60.7	81.8	96.9	93.9	40.6	100	69.5	93.8	76.5
Phylum Arthropoda										
Amphipods		3.6	4.5			14.4				2.8
Brachyurans		3.6		3.1		2.5			2.1	1.4
Cumaceans					1.2	16.1				2.9
Mysids								4.35		0.1
Isopods		7.1	4.5			3.3			2.1	1.3

Zones: HW: High water; MW: Mid-water; LW: Low water

Table 7.9: Macrobenthos in the subtidal regions of Dahej during Oct-22.

Station	Biomass (Wet wt.; g/m²)	Population (no./m²)	Faunal group (no.)	Major group
GR	NIL			
GN1	NIL			
GN2	0 – 1.3 (0.4)	0 – 50 (17)	0 – 1 (1)	Polychaetes
GC1	0 – 0.11 (0.04)	0 – 50 (17)	0 – 1 (1)	Polychaetes
GC2	0 – 0.2 (0.1)	0 – 50 (17)	0 – 1 (1)	Polychaetes
GS1	NIL			
GS2	0 – 1.1 (0.7)	0 – 75 (42)	1*	Polychaetes
GS3	0 – 0.14 (0.1)	0 – 50 (17)	0 – 1 (1)	Polychaetes
NE	NIL			
GCD	NIL			
Overall Avg.	0 – 1.3 (0.13)	0 – 75 (11)	0 – 1 (1)	

*Indicates similar values of replicates NIL: No biomass observed
Values as range and average in parenthesis

Table 7.10: Macrobenthos group compositions (%) in the subtidal regions of Dahej during Oct-22.

Faunal groups	GR	GN1	GN2	GC1	GC2	GS1	GS2	GS3	NE	GCD	Avg.
Phylum Annelida											
Polychaetes	NIL	NIL	100	100	100	NIL	100	100	NIL	NIL	100

Table 7.11: Meiobenthos in the intertidal regions of Dahej during Oct-22.

Stations	Zones	Biomass (µg/10 cm²)	Population (ind./10 cm²)	Group (nos)
ITN	HW	0.14 – 4.32 (2.41)	48 – 93 (72)	1 – 2 (2)
	MW	54.35 – 197.14 (123.31)	58 – 253 (160)	5*
	LW	0 - 8.31 (2.86)	0 – 11 (6)	0 – 2 (1)
ITC	HW	18.51 – 54.13 (31.67)	65 – 156 (122)	3*
	MW	212.43 – 399.31 (304.07)	1021 – 1304 (1184)	6*
	LW	4.44 – 567.77 (200.90)	21 – 439 (192)	4 – 5 (5)
ITS	HW	0.15 – 4.60 (2.15)	7 – 290 (181)	1 – 2 (1)
	MW	13.61 – 78.34 (46.18)	619 – 937 (809)	3 – 4 (4)
	LW	3.28 – 12.74 (8.20)	37 – 160 (82)	3 – 4 (4)

Zones: HW: High water; MW: Mid-water; LW: Low water

Table 7.12: Meiobenthic group compositions (%) in the intertidal regions of Dahej during Oct-22.

Faunal groups	Station									Avg.
	ITN			ITC			ITS			
	HW	MW	LW	HW	MW	LW	HW	MW	LW	
Copepoda	1	27	8	7	18	32	0	2	5	11
Cumacea	0	0	0	0	0	8	0	0	0	1
Halacaroida	0	0	0	0	0	0	0	0	0	0
Nauplius	0	8	0	0	8	14	0	0	27	6
Nematoda	98	41	92	92	67	35	98	96	67	76
Nemertina	0	0	0	0	0	0	0	0	0	0
Ostracoda	0	1	0	0	1	0	0	0	0	0
Polychaeta	1	22	0	1	6	11	2	3	1	5

Zones: HW: High water; MW: Mid-water; LW: Low water

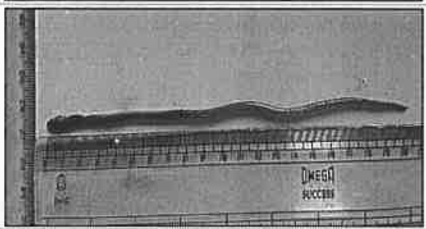
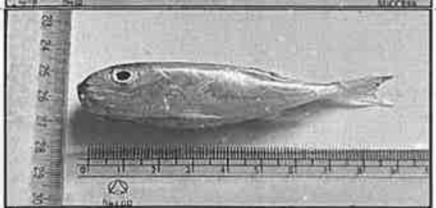
Table 7.13: Meiobenthic diversity in the subtidal regions of Dahej during Oct-22.

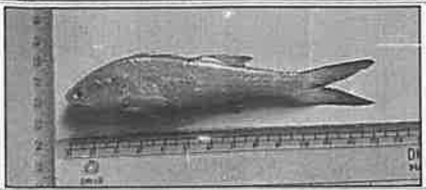
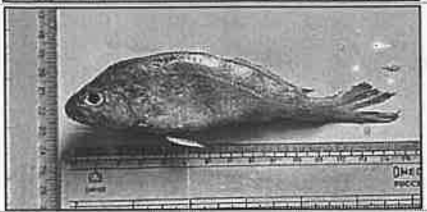
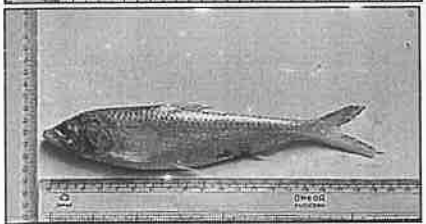
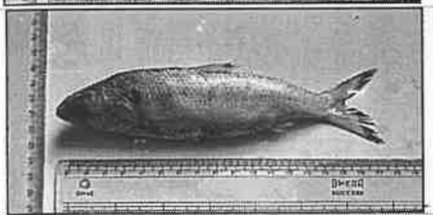
Station	Biomass (µg/10 cm²)	Population (ind./10 cm²)	Group (nos)
GR	1.4 – 1.6 (1.5)	1 – 8 (4)	1 – 2 (1)
GN1	0 – 0.3 (0.2)	0 – 1 (1)	0 – 1 (1)
GN2	0 – 108.4 (36.2)	0 – 8 (3)	0 – 4 (2)
GC1	0.5 – 1.9 (1.02)	3 – 6 (4)	1 – 3 (2)
GC2	NIL		
GS1	0.5 – 1.6 (1.1)	14 – 34 (25)	2 – 4 (3)
GS2	0 – 0.2 (0.1)	0 – 1 (1)	0 – 1 (1)
GS3	0 – 0.2 (0.1)	0 – 3 (1)	0 – 1 (1)
NE	0 – 0.3 (0.2)	0 – 4 (2)	0 – 1 (1)
GCD	0 – 12.9 (4.4)	0 – 6 (4)	0 – 3 (2)

Table 7.14: Meiobenthic group composition (%) in the subtidal regions of Dahej during Oct-22.

Faunal groups	Station									
	GR	GN1	GN2	GC1	GC2	GS1	GS2	GS3	NE	GCD
Amphipoda	0	0	0	0	0	0	0	0	0	25
Copepoda	25	0	14	13	0	4	0	0	0	25
Halacaroida	13	0	29	0	0	0	0	0	0	0
Insecta	0	0	0	0	0	0	0	0	0	13
Nauplius	0	0	0	0	0	8	0	0	0	0
Nematoda	63	100	43	75	0	85	100	100	100	13
Ostracoda	0	0	0	0	0	0	0	0	0	0
Polychaeta	0	0	14	0	0	0	0	0	0	25
Oligochaeta	0	0	0	13	0	0	0	0	0	0
Minor phyla	0	0	0	0	0	4	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100

Table 7.15: Fish samples collected around the sampling region Dahej during Oct-22.

Fishes	Scientific name	Length (cm)	Weight (gm)	No.
	*Takifugu niphobles*	3.5-7	1.5-10	14
	*Strongylura strongylura*	16-17.5	5.9-7.7	2
	*Anguilla sp.*	17.5-20.5	0.8-1.5	2
	*Planiliza sp.*	8.2-9.5	5.6-10.2	2
	*Crenimugil Crenilabis*	6.5-16.0	3.3-40.7	6
	*Lagicephalus lunaris*	8.9	16.86	1
	*Unidentified*	6-21.9	1.0-88.3	1

	*Aruis sp.*	23.2	130.10	1
	*Eleutheronema tetradactylum*	13.2	17.77	1
	*Johnius dussumiori*	14.6	43.09	1
	*Otolithes sp.*	16.5	38.30	1
	*Dussumieria elopsoides*	19.5	67.53	1
	*Tenualosa ilisha*	17.4	69.70	1
	*Harpadon nehereus*	22.5	64.70	1

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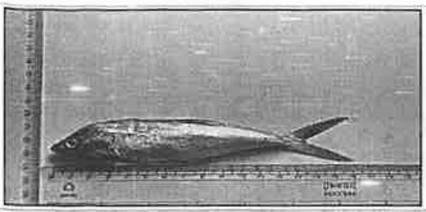	*Rastrelliger kanagurta*	16	28.90	1

Supplementary A: Water quality parameter limits along the Indian coast.

Place	Water Body	DO (mg/L)	BOD (mg/L)	PO_4^{3-}-P (µmol/L)	NO_2^--N (µmol/L)	NO_3^--N (µmol/L)	NH_4^+-N (µmol/L)	PHc (µg/L)	Phenol (µg/L)	Reference
Dahej Subtidal	Gulf of Khambat	4.2-8.2	0.5-4.6	0.9-3.2	0.1-0.4	7.6-60.1	0.1-16.4	3.8-6.4	24.8-80.9	This study
Dahej Intertidal	Gulf of Khambat	0-8.1	1.3-70	2.1-33.7	0.5-110	1.5-29.4	3.3-148.7	7.3-12	29.1-52.4	This study
Kandla	Gulf of Kachchh	5.2-6.3	-	3.9-4.9	2.3-2.6	6.0-8.3	4.3-6.0	-	-	Shirodkar et al., 2010
Vadinar	Coast	6.3-8.3	6.3-8.3	0.2-1.3	0.1-0.3	1.0-9.4	0.5-1.1	2.7-5.7	13-160.1	COMAPS 2011
Vadinar	Coast	7.0-7.95	7.0-7.95	0.8-1.0	0.1-0.3	2.3-4.9	0.6-1.2	15.8-21	79.5-130.2	COMAPS 2012
Vadinar	Coast	7.0-7.1	7.0-7.1	0.7-0.8	0.3-0.4	0.6-1.1	0.5-1.1	3.3-5.9	56.6-88.6	COMAPS 2016
Veraval	Coast	3.5-7.5	3.5-7.5	0.5-3.8	0.3-0.8	6.0-10.7	0.6-20.6	19.9-25.6	69.4-272.3	COMAPS 2011
Veraval	Coast	2.5-7.0	2.5-7.0	1.2-5.1	1.1-1.4	3.7-7.2	2.8-44.8	11.3-26.9	66.7-97.3	COMAPS 2012
Veraval	Coast	3.5-6.0	3.5-6.0	0.9-4.0	1.0-1.1	10.0-30.0	10.8-33.6	5.0-19.8	58.2-103.6	COMAPS 2016
Tadgam	Beach	5.6-7.2	0.3-27.5	1.0-4.6	0.3-1.4	8.7-15.7	0.4-4.1	2.4-46.2	68.6-131.8	NIO Report, 2018
Jampore	Beach	3.6-8.5	1.6-5.2	1.0-4.8	0.2-1.2	5.8-13.8	1.1-7.7	1.9-12.5	28.3-152.2	NIO Report, 2018
Devka	Beach	4.9-9.8	1.0-4.2	0.6-7.3	0.8-2.0	11.3-15.1	0.5-9.9	2.4-10.7	19.9-205	NIO Report, 2018
Tithal	Beach	4.9-7.5	0.3-4.6	1.6-8.4	0-4	5.4-14.7	0.3-5.8	2.8-8.1	16.1-155.3	NIO Report, 2018
Thane	Creek	5.5-6.2	1.7-2.9	1.4-3.1	1.8-6.3	7.8-32.5	1.3-4.3	4.4-19.5	71.4-110.2	COMAPS 2011
Thane	Creek	5.8-6.7	1.8-2.6	1.5-2.9	1.2-4	11.7-23.5	1.7-4.3	20.7-63.2	10.0-41.1	COMAPS 2012
Thane	Creek	5.3-6.7	1.5-3.7	0.8-2	0.3-1.4	4.4-24	0.6-3.1	1.0-3.9	66.5-103.0	COMAPS 2016
Dwarka	Coast	5.67-6.35	-	0.06-0.08	-	-	0.01-0.02	-	-	Bhadja and Kundu, 2012
Mangrol	Coast	5.62-6.17	-	0.06-0.07	-	-	0.01-0.02	-	-	Bhadja and Kundu, 2012
Kodinar	Coast	5.74-6.25	-	0.06-0.07	-	-	0.01-0.02	-	-	Bhadja and Kundu, 2012
Diu (UT)	Coast	5.71-6.08	-	0.06-0.08	-	-	0.02	-	-	Bhadja and Kundu, 2012
Ratnagiri	Coast	4.9-6.0	4.9-6.0	1.0-1.6	0.1-4.0	0.5-7.3	0.4-7.3	6.4-14.8	55.7-94.0	COMAPS 2011
Ratnagiri	Coast	5.9-6.4	5.9-6.4	0.6-0.7	0.8-0.9	2.0-2.7	1.1-3.4	11.0-28.3	66.6-79.2	COMAPS 2012
Ratnagiri	Coast	6.3-6.3	6.3-6.3	0.3-0.5	0.1	0.7-1.6	0.3-0.6	2.5-4.8	61.0-83.4	COMAPS 2016
Malvan	Coast	5.9-6.2	2.2-2.5	0.9-1.3	0.1-0.2	1.1-1.3	0.9-3.9	9.2-14.7	84.0-113.9	COMAPS 2011
Malvan	Coast	6.3-7.0	2.1-3.3	0.7-0.9	0.2-0.3	1.5-3.0	0.9-1.6	19.3-29.4	85.6-98.6	COMAPS 2012
Malvan	Coast	6.4-6.8	1.3-2.7	0.4-0.6	0.1-0.1	0.1-2.2	1.3	4.3-18.9	49.9-63.1	COMAPS 2016
Kasargod	Coast	6.48-8.78	-	0.26-127	-	4.0-232	-	-	-	Rai and Rajsekhar, 2014
Alaapuzha	Coast	-	-	0.5-1.8	-	0.4-11.4	-	-	-	Rai and Rajsekhar, 2014
Cochin	Coast	2.7-3.6	-	0.01-0.02	0.01-0.02	0.3-0.3	-	-	-	Rajagopalan et al., 1992

Supplementary B: Sediment metal limits around the Indian coast.

Place	Water body	Al (%)	Cr (µg/g)	Mn (µg/g)	Fe (%)	Co (µg/g)	Ni (µg/g)	Cu (µg/g)	Zn (µg/g)	Hg (µg/g)	References
Dahej Subtidal	Gulf of Khambat	1-7	67-113	766-1097	2-6	16-29	27-53	33-75	51-104		This study
Dahej Intertidal	Gulf of Khambat	3-6	86-293	773-2142	3-16	26-110	41-69	70-149	75-224		This study
Vadinar, Gujarat	Gulf of Kachchh	1.6-7.4	10-108	470-757	1.4-6.4	5-23	14-63	11-83	22-142	0.02-0.11	COMAPS 2011-12
Vadinar, Gujarat	Gulf of Kachchh	6-6.3	63-86	515-598	3.75.1	14-20	36-42	25-54	50-121	0.02-0.03	COMAPS 2016-17
Veraval, Gujarat	Gulf of Kachchh	3.9-6.9	79-125	620-874	3.2-4.7	16-29	42-56	41-65	64-95	0.07-0.16	COMAPS 2011-12
Veraval, Gujarat	Gulf of Kachchh	3.2-5.6	58-171	310-717	2.9-5.5	25-29	35-50	49-70	51-115	0.07-0.26	COMAPS 2016-17
Worli, Mumbai	Outfall	3.5-7.9	107-235	835-1243	4.6-7.7	25-40	44-67	93-130	70-180	0.08-0.45	COMAPS 2011-12
Worli, Mumbai	Outfall	6.2-8.6	111-216	685-1133	6.1-9.3	44-50	70-87	100-123	92-140	0.16-0.20	COMAPS 2016-17
Tadgam	Beach	4.3-5.8	188-285	945-1330	8.2-10.5	42-66	56-64	53-82	84-112	0.05-0.12	NIO Report, 2018
Jampore	Beach	3.7-7.3	137-211	985-1755	7.9-9.3	40-70	46-54	40-88	63-96	0.04-0.14	NIO Report, 2018
Devka	Beach	6.2-7.7	136-181	1070-1235	8.7-9.7	38-49	53-56	79-96	99-118	0.07-0.19	NIO Report, 2018
Tithal	Beach	5.6-7.5	146-295	1142-1535	9.3-14.4	44-91	53-63	98-123	107-184	0.05-0.14	NIO Report, 2018
Mumbai	Harbour	-	-	460-2500	-	7-23	-	40-245	75-350	-	Gogte et al.,1976
Mumbai	Harbour	-	-	719-1059	6.7-8.1	35-51	112-146	105-142	127-206	-	Zingde et al.,1979
Mumbai	Harbour	-	124.00	1140.00	8.60	50.00	111.00	105.00	155.00	-	Patel et al.,1985
Thane, Mumbai	Creek	7-7.8	116-128	772-918	7.1-7.8	26-39	58-66	89-100	59-102	0.09-0.19	COMAPS 2011-12
Thane, Mumbai	Creek	6.3-8.4	130-248	861-1300	7.1-10.7	49-60	74-85	110-115	89-144	0.09-0.29	COMAPS 2016-17
Mahim, Mumbai	Bay	-	-	746-1318	7-8	-	-	162-276	153-292	-	Matkar et al.,1981
Mahim, Mumbai	Bay	-	41-123	456-1132	-	19-35	49-82	71-150	48-345	-	Sabnis,1984
Mumbai	Coastal	-	102-120	886-1216	6.5-7.4	31-57	42-59	87-106	95-147	-	Dilli,1986
Mahim, Mumbai	Coastal	-	29-200	422-1036	-	11-30	35-61	93-123	135-291	-	Sabnis,1984
Ratnagiri, Mumbai	Coastal	4.1-7.4	104-157	664-1726	7.7-14.4	28-54	60-91	94-353	74-191	0.03-0.04	COMAPS 2011-12
Ratnagiri, Mumbai	Coastal	6.1-8.5	123-199	664-1196	8.1-10.8	43-60	64-85	104-120	71-113	0.02-0.06	COMAPS 2016-17
Malvan, Mumbai	Coastal	0.9-4.6	8-83	349-843	1.2-6.0	3-21	5-42	5-70	4-76	0.04-0.10	COMAPS 2011-12
Malvan, Mumbai	Coastal	1.3-4.7	56-134	337-785	2.7-6.0	16-59	9-53	17-73	25-71	0.01-	COMAPS 2016-17
Arabian Sea	Sea	-	-	1034-1212	-	-	66-87	99-130	109-204	-	Borole et al.,1982

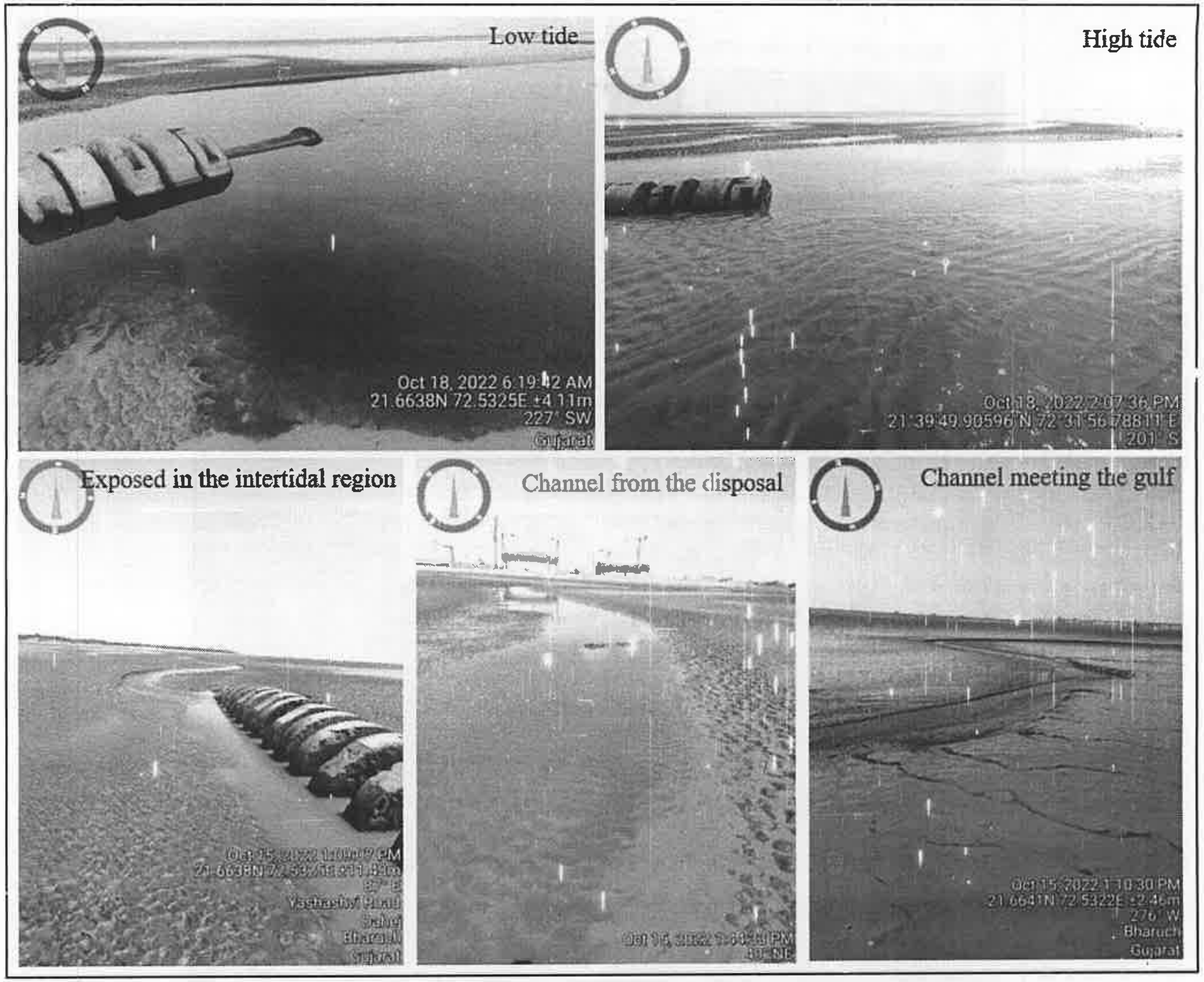

Plate 1: The current disposal pipeline in the intertidal region of Dahej.

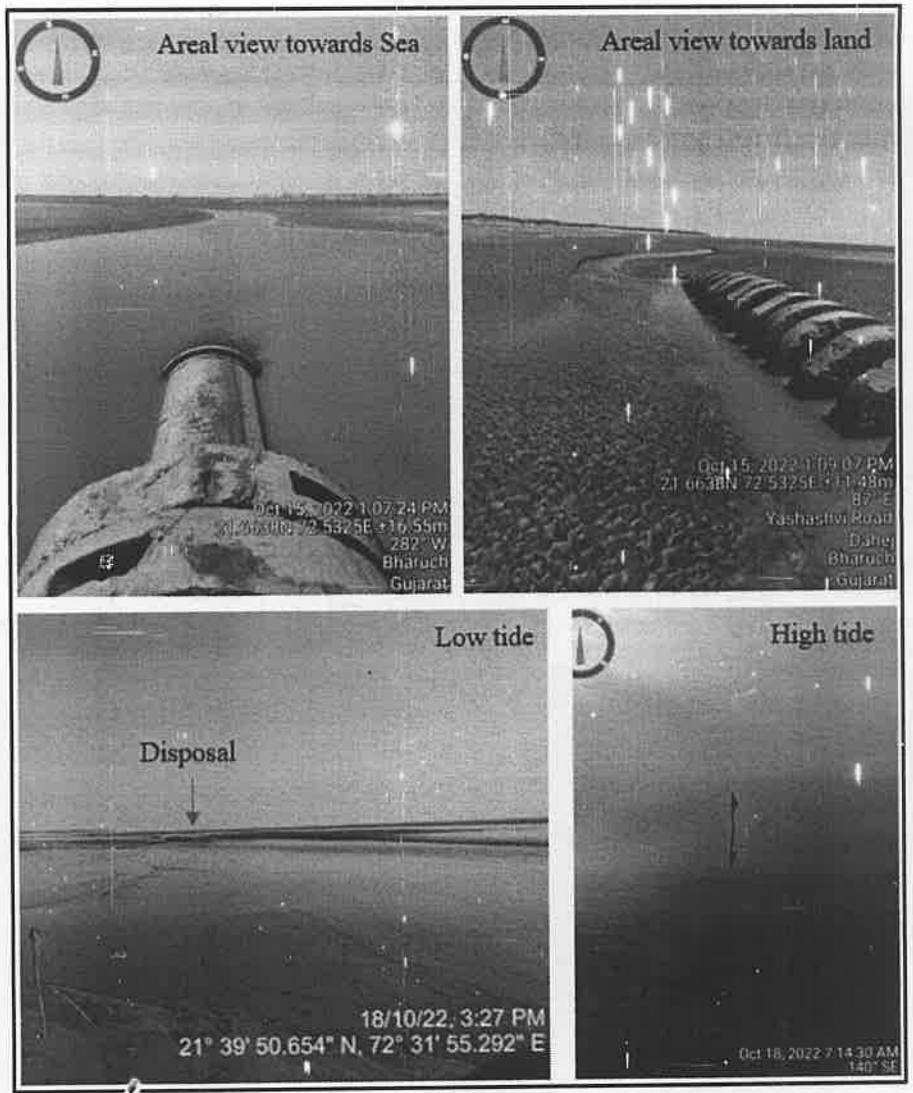

Plate 2: General high tide-low tide condition near the disposal location.

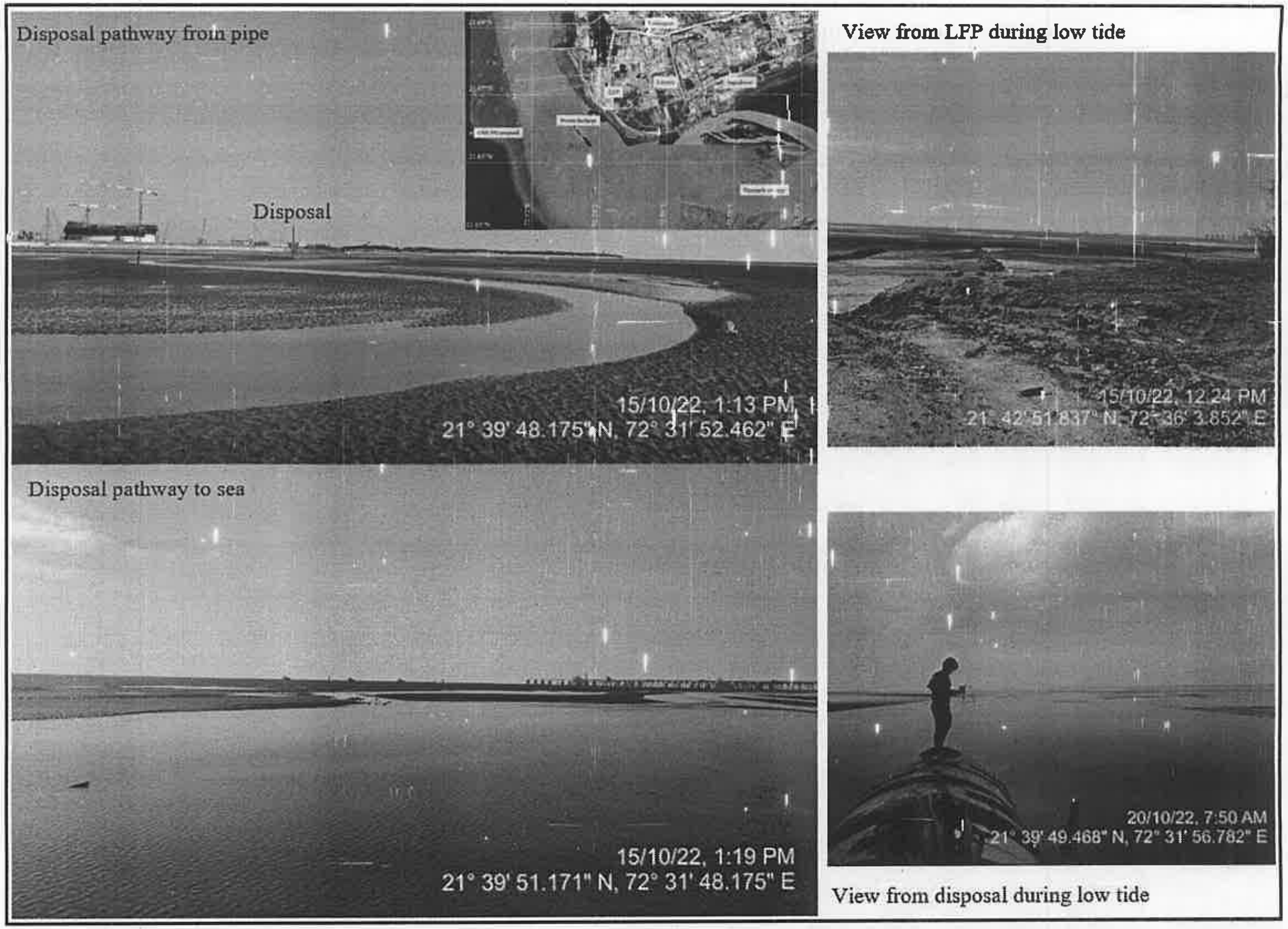

Plate 3: Channel formation in the intertidal region by the flow from the disposal pipeline.

Plate 4: Sampling activity along the effluent flow channel in the intertidal region.

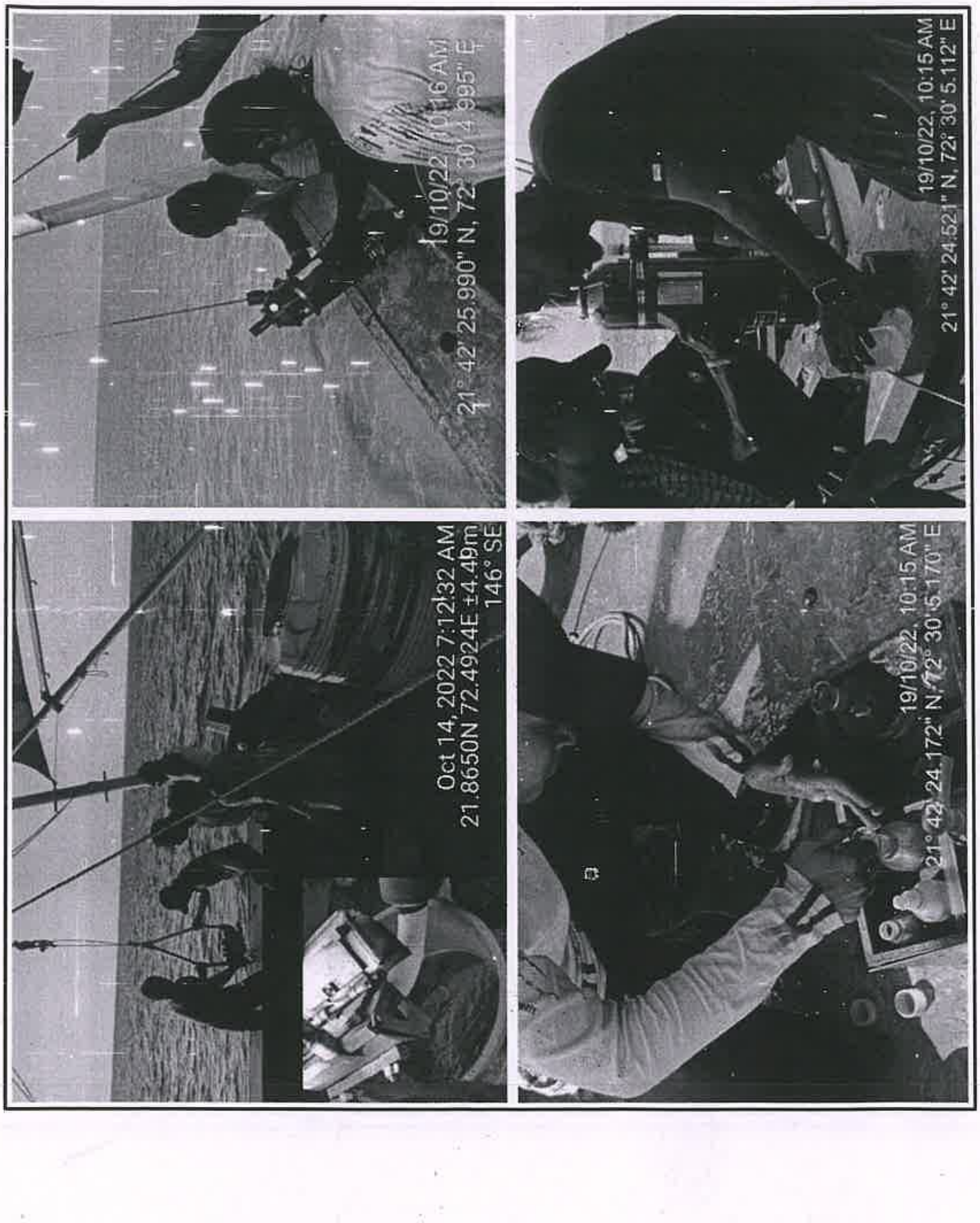

Plate 5: Water and sediment sample collection on a mechanized boat.

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Annexure-10

TOC Meter Installation in Pumping Stations at Dahej PCPIR

Location:- Final Pumping Station

Location:- Pumping Station A

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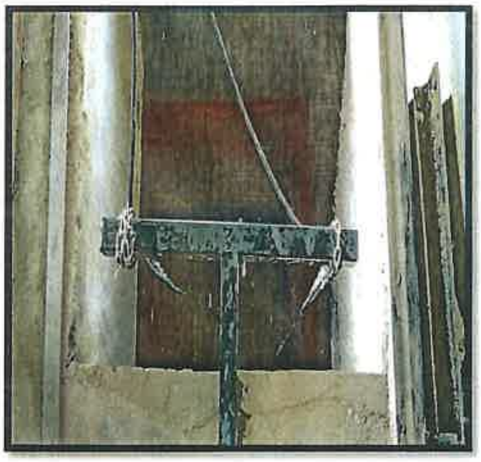
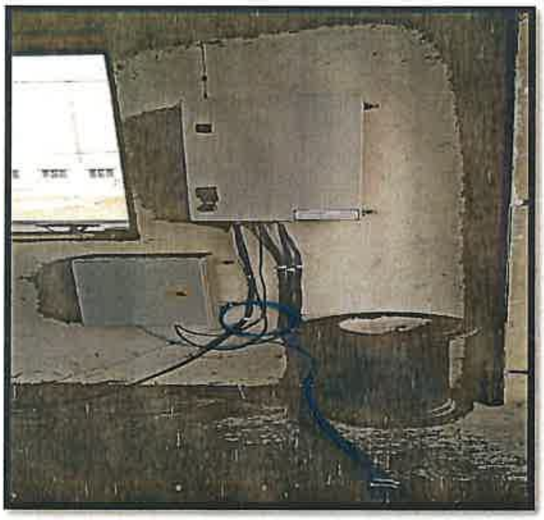
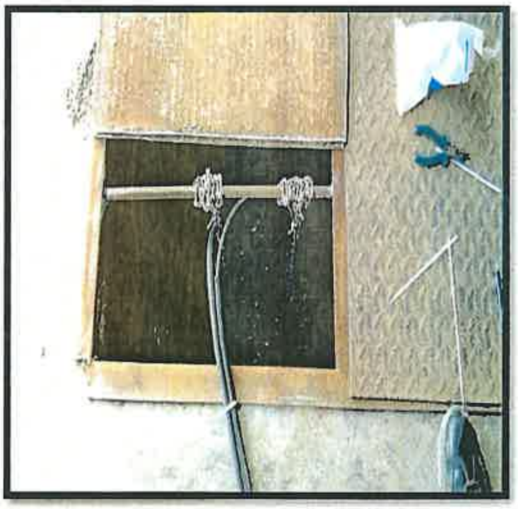
Location:- Pumping Station A1

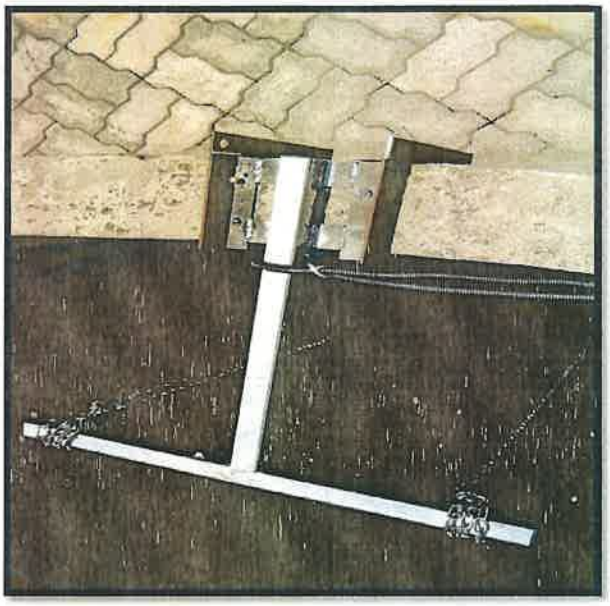


Location:- Pumping Station A2

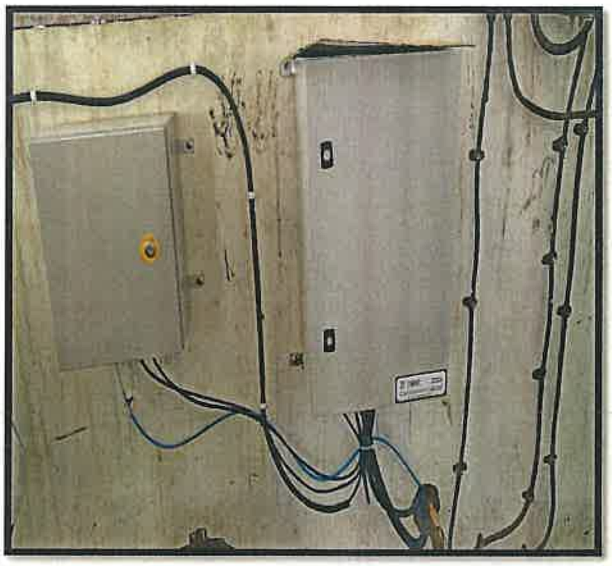


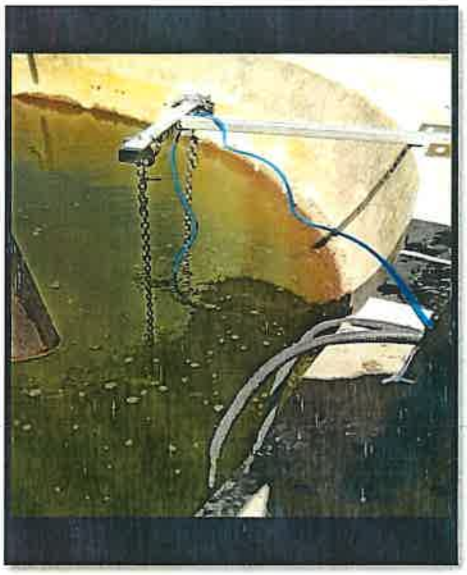


Location:- DRAINAGE PUMPING PS-1



Location:- DRAINAGE PUMPING PS-2

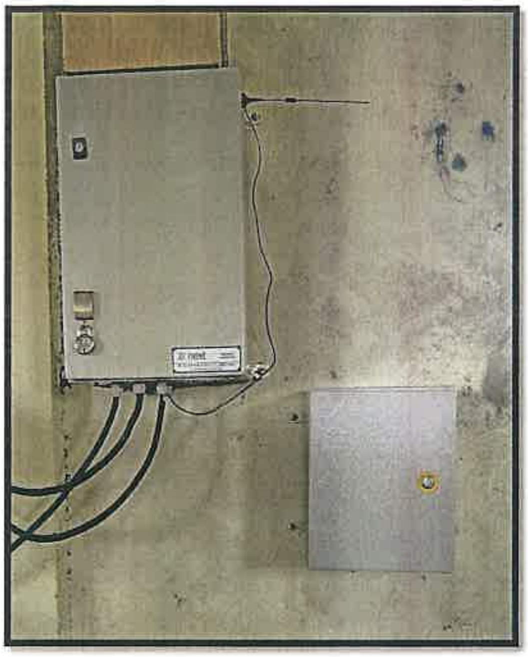




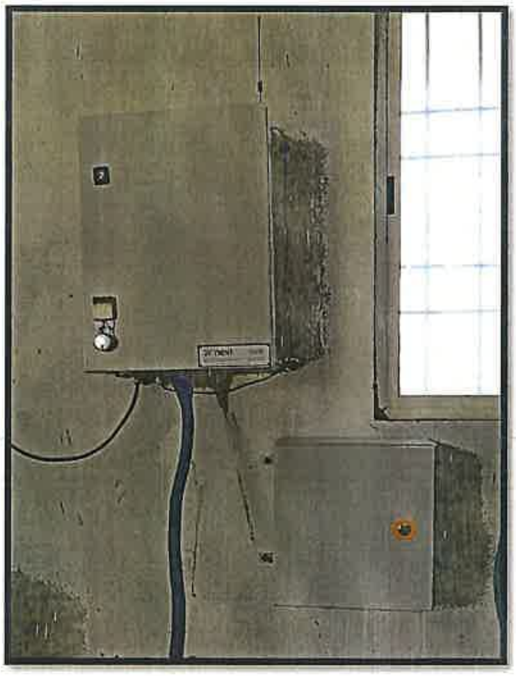
Location:- DRAINAGE PUMPING PS-4

Location:- DRAINAGE PUMPING PS-5

Location:- DRAINAGE PUMPING –D

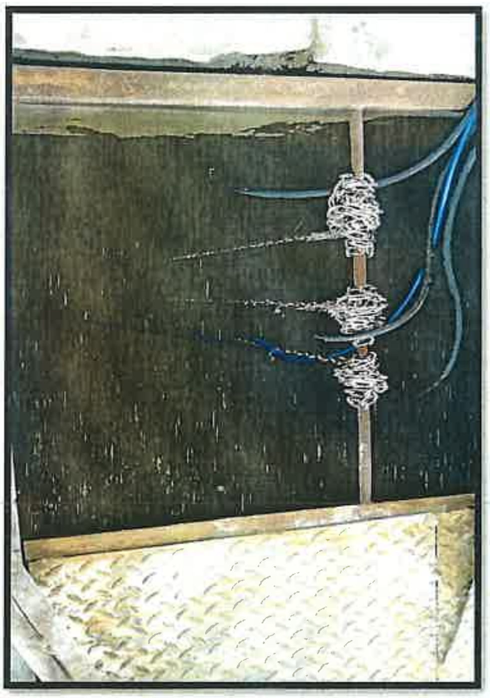


Location:- PUMPING STATION-C



Location:- PUMPING STATION-C1

Location:- PUMPING STATION-C2



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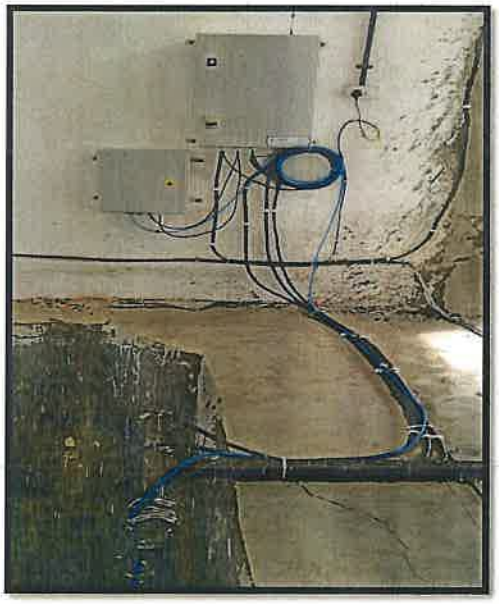
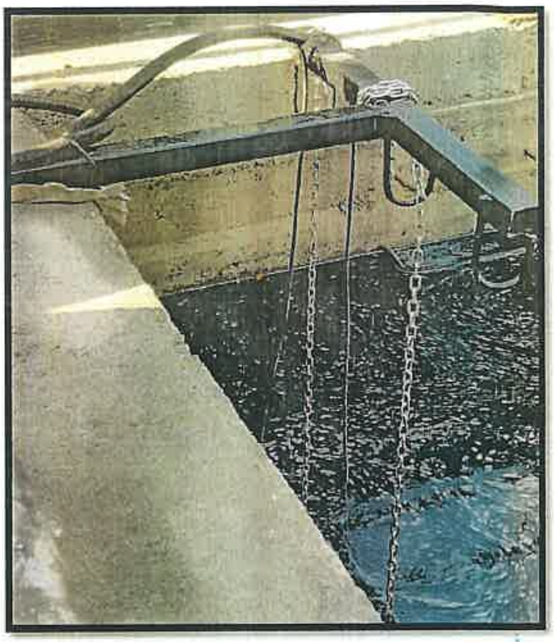
Location:- SAYKHA PUMPING STATION – 1

Location:- SAYKHA PUMPING STATION – 2



Location:- DRAINAGE PUMPING STATION – GIDC VILAYAT



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