GOPALPUR PORTS LIMITED
CIN. NO. : U63032OR2006PLC008831

Ref:GPL/ENV/ 2022-23/ 01

April 4, 2022

To,

The Director
Ministry of Environment, Forest & Climate Change
INDIRA PARYAVARAN
JOR BAGH ROAD,
NEW DELHI – 110 003.

Subject : Development of Gopalpur Ports Ltd." : Env. Compliance.

Ref. : No.10-12/2009-IA.III dt. 30th Mar, 2011, 14th Aug.2018

Dear Sir,

With reference to the above, we are submitting herewith our compliance of the conditions as laid down in different permissions and clearances. The Compliance report till end of March. 2022 is being enclosed for your kind consideration.

Yours faithfully,

For Gopalpur Ports Limited,

SAgarwal.

Authorized signatory

Copy to:

1. Additional Chief Secretary, Department of Forest & Wildlife, Govt. of Odisha, Secretariat, Bhubaneswar – 751 001.
2. The Chairman, Central Pollution Control Board, Parivesh Bhavan, CBD-Cum-Office Complex, East Arjun Nagar, Delhi – 110 032.
3. Addl. Principal Chief Conservator of Forests (Central), Ministry of Environment, Forest and Climate Change, Regional Office (EZ), A/3, Chandersekharpur, Bhubaneswar – 751 023.
4. The Member Secretary,Odisha State Pollution Control Board, Paribesh Bhavan, A/118, Nilakantha Nagar, Unit – VIII, Bhubaneswar - 751 012.Regional Officer, Odisha State Pollution Control Board Bharampur, Ganjam

Compliance Report for Environmental Clearance No.10-12/2009-IA-III Dated 30th March 2011

Sl. No.	Conditions	Compliance Status
6.		
(i)	"Consent for Establishment" shall be obtained from State Pollution Control Board under Air and Water Act and a copy shall be submitted to the Ministry before start of any construction work at the site.	Complied
(ii)	No construction work other than those permitted in Coastal Regulation Zone Notification, 2011 shall be carried out in Coastal Regulation Zone area.	Being complied with.
(iii)	The shore line map prepared by Institute for Ocean Management, Chennai with regard to the stretch at Gopalpur Port has been examined and it is observed that on the southern side of the port, the area is shown as high to medium accretion while, on the northern side the area is shown as low to medium erosion. This is because the net littoral drift is towards the northern side and due to the break water at the southern port there seems to be accretion at the southern breakwater and low to medium erosion on the northern side. This has to be ratified by adopting suitable sand bypass system from south break water to the northern side of the north break water.	Beach nourishment undertaken for 4 MCM in the groyne field to address the erosional aspect Environmental monitoring report (From Oct. 2021 to Mar. 2022) attached.
(iv)	Controlled and proper methods of dredging including state of the art equipment and planning the dredging operation and disposal shall be employed.	Dredging is carried out by use of controlled cutter suction. Other mitigation measures are also implemented to curtail the turbidity.
(v)	Technically qualified institution shall be engaged to monitor the impact right from the beginning to	Department of Marine Sciences, Berhampur

	suggest scientifically accepted mitigation measures as and when required on annual basis at least for first 3 years, shall be obtained.	University have been engaged since June, 2012 to carry out the environmental monitoring of Gopalpur port.
(vi)	A high level expert committee shall be constituted including the experts for Monitoring the population of benthic life during and after the construction phase and also to ensure the compliance of other conditions stipulated in the clearance.	High level expert committee has been constituted and periodically reviews the compliance conditions stipulated in the clearance.
(vii)	An additional substratum shall be provided with the breakwaters, thereby adding to the habitat of benthic community especially flora which is very low due to the present geo physical characteristics of the area.	Additional substratum provided during construction of break water and from the studies being carried out by department of Marine Science dept., Berhampur University there is increase in habitat of benthic community.
(viii)	Oil spills if any shall be properly collected and disposed as per the Rules.	Oil Spill Contingency Plan (OSCP) is in place.
(ix)	There shall be no drawl of ground water in CRZ area.	Complied with.
(x)	Environment Management Plan as suggested shall be strictly complied with.	Complied with.
(xi)	There shall be no disposal of solid and liquid wastes into the Coastal areas.	Being complied with and taken care off.
(xii)	Sewage Treatment facility should be provided in accordance with the CRZ notification, 2011. Treated sewage shall be reused for flushing of toilets and horticulture purposes.	Complied with.
(xiii)	The solid waste shall be properly collected, segregated and disposed as per the provision of solid Waste (Management and Handling) Rules, 2000.	Waste management Plan is in place.
(xiv)	Installation and operation of DG set if any shall comply with the guidelines of CPCB.	CPCB approved DG sets are installed.

(xv)	The approach channel shall be properly demarcated with lighted buoys for safe navigation and adequate traffic control guidelines shall be framed. The fishermen shall be suitably educated and informed about the traffic guidelines.	Channel Marker Buoys have been installed for safe navigation. Fishermen Sensitization shall also be done regularly for harmony with port operation.
(xvi)	The project proponent shall set up separate environmental management cell for effective implementation of the stipulated environmental safeguards under the supervision of a Senior Executive.	Environment Management Cell has been created Headed by DGM Environment
(xvii)	The project proponent shall take up mangrove plantation/green belt in the project area, wherever possible. Adequate budget shall be provided in the Environment Management Plan for such mangrove development.	Green Belt development work is in progress following land shaping and plantation work.
(xviii)	The funds earmarked for environment management plan shall be included in the budget and this shall not be diverted for any other purposes.	Adequate fund is ear-marked and available.
(xix)	Under the provisions of Environment (Protection) Act, 1986, legal action shall be initiated against the project proponent if it was found that the construction of the project has been started without obtaining environmental clearance.	Construction of the project commenced after obtaining the Environmental Clearance. Date of project commencement is 10th Nov. 2011.
7.		
(I)	Adequate provision for infrastructure facilities including water supply, fuel and sanitation must be ensured for construction workers during the construction phase of the project to avoid any damage to the environment.	Being complied with.
(ii)	Appropriate measures must be taken while undertaking digging activities to avoid any likely degradation of water quality.	Being complied with.
(iii)	Borrow sites for each quarry sites for road	Being complied with.

	construction material and dump sites must be identified keeping in view the following: a) No excavation or dumping on private property is carried out without written consent of the owner. b) No excavation or dumping shall be allowed on wetlands, forest areas or other ecologically valuable or sensitive locations. c) Excavation work shall be done in close consultation with the soil Conservation and Watershed Development Agencies working in the area, and d) Construction spoils including bituminous material and other hazardous materials must not be allowed to contaminate water courses and the dump sites for such materials must be secured so that they shall not leach into the ground water.	
(iv)	The construction material shall be obtained only from approved quarries. In case new quarries are to be opened, specific approvals from the competent authority shall be obtained in this regard.	Being complied with.
(v)	Adequate precautions shall be taken during transportation of the construction material so that it does not affect the environment adversely.	Being complied with.
(vi)	Full support shall be extended to the officers of this Ministry/Regional Office at Bhubaneswar by the project proponent during inspection of the project for monitoring purposes by furnishing full details and action plan including action taken reports in respect of mitigation measures and other environmental protection activities.	GPL is committed to provide necessary support.

(vii)	A Six monthly monitoring report shall need to be submitted by the project proponents to the Regional Office of this Ministry at Bhubaneswar regarding the implementation of the stipulated conditions.	Being complied with.
(viii)	Ministry of Environment and Forests or any other competent authority may stipulate any additional conditions or modify the existing ones, if necessary in the interest of environment and the same shall be complied with.	GPL is committed to comply with such condition, if any.
(ix)	The Ministry reserves the right to revoke this clearance if any of the conditions stipulated are not complied with the satisfaction of the Ministry.	Taken note of.
(x)	In the event of a change in project profile or change in the implementation agency, a fresh reference shall be made to the Ministry of Environment and Forests.	Will be complied, if any.
(xi)	The project proponents shall inform the Regional Office as well as the Ministry, the date of financial closure and final approval of the project by the concerned authorities and the date of start of land development work.	Complied The Land development work commenced on 10th November 2011 after approval of the project.
(xii)	A copy of the clearance letter shall be marked to concern Panchayat / local NGO, if any, from whom any suggestion / representation have been made, received while processing the proposal.	Noted and complied.
(xiii)	Orissa Pollution control Board shall display a copy of the clearance letter at the Regional Office, District Industries Centre and Collector's Office/Tahasildar's office for 30 days.	Noted
8.	These stipulations would be enforced among others under the provisions of Water (Prevention and Control of Pollution) Act 1974, the Air (Prevention and Control of Pollution) Act	Noted

	1981, the Environment (Protection) Act, 1986, the Public Liability (Insurance) Act, 1991 and EIA Notification 1994, including the amendments and rules made thereafter.	
9.	All other statutory clearances such as the approvals for storage of diesel from Chief Controller of Explosives, Fire Department, Civil Aviation Department, Forest Conservation act, 1980 and Wildlife (Protection) Act, 1972 etc. shall be obtained, as applicable by project proponents from the respective competent authorities.	Agreed
10.	The project proponent shall advertise in at least two local Newspapers widely circulated in the region, one of which shall be in the vernacular language informing that the project has been accorded Environmental Clearance and copies of clearance are available with the State Pollution Control Board and may also be seen on the website of the Ministry of Environment and forests at http://www.envfor.nic.in. The advertisement should be made within 10 days from the date of receipt of the Clearance letter and a copy of the same should be forwarded to the Regional Office of this Ministry at Bhubaneswar.	Complied, Vide letter No. GPL/2011/59, dated 11/04/2011
11.	Environmental clearance is subject to final order of the Hon'ble Supreme court of India in the matter of Goa Foundation vs. Union of India in Writ Petition (Civil) No.460 of 2004 as may be applicable to this Project.	Agreed
12.	Status of compliance to the various stipulated environmental conditions and environmental safeguards will be uploaded by the project proponent in its website.	Complied
13.	The project proponent shall also submit six	Complied

	monthly reports on the status of compliance of the stipulated EC conditions including results of monitoring data (both in hard copies as well as by e-mail) to the respective Regional Office of MoEF, the respective Zonal Office of CPCB and the SPCB.	
14.	The environmental statement for each financial year ending 31st March in Form-V as is mandated to be submitted by the project proponent to the concerned State Pollution Control Board as prescribed under the Environment (Protection) Rules, 1986, as amended subsequently, shall be put on the website of the company along with the status of compliance of EC conditions and shall also be sent to the respective Regional Offices of MoEF& CC by e-mail.	Complied
Additional Conditions of the EC Validity Extension Order dated 14th August 2018		
1.	The Project Proponent will submit a Certified Compliance Report within 03 months issued by the MoEF& CC, Regional Office or concerned Regional Office of the Central Pollution Control Board or the Member Secretary of the respective State Pollution Control Board for the conditions stipulated in the Environmental and CRZ Clearance issued earlier	Being Complied
2.	The development plan shall be implemented strictly in accordance to the Coastal Zone Management Plan as drawn up in compliance to the orders of the NGT in this regards. A copy of the compliance report shall be submitted within 30 days to the MoEF& CC.	Being Complied
3.	As per the Ministry's Office Memorandum F.No22-65/2017-Ia.III dated 1st May 2018, the project proponent is required to prepare and	As per the Para 6 (IX) of the said notification which states that *the CER is not applicable*

	implement Corporate Environment Responsibility (CER) Plan. As per the para 6(II) of the said O.M appropriate funds shall be earmarked for the activities such as infrastructure creation for drinking water supply, sanitation, health, education, skill development, roads, cross drains, electrification including solar power, solid waste management facilities, scientific support and awareness to local farmers to increase yield of crop and fodder, rain water harvesting, soil moisture conservation works, avenue plantation, plantation in community areas etc. The activities proposed under CER shall be restricted to the affected area around the project. The entire activities proposed under the CER shall be treated as project and shall be monitored. The monitoring report shall be submitted to the regional office as a part of half yearly compliance report, and to the District Collector. It should be posted on the website of the Project Proponent.	*in name change, transfer, amendment involving no additional project investment*; this is not applicable to us, as there is no additional project investment.

ENVIRONMENTAL MONITORING OF GOPALPUR PORT

Report
October, 2021 to March, 2022

Prepared by

Department of Marine Sciences
Berhampur University
Berhampur-760007, Odisha

C E R T I F I C A T E

This is to certify that this report is based on our own observation and analysis of data both in the Department as well as through an outsource agency accredited by NABET. A team of Oceanography and Meteorology experts at the Department of Marine Sciences, Berhampur University, Berhampur have contributed on the shoreline change, beach profile, erosion/accretion environment, sediment grain size, littoral environment observation, ambient air quality, noise level, water and sediment quality while a team of Marine Biology experts at the Department of Marine Sciences, Berhampur University have contributed on the biological parameters of coastal water and sediment around Gopalpur Port Environment.

(Dr. P. K. Mohanty)
Nodal Expert & Professor
Department of Marine Sciences
Berhampur University

(Dr. Shesdev Patro)
Consultant & Asst. Professor
Department of Marine Sciences
Berhampur University

PROJECT TEAM, BERHAMPUR UNIVERSITY

Prof. Pratap K. Mohanty, Nodal Expert

Dr. Shesdev Patro, Consultant

Dr. Asim Amitav Pattanayak, Project Scientist

Dr. Prabin K. Kar, Project Scientist

Mr. Balaji Behera, Project Scientist

Miss Bhubaneswari Panda, Project Fellow

Table of Contents

ACRONYMS AND ABBREVIATIONS

GPL	: Gopalpur Port Limited
MoEFCC	: Ministry of Environment and Forest and Climate Change
IREL	: Indian Rare Earth Limited
CD	: Chart Datum
CRZ	: Coastal Regulation Zone
IB	: Intermediate Breakwater
SB	: Southern Breakwater
NG	: Northern Groyne
SG	: Southern Groyne
SPM	: Suspended Particulate Matter
DGPS	: Differential Global Positioning System
LEO	: Littoral Environment Observation
BMAP	: Beach Morphology Analysis Package
GPLS	: Gopalpur Port South
GPLN	: Gopalpur Port North
GPB	: Gopalpur Beach
BS	: Backshore
MS	: Midshore
FS	: Foreshore
ESE	: East South East
SSE	: South South East
SE	: South East
BOD	: Biological Oxygen Demand
DO	: Dissolved Oxygen
TSS	: Total Suspended Solids
NAAQ	: National Ambient Air Quality
STD	: Standard Deviation

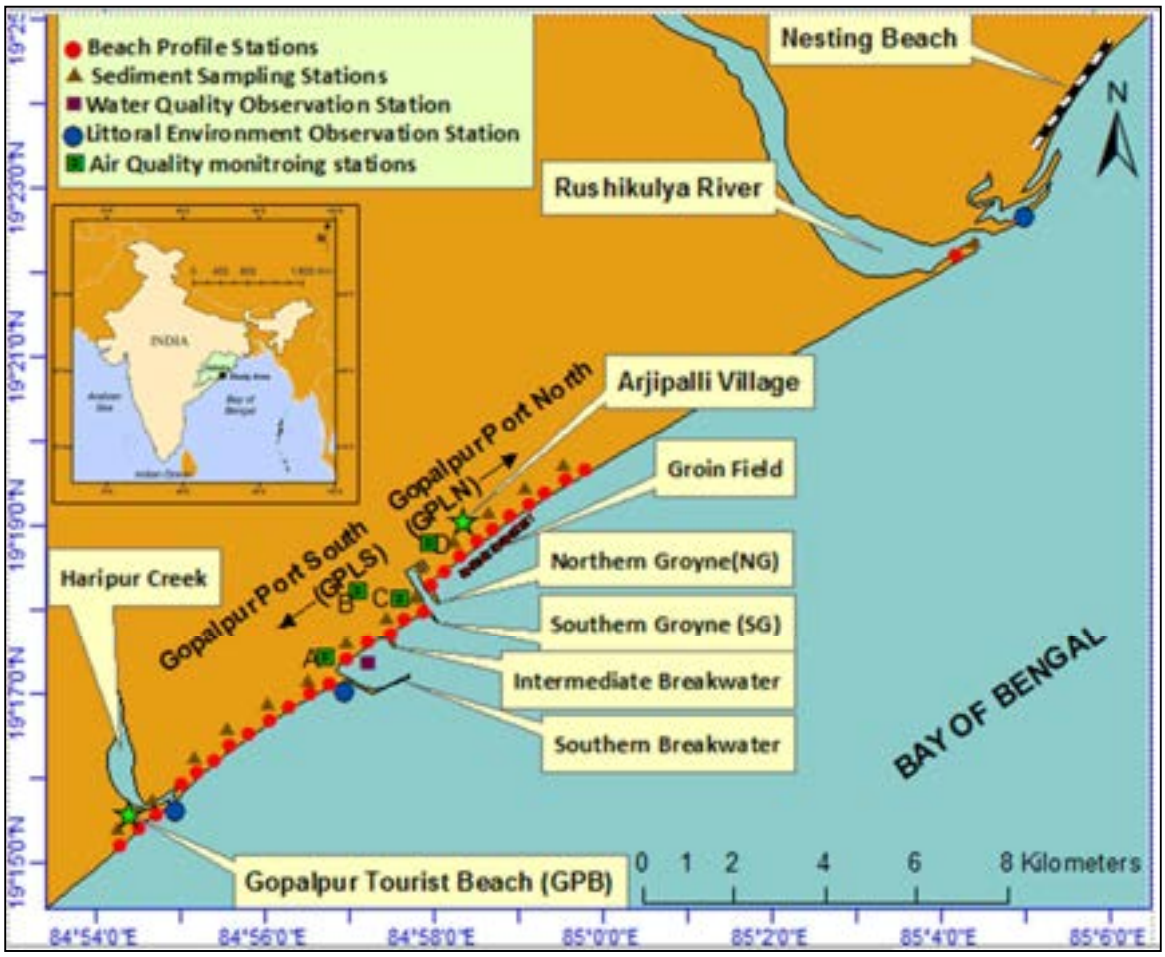
Chapter-1

INTRODUCTION

1. Introduction

Gopalpur Ports Limited (GPL) is located at latitude 19˚ 18′ 13″ N and longitude 84˚ 57′ 52″ E along Odisha coast, east coast of India (Figure 1.1). GPL is being developed as an all weather direct berthing port from a small fair weather port which existed since 1987. As a fair weather port, it was operational only during November to March, and had a channel of 5m depth across the beach connecting the basin on the backshore to the Bay of Bengal. The structures associated with the fair weather port were a 400m northern pier to support moving of dredgers (to keep the channels free from sedimentation) and a 500m southern jetty to support cargo handling. Two groynes, 530m south groyne (SG) and 362m north groyne (NG) located within a distance of 250m, were constructed on the north and south of the 500m jetty which existed earlier. Now, the lengths of SG and NG is 488m and 271m (March, 2021, Table-1.1) respectively in the month of March, 2021. The top levels of these two groynes with respect to chart datum (CD) are at 5m at the start of the groyne and at 5.5m at the end of the groyne. The proposed port facilities comprises of construction of Intermediate and southern breakwater (Intermediate breakwater: length of 435m up to depth of 8 m w.r.t CD, southern breakwater: length of 2.17 km up to depth of -14 m w.r.t CD), development of berths and back up areas (to the south of the existing structures), dredging of approach channel and harbour basin (-15m of CD) and a series (eleven) of northern groynes (groyne field). Keeping in view the above developments associated with the development of the port, the Ministry of Environment Forest and Climate Change (MoEFCC), Govt. of India while according environmental and CRZ clearance for establishment of an all weather port, has laid some conditions for necessary compliance by GPL. In compliance to the conditions of MoEFCC and the State Pollution Control Board, the following monitoring programme is being carried out since May, 2012. The report presented here contains information on the shoreline change, beach profile and beach width/volume changes, sediment and ambient air quality, Littoral environment, sea and harbour water quality, terrestrial and marine environment. The data are collected and analyzed on monthly basis from October, 2021 to March, 2022. The results are presented month wise to understand the monthly variability as well as the net variability during the study period. This report explains the impact of coastal structures

and port activities on geomorphological and coastal (water, sediment and biology) environment at Gopalpur Port and its vicinity during the period of report.



Breakwater/Groyne	Elevation Height(m) (Ref. Point)	Length (m)
Intermediate Breakwater (IB)	4.51	463.57
Southern Breakwater (SB)	3.89	2170.0
Southern Groyne (SG)/southern lip of old anchorage port	1.53	488.00
Northern Groyne (NG)/ Northern lip of old anchorage port	1.41	271.00
Groyne-4	1.19	5
Groyne-9	5.09	4.5

Figure 1.1: Sampling locations of different parameters near Gopalpur coast (Gopalpur Tourist Beach, Gopalpur Ports Limited and Rushikulya River mouth)

Table-1.1: Status of Breakwaters and Groynes located along south and north of Gopalpur port during March, 2022.

Chapter-2

OBJECTIVES AND OBSERVATION SCHEDULE

2. Objectives and observation schedule

Table 2.1 provides details on types of observation, observation frequency and spatial variability.

2.1 Monitoring of Ambient Air Quality

Monitoring of Ambient Air Quality were carried out at 4 stations; two in the windward side and two in the leeward side within the port premises for PM_{10}, $PM_{2.5}$, SO_2, NO_2 to measure the maximum ground level concentration (Fig. 1.1).

2.2. Monitoring of noise level during piling, transport and erection of structures etc.

Ambient noise level was monitored during day time at four locations within port premises (Fig. 1.1).

2.3. Shoreline Monitoring

Monitoring the beach profile, erosion/accretion environment, shoreline change along a stretch of approximately 26km (from Gopalpur light house to Rushikulya Mouth), which lies within the Port limit, on monthly basis.

Monitoring the sediment characteristics, littoral environment observations (LEO) were carried out along 26km stretch on monthly basis (Fig. 1.1).

2.4 Marine Water Sample

2.4.1 Chemical parameters

Coastal water samples for the parameters pH, DO, Colour, Odour, Fecal Coliform, BOD, Salinity, EC, TDS, TSM, Phosphate, Nitrate, Chlorides, Sulphate, PHc, Lead and Hexavalent Chromium & Mercury were analysed every month.

2.4.2 Biological parameters

Biological parameters such as light penetration, chlorophyll, primary productivity, phytoplankton, zooplankton within the harbour were analysed at every three month interval.

2.5 Sediment Sample

2.5.1 Chemical Parameters

Sediment samples were collected every month at one location within the port premises and analysed for the parameters texture, pH, Sodium, Potassium, Phosphate, Chlorides, Sulphates, PHc, Lead, Mercury, Hexavalent Chromium, Organic Carbon etc.

2.5.2 Biological Parameters

Benthic meio fauna and benthic macro fauna were analysed quarterly for the samples collected from the harbour area.

2.6 Observation Schedule

Table 2.1: Types and frequency of Observations

Types of Observations	Schedule of Observation	Spatial variability of observation
Ambient air quality (PM_{10}, $PM_{2.5}$, SO_2, NO_2)	Twice in a Week	From the four sampling stations within the port environment (landward)(Fig. 3.12)
Noise level	Twice in a Week	Within the port environment (landward) as per the guidelines of Central Pollution Control Board (CPCB)
Soil analysis	Yearly	pH, Conductivity, Nitrogen, Phosphorous, Potassium, Alkalinity, Chlorine, Sulphate, Magnesium, Organic Matter, Iron, Copper, Manganese, Zinc, Chromium, Lead, Nickel, Arsenic, Cadmium, Mercury at a particular location within port premises.
Shoreline (ARCPAD_DGPS)	Monthly	Mapping the berm line, representing the shoreline, within the port limit covering 26 km stretch
Beach Profile (RTK_GPS/TOTAL STATION)	Monthly	30 transects covering about 26 km stretch of the coast line (Fig. 1). Within 4.5km north and south of the port the distance between two successive transects is maintained at 500m while for other locations, the distance is maintained at 1km.
Sediment	Monthly	Sediment samples are collected for grain size analysis at backshore, midshore and foreshore of a transect at every 1km interval covering the 26 km stretch of the coast.
Littoral Environmental Observations (LEO)	Monthly	At three points; Gopalpur port, near Gopalpur tourist beach and at the mouth of the Rushikulya river (Fig. 1.1).
Coastal Water sample: a. Chemical parameters	Monthly	pH, DO, Colour, Odour, Fecal Coliform, BOD, Salinity, EC, TDS, TSM, Phosphate, Nitrate, sulphates, Chlorides, PHC, Lead, Mercury, Hexavalent Chromium, light penetration.
b. Biological parameters	Quarterly	Chlorophyll, phytoplankton, zooplankton within harbour

Sediment sample a. Chemical parameters b. Biological parameters	Monthly Quarterly	pH, Sodium, Potassium, Phosphate, Potassium, Chlorides, Sulphates, PHC, Lead, Hexavalent Chromium and Organic Carbon Benthic Meio-Fauna, Benthic Macro-Fauna, Benthic Biomass, abundance and distribution.

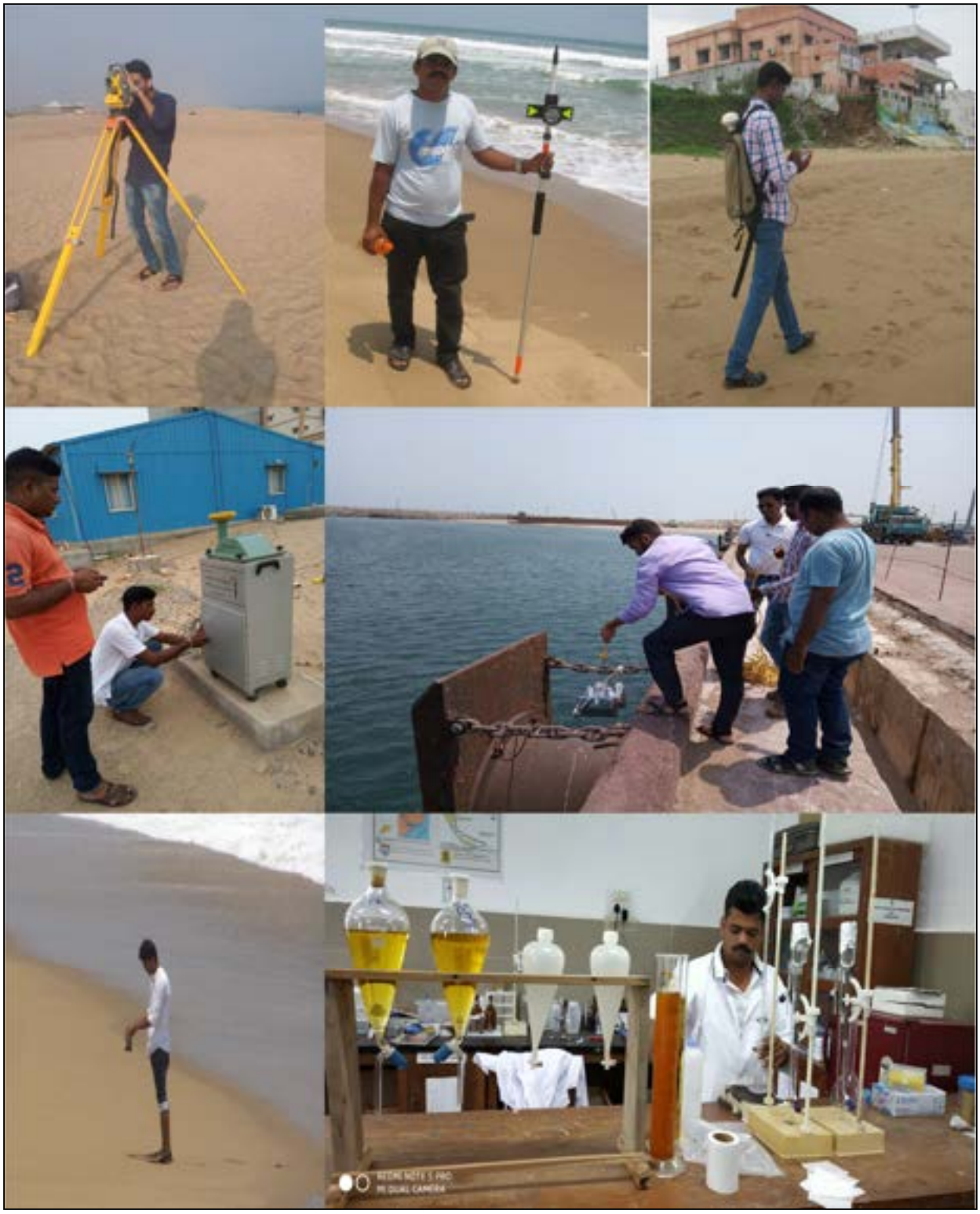


Figure 2.1: Members of the Project Team during field observation and laboratory analysis of samples

2.7 Significant observation and analysis results

Observation and analysis of results for the period from October, 2021 to March, 2022 are presented in two parts:

Part-I represents the Shoreline change, beach profile, erosion/accretion, sediment characteristics, ambient air quality and noise level while Part-II represents chemical and biological parameters of coastal water and sediment.

PART-I: REPORT ON SHORELINE CHANGE, BEACH PROFILE, EROSION/ACCRETION, SEDIMENT CHARACTERISTICS, LITTORAL ENVIRONMENTAL OBSERVATION, AMBIENT AIR QUALITY AND NOISE LEVEL

&

PART-II: WATER, SEDIMENT AND BIOLOGICAL ENVIRONMENT

PART-I

Report on Shoreline Change, Beach Profile, Erosion/Accretion, Sediment characteristics, Littoral Environmental Observation, Ambient Air Quality and Noise Level

Chapter-3

3. COASTAL AND TERRESTRIAL ENVIRONMENT

3.1 Shoreline Change

The shoreline in the present study refers to the first berm during spring low tide while moving from foreshore to backshore which is not disturbed at the time of observation. The position of the berm and its landward/seaward shifting with time with respect to a fixed reference line represents the area of the beach subjected to erosion/ accretion. The berm position was monitored from Gopalpur light house in the south to Rushikulya mouth in the north covering a total distance of 23.5 Km along the coastline. Figure 3.1 to Figure 3.4 depict the berm positions at four beach environment during October, 2021 to March, 2022 and monthly oscillation of bermline. Since wave height during northeast monsoon and post-monsoon period are relatively less compared to the waves during south-west monsoon, impact of ocean waves on coastal environment is also discussed vividly.

The information on shoreline position from a fixed reference line has been generated at every transect with 500m interval covering 4.5 Km to the south of southern groyne (SG) and 4.5 km to the north of northern groyne (NG). At present, the length of the two groynes are; 488m SG and 271m NG. At present, two breakwaters on the south and two groynes on the north exist with different dimensions (Table 1.1) while other groynes are submerged in the sea. Three berths (Total length of 800m) were developed in between two breakwaters since June, 2019. Besides the Port area, information on shoreline position (month wise) for Gopalpur tourist beach and Rushikulya nesting beach have been presented for the assessment of shoreline change from October, 2021 to March, 2022.

3.1.1 Gopalpur Port South

Shoreline positions of the beach located south of southern groyne was observed for the period from October, 2021 to March, 2022 and the results are presented in Figure 3.1 and Table-3.4. The negative sign (-) indicates movement of the shoreline towards the land (erosion) while positive sign (+) indicates the movement of shoreline towards sea (accretion). The shoreline between 1.5 Km and 2 Km south of SG is presently within the two breakwater system and these portions of beach are under regular maintenance for development of berth. Therefore, shoreline

information at 1.5 Km and 2 Km transects are not taken. During the period of observation, shoreline position moved intermittently seaward (positive) or landward (negative) indicating development of shoreline. At 0.0 Km, 4.0 Km and 4.5 Km, shoreline moved landward while at rest of the positions, shoreline experienced accretion. The magnitude of seaward movement of shoreline is maximum at 2.5 Km (1091.8) during February, 2022. Net shoreline change at south of Gopalpur port during October, 2021 to March, 2022 varies between -26.95 to 24.03 m. Standard deviation of the shoreline is maximum (19.92) on the south of the port to the while minimum STD (7.57 m) is observed at 0.5 Km south of SG. Considering the spatial variability, standard deviation of shoreline position is minimum during November, 2021 and maximum during March, 2022. Similarly, mean shoreline is observed maximum during February, 2022 and minimum during December, 2021 (Table 3.1).

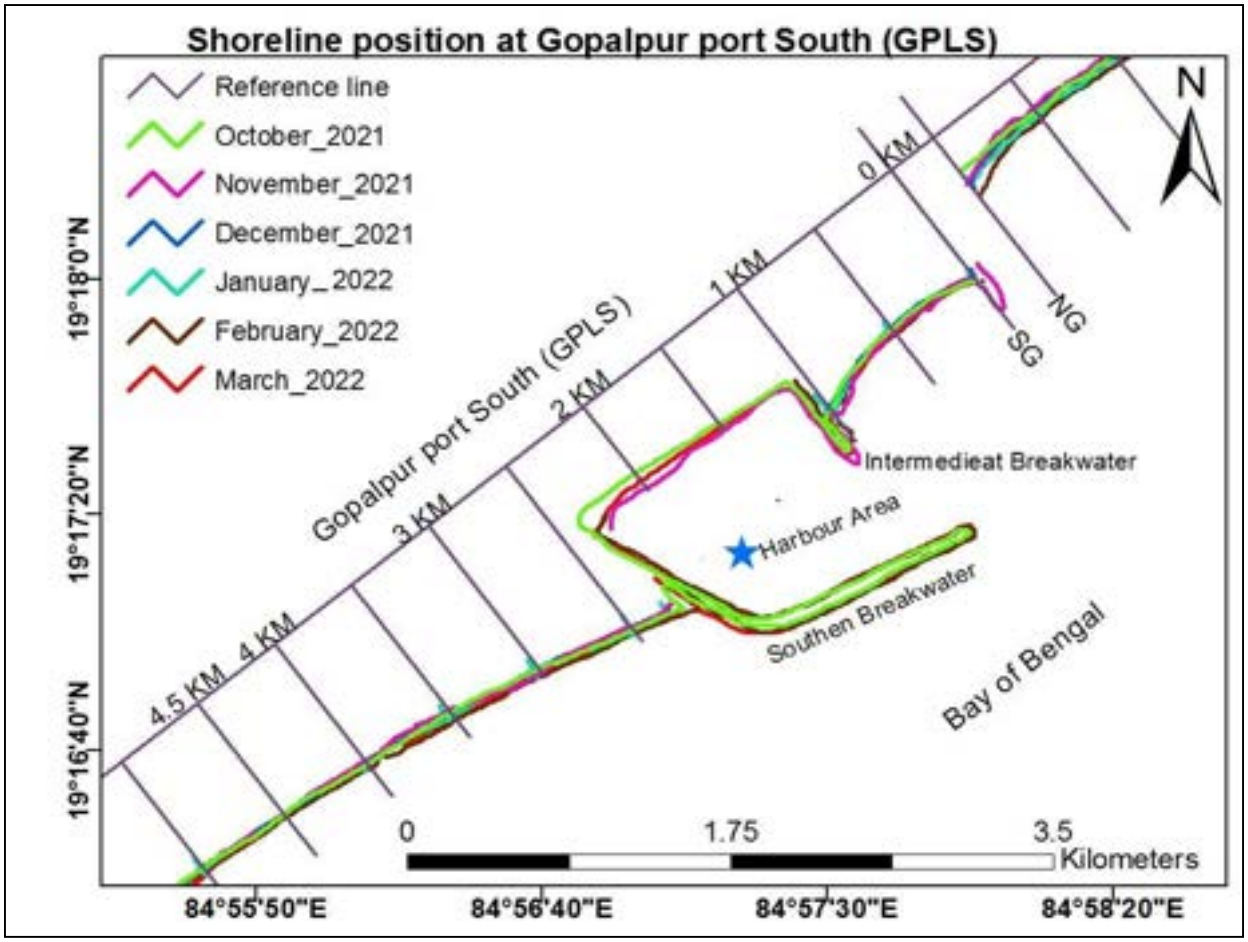


Figure 3.1: Shoreline position near Gopalpur Port South during October, 2021 to March, 2022

Maximum length of shoreline at 2.5 Km represents the fully developed beach at south of southern breakwater. However, minimum length in shoreline near 0.5 km south of SG could be due to scouring effect.

Table 3.1: Shoreline (m) analysis along Gopalpur Port South (Shoreline represents the distance in meter between berm line and the reference line in Fig. 3.1) from October, 2021 to March, 2022.

GPLS	SG 0km	0.5 km	1.0 km	2.5 km	3.0 km	3.5 km	4.0 km	4.5 km	Mean	STD
OCT_21	727.9	656.8	790.0	1068.9	942.0	838.1	784.7	735.5	818.0	131.76
NOV_21	745.1	670.1	818.7	1057.8	936.2	826.0	771.7	724.0	818.7	125.20
DEC_21	707.1	652.4	783.5	1052.5	933.1	839.9	774.8	727.3	808.8	130.42
JAN_22	716.3	653.0	834.3	1078.3	941.8	859.7	775.6	732.4	823.9	137.05
FEB_22	723.5	665.4	817.9	1091.8	978.5	880.8	808.1	748.1	839.3	140.53
MAR_22	701.0	666.5	814.1	1082.8	964.5	861.4	780.4	730.3	825.1	140.81
Min	700.99	652.40	783.46	1052.49	933.11	825.96	771.68	723.98	--	--
Max	745.07	670.06	834.25	1091.80	978.49	880.76	808.09	748.14	--	--
Mean	720.14	660.70	809.73	1072.01	949.35	850.97	782.53	732.94	--	--
STD	15.78	7.57	19.21	15.10	18.02	19.92	13.33	8.45	--	--
Net Change	-26.95	9.68	24.03	13.87	22.46	23.23	-4.29	-5.17	--	--

3.1.2 Gopalpur Port North

Shoreline position from October, 2021 to March, 2022 at Gopalpur Port north beach is shown in Figure 3.2 and Table-3.2. It is observed that shoreline of port north beach moved seaward at 100% of the total transects indicating accretion. Maximum seaward movement of shoreline is observed at 0 Km (127.4 m) north of NG followed by at 2.5 km north of the NG. Temporal mean shoreline is observed maximum at 4.5 Km (386.4 m) followed by at 4.0 Km while minimum is observed at 0.5 Km (227.1 m). Standard deviation of shoreline position is maximum at 0 Km (44.8m) followed by at 2.0 Km and minimum at 1.5 Km (19.5 m) indicating dynamic and stable nature of shoreline at those respective transects. Similarly, spatial mean of shoreline position is maximum and minimum during February, 2022 and November, 2021 respectively.

However, spatial variability of shoreline position is observed maximum during December, 2021 and minimum during November, 2021. Low standard deviation and higher mean width of shoreline from January to March, 2022 suggests the impact of low wave energy.

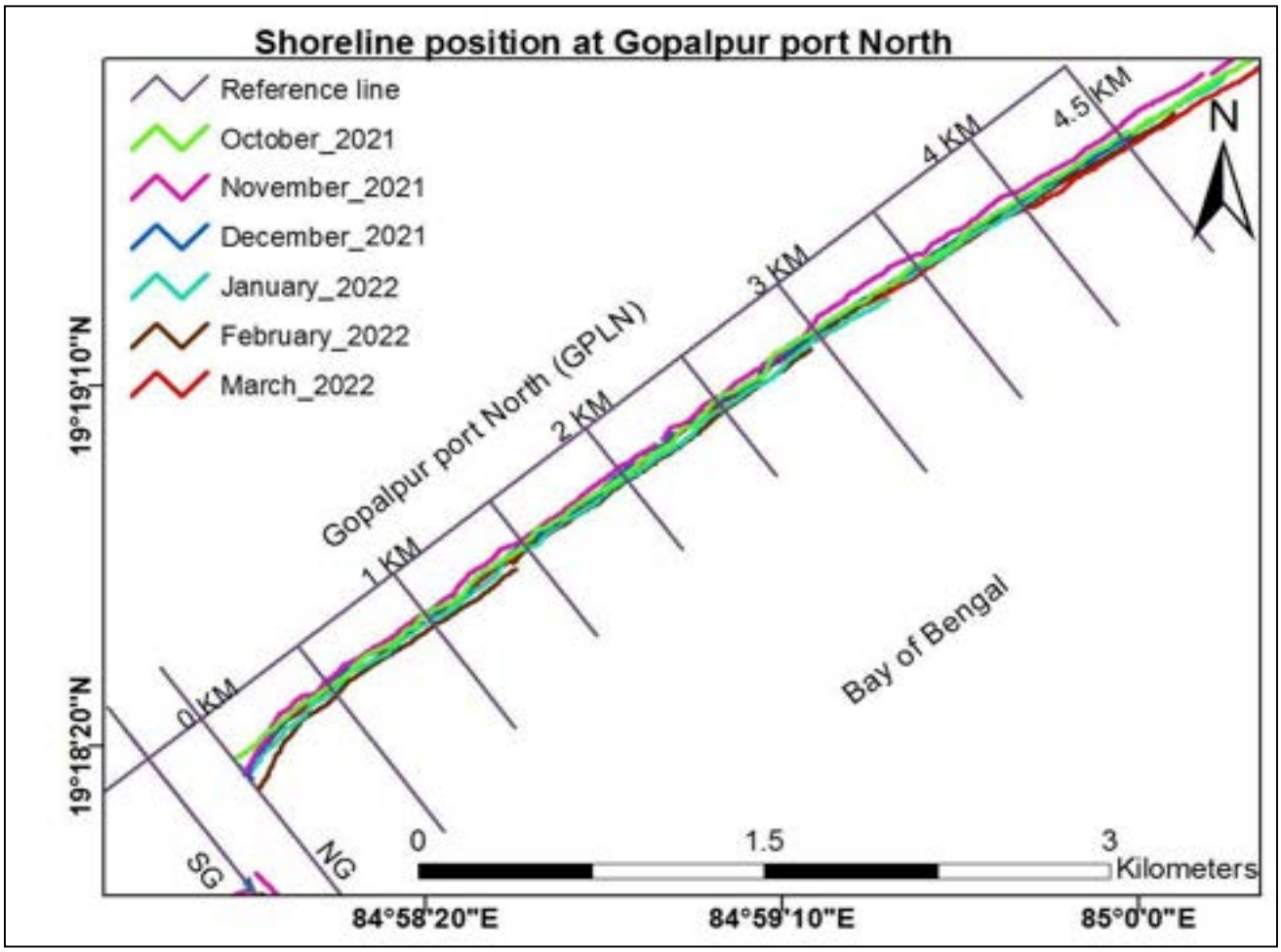


Figure 3.2: Shoreline position near Gopalpur Port North during October, 2021 to March, 2022.

Table 3.2: Shoreline (m) analysis along Gopalpur port North (Shoreline represents the distance in meter between berm line and the reference line in Fig. 3.2) from October, 2021 to March, 2022.

3.1.3 Gopalpur Tourist Beach

Shoreline positions during October, 2021 to March, 2022 are observed for Gopalpur tourist beach and details of shoreline are presented in Figure 3.3 and Table-3.3. Observation is carried out from light house (0 Km) to north of Haripur creek covering a 3 Km of coastal stretch. Because of mining activity of IREL, stretches of Gopalpur beach located north of Haripur creek (i.e. shoreline from 2km to 3km) is very wide compared to beach between LH and 1.5km, which is bounded by coastal constructional features and is popularly known as the tourist beach. Shoreline of the tourist beach during the period of observation has consistently progressed seaward at all transects from 1.5 km to 3.0 km while to the south of Haripur creek, negative change in shoreline is experienced. Maximum sea movement of shoreline is experienced at 2.5 Km located north of Haripur creek while minimum landward movement of shoreline is observed at 0 Km in front of LH. Temporal standard deviation of shoreline found maximum at 1.5 Km and minimum at 0 Km indicating higher and lower rate of shoreline oscillation at these respective transects. Significant enhancement of shoreline length at 2.0 Km followed by 2.5 Km could be attributed to Haripur creek which remains closed during winter season and helps to develop the beach which suggests the dynamic nature of the beach as compared to the other zones. Spatial

GPLN	NG 0km	0.5 km	1.0 km	1.5 km	2.0 km	2.5 km	3.0 km	3.5 km	4.0 km	4.5 km	Mean width	STD
OCT_21	224.1	220.6	218.2	237.3	256.3	234.9	255.0	290.8	329.9	372.1	218.2	51.66
NOV_21	294.5	200.1	212.6	224.9	229.1	226.5	232.7	247.4	293.6	341.4	200.1	44.78
DEC_21	301.3	204.5	220.0	230.7	240.8	246.6	260.9	290.6	338.2	390.3	204.5	58.01
JAN_22	317.3	240.1	251.6	253.8	271.1	282.1	281.7	316.0	358.0	397.2	240.1	50.35
FEB_22	337.3	263.1	278.8	278.1	308.5	292.3	297.8	331.4	365.1	414.5	263.1	46.40
MAR_22	351.5	234.2	240.1	253.8	284.7	267.1	268.7	306.6	353.7	402.9	234.2	56.16
Min	224.1	200.1	212.6	224.9	229.1	226.5	232.7	247.4	293.6	341.4	--	--
Max	351.5	263.1	278.8	278.1	308.5	292.3	297.8	331.4	365.1	414.5	--	--
Mean	304.3	227.1	236.9	246.4	265.1	258.3	266.1	297.1	339.7	386.4	--	--
STD	44.8	23.6	25.3	19.5	29.2	26.4	22.5	28.9	26.1	26.2	--	--
Net Change	127.4	13.7	22.0	16.5	28.5	32.2	13.7	15.8	23.8	30.9	--	--

Standard deviation of shoreline is observed maximum during February, 2022 and minimum during October, 2021 indicating higher shoreline variability during initial stage of pre-monsoon compared to during the north east monsoon period. The results of the present study at Gopalpur tourist beach indicates accretional and developed beach.

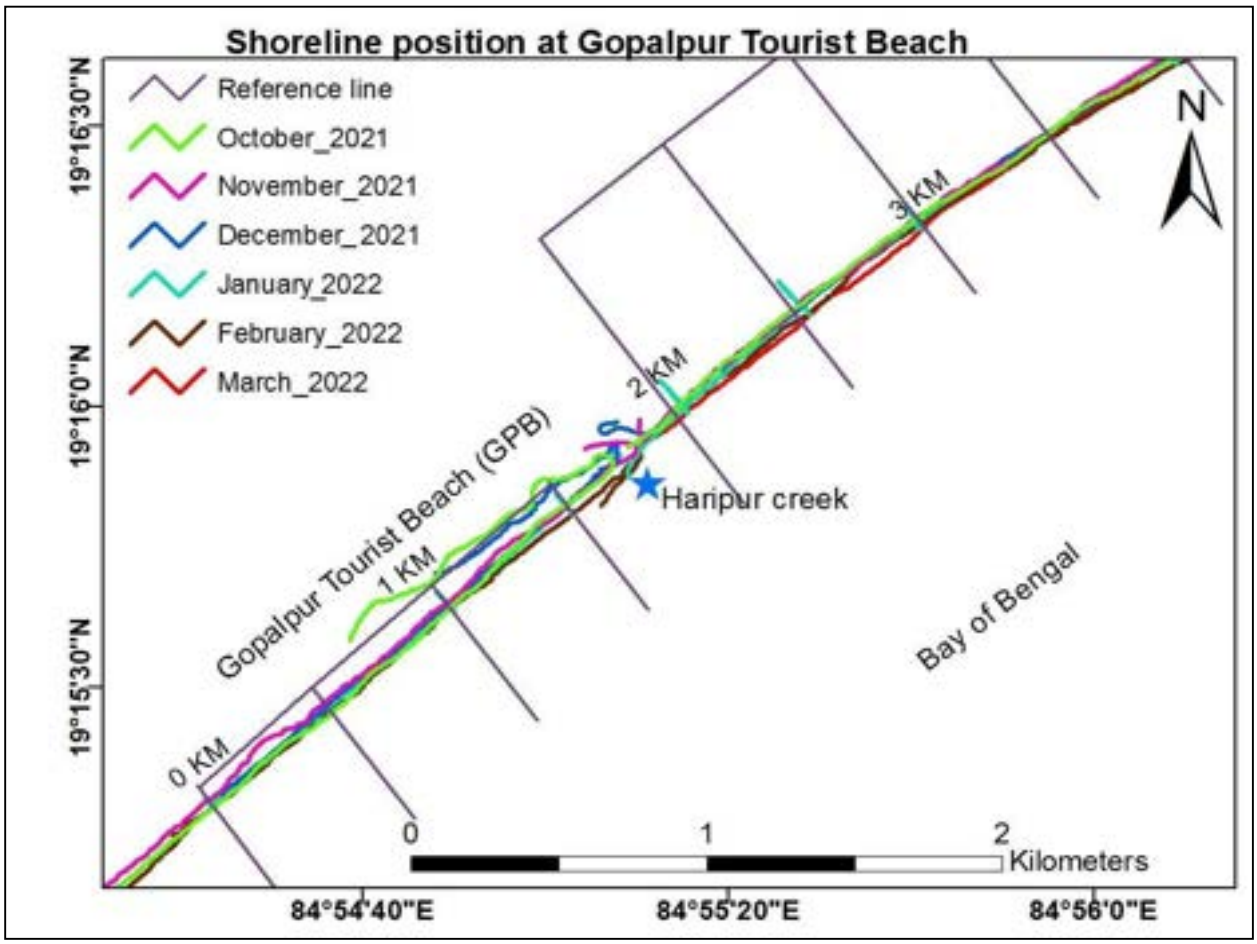


Figure 3.3: Shoreline position at Gopalpur Tourist Beach during October, 2021 to March, 2022.

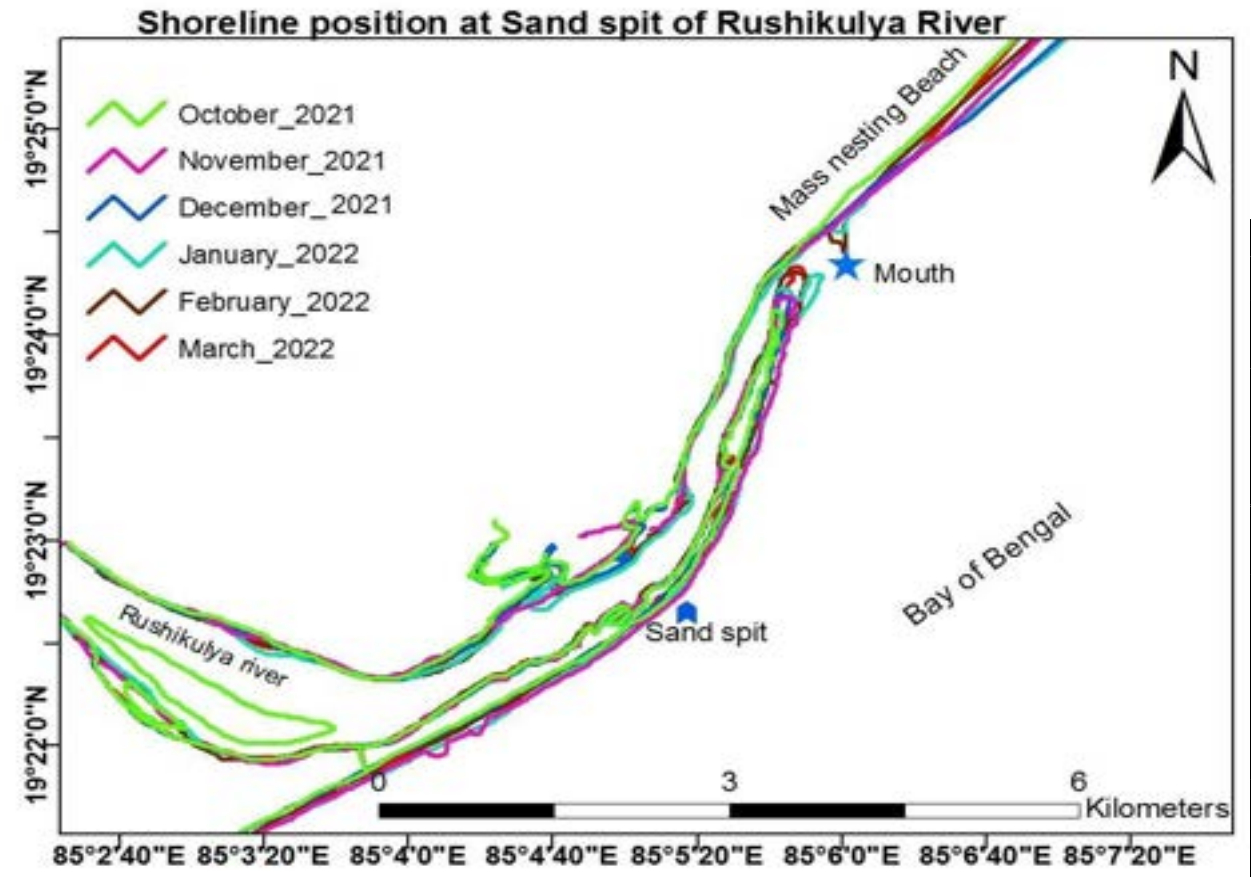
Table 3.3: Shoreline analysis along Gopalpur Tourist Beach (Shoreline represents the distance in meter between berm line and the reference line in Fig. 3.3) during October, 2021 to March, 2022.

GPB	LH 0km	0.5 km	1.0 km	1.5 km	2.0 km	2.5 km	3.0 km	Mean width	STD
OCT_21	89.8	91.8	101.8	89.3	715.0	685.9	692.7	352.30	323.36
NOV_21	78.7	80.6	84.6	94.6	705.9	691.5	697.7	347.65	328.12
DEC_21	75.8	83.5	82.8	81.2	703.1	694.7	697.9	345.58	330.20
JAN_22	75.07	85.78	94.88	89.62	724.87	700.83	702.23	353.33	333.14
FEB_22	77.7	97.1	95.5	117.1	734.6	714.6	712.1	364.08	333.59
MAR_22	76.6	88.0	100.51	113.66	728.4	716.0	706.0	361.32	332.80
Min	75.07	80.60	82.80	81.23	703.13	685.91	692.65	--	--
Max	89.76	97.07	101.77	117.06	734.58	715.99	712.09	--	--
Mean width	78.94	87.80	93.34	97.58	718.65	700.58	701.42	--	--
STD	5.46	5.94	7.96	14.47	12.69	12.38	6.92	--	--
Net Change	-13.16	-3.85	-1.26	24.39	13.49	30.08	13.39	--	--

3.1.4 Rushikulya River Mouth

Table-3.4 and Figure 3.4 depict shoreline positions of sand spit near the Rushikulya mouth from October, 2021 to March, 2022. The sand spit located south of the river mouth shows intermittent change in its dimension between the study period. Length of sand spit does not vary much during the study period. Length of the spit is found maximum during January, 2022. Similarly, perimeter of the sand spit found maximum during January, 2022 (13.5 Km) followed by March, 2022 indicates the northward growth is maximum during that period. The net change in surface area, perimeter and length of the sand spit during March, 2022 is positive compared to its dimension during October, 2021. However, the gain in area, perimeter and length of sand spit could be attributed to the impact of north east monsoonal wave and weak river discharge. The results show that shoreline oscillation at the nesting beach, located north of the river mouth, is mostly seaward while at some locations it remained unchanged. The change in shoreline position at the nesting beach is mostly controlled by the northward growth of the sand spit.

Table 3.4: Area, perimeter and length of sand spit near Rushikulya mouth during October, 2021 to March, 2022.



STD	0.23	0.38	0.25
Net change	0.19	0.52	0.42

Figure 3.4: Shoreline position near Rushikulya River mouth from October, 2021 to March, 2022.

3.2 Beach Profile

3.2.1 Gopalpur Port South

Beach profiles are observed every month at 500m interval using Total Station along different stretches of the beach. Profiles for the Port south beach are taken from SG (0km) to 4.5 Km south covering 10 transects. However, profiles at GPLS_4 and GPLS_5 could not be taken as the berth is being developed in these areas. Beach profiles for the eight transects (GPLS_1-GPLS_3 and GPLS_6-GPLS_10) are presented (Figure 3.5) for the period from October, 2021 to March, 2022. Distinct gain in beach volume and width are observed at most of transects. The change in beach width and volume between transects GPLS_2, GPLS_6 and GPLS_10 are relatively

higher compared to other transects. Beach volume and width have increased substantially with respect to October, 2021. Positive change in volume is observed at midshore, foreshore and very less change in the backshore (Figure 3.5). Beach profiles on port south indicate wide and flat beach. Stable berm and trough/ridge are present on the midshore region. Berm oscillation is distinct at GPLS_2, 3 & 10 while at rest of the transects its oscillation is moderate. Cross shore variation of beach profile shows relatively higher elevation at backshore compared to midshore and forshore region. The slope of transects are gentle at most of the profiles, while it is steep at GPLS_1, 2 and 9. The gain in beach width and volume at most of the transects are higher in port south beach due to accretion of sediment caused by low wave energy.

3.2.2 Gopalpur Port North

Profiles for the Port North beach are taken from NG (0km) to 4.5 km north at 500m interval covering 10 transects (GPLN_1 to GPLN_10 shown in Fig. 3.6) from October, 2021 to March, 2022. The beach at north of the port is mostly backed by high coastal sand dunes. Beach width and volume of the port north beach are much wider and elevated during month of February and March, 2022 compared to other months particularly at GPLN_2, GPLN_4 and GPLN_8 and GPLN_9 because of beach nourishment by Port authority. Distinct variation in beach profile is visible in the midshore/foreshore region compared to the backshore. Due to dredging of sand material and its disposal on the port north beach, profiles at north beach are gentle while it is relatively steeper at midshore of GPLN_1, GPLN_3 and GPLN_4. However, rest of the profiles at north is of gentle having moderate slope and visible berms. Significant gain in beach width and volume at most of the transects at Gopalpur port north is observed during January and February, 2022 as compared to previous observations. GPLN_5 is the only zone having beach width more than 200 m for all profiles while GPLN_9 and GPLN_10 is the zone having beach width less than 100 m for all profiles during the period of observation.

3.2.3 Gopalpur Tourist Beach

Profiles for the Gopalpur tourist beach are taken from the light house (LH) to 3km north covering 7 transects (GPB_1 to GPB_7). Beach profiles at these transects are observed from October, 2021 to March, 2022 and presented in Figure 3.7. Width of beach near GPB_1 is very narrow as vegetation line fall at close proximity to coastal constructional features while it is relatively wide towards north direction. The wider beach towards north of light house is backed

by extended coastal sand dunes. Some of the beach profiles are gentle while others are either with steep slope or flat by nature. Some of the beach profiles are either gentle or having steep slope while profiles GPB_3 & 4 shows convex shape in its midshore region. Sharp cut in foreshore region is visible near transect GPB_4 while transect GPB_3 shows a convex type of beach profile. Profiles from GPB_5 to GPB_7 are flat and extended type because of sediment trapping by port southern breakwater. Highest length of the beach is experienced in the month of March, 2022 at all the transects except at GPB_1, 2 &7. Significant changes in profile is visible at midshore and foreshore region near the transect GPB_4, 5, 7 while subtle changes are observed at other transects. Dimension of beach profile significantly enhanced during either Febru or March, 2022 due to prevalence of low energy ocean waves during north-east monsoon. Prominent signature of bermline is visible at all transects except at GPB_1, 4 & 5. Steep slope at backshore is evident at GPB_5 & 7 while steep slope at midshore is evident at GPB_2,3 & 4. Long shore sediment transport process plays a key role in changing foreshore region at tourist beach of Gopalpur. Geomorphology of all transects indicates that variability of profile is more at transects all the transects except at GPB_1, which could be due to prevalence of oceanographic processes.

Overall analysis of beach profile indicates gain in beach width and volume mostly at all the sectors except in few stretches of coastline. The variability of beach profile is relatively higher at Gopalpur tourist beach compared to port south beach and port north beach. The positive development of beach profile at north of Gopalpur port is mainly due to nourishment activity of Gopalpur port while development in beach environment at Port south beach and Gopalpur tourist beach are due to trapping of longshore sediment by southern breakwater.

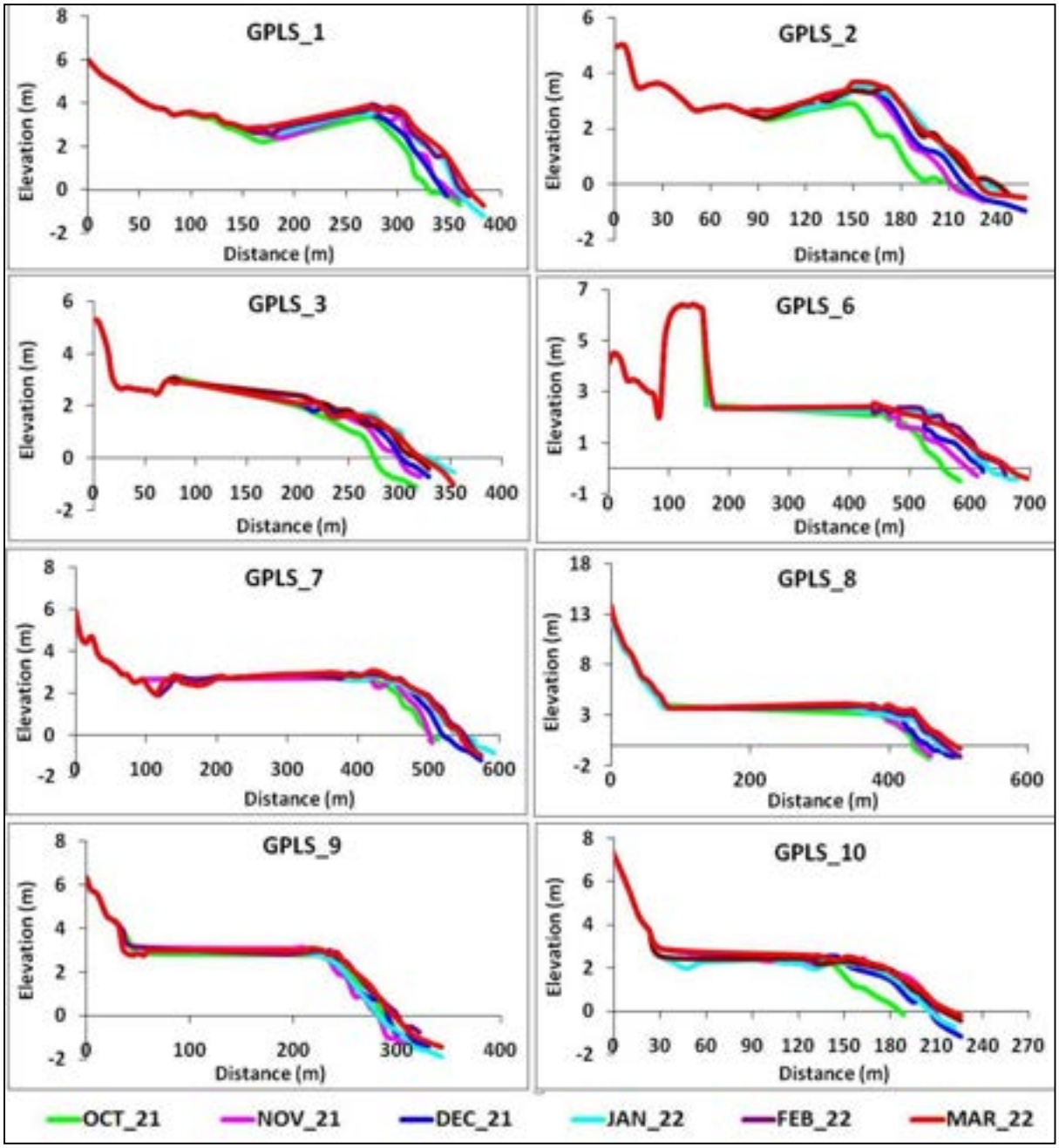


Figure 3.5: Beach Profiles (GPLS_1-GPLS_10) at Gopalpur port south during October, 2021 to March, 2022.

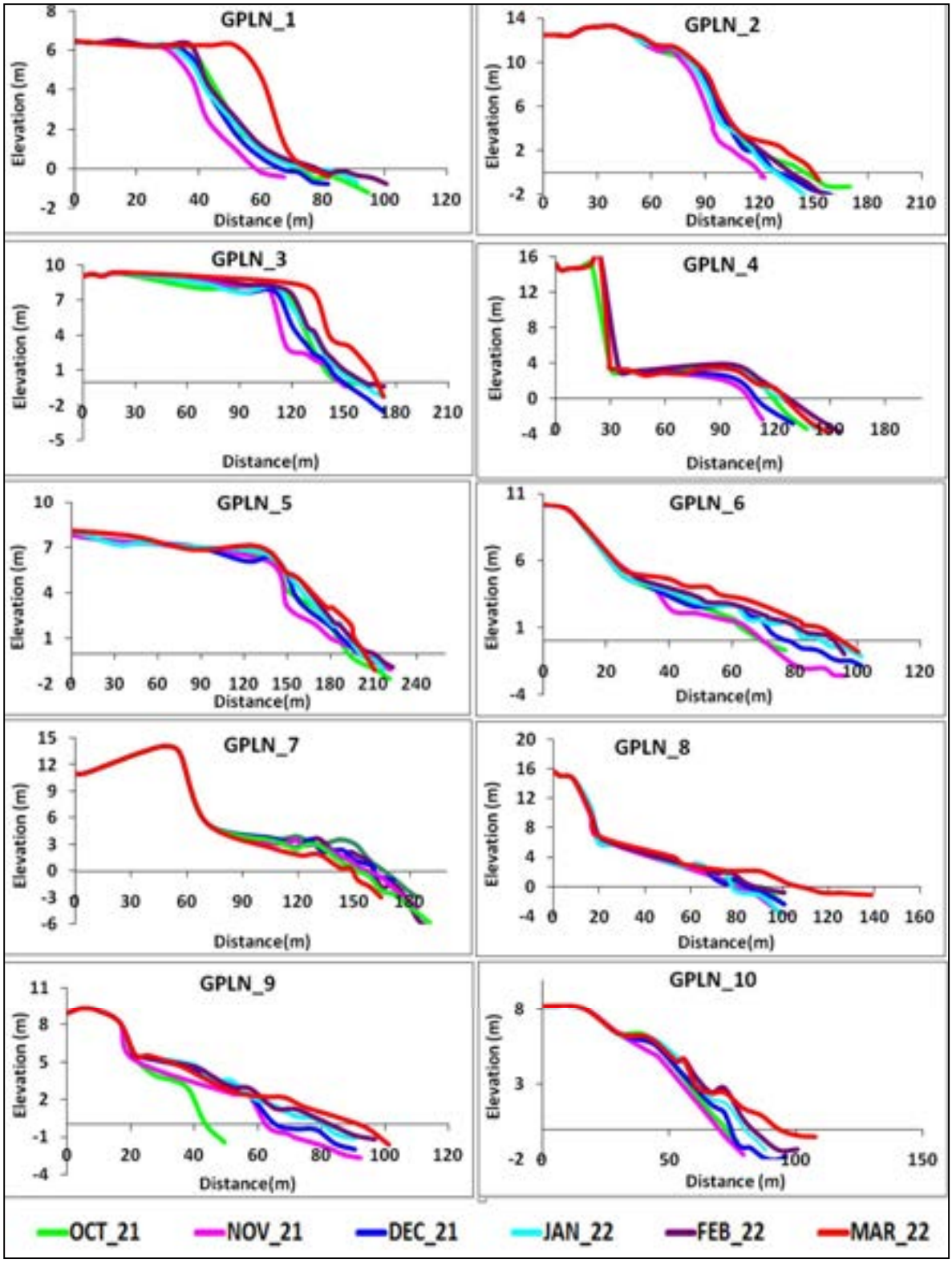


Figure 3.6: Beach Profiles (GPLN_1-GPLN_10) at Gopalpur port north during October, 2021 to March, 2022.

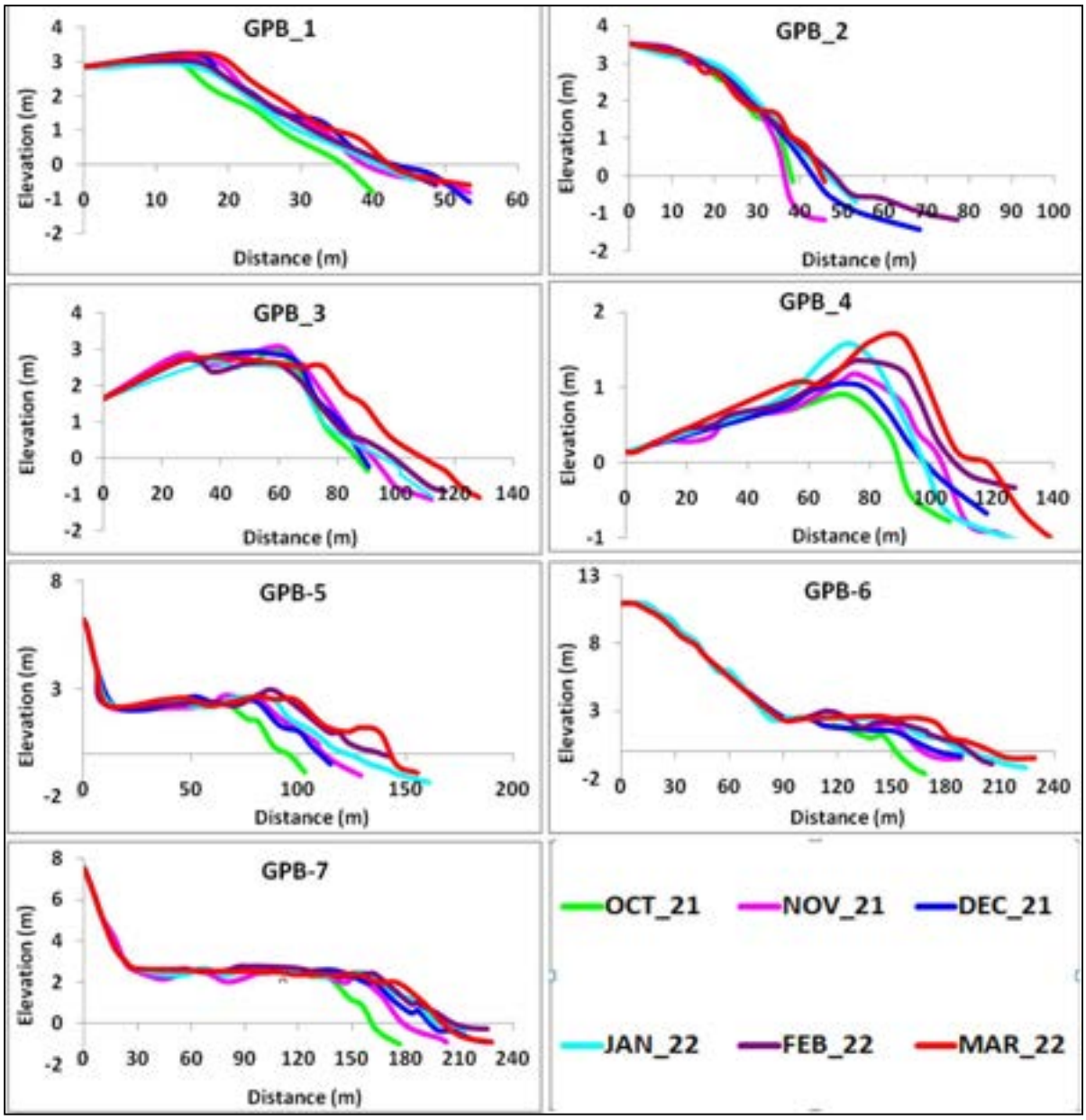


Figure 3.7: Beach profiles (GPB_1-GPB_7) along Gopalpur Tourist Beach during October, 2021 to March, 2022.

3.3 Erosion-Accretion Environment

Based on beach profile data, beach width and volume changes are estimated using Beach Morphology Analysis Package (BMAP) version 2.0 developed by U.S. Army Corps of Engineers. Erosion-accretion environment along the coastal environment from Gopalpur tourist beach to port north beach is discussed in the following section.

3.3.1 Gopalpur Port South

Table-3.5 represents beach width and volume during October, 2021 to March, 2022 along with their other statistical parameters for Gopalpur port south beach, while Figure 3.8 depicts change in beach width and volume with respect to October, 2021. It is observed that temporal mean beach width near each transects varies from 207.3 to 620.4 m with maximum and minimum width observed at transects GPLS_6 and GPLS_10 respectively. Similarly, standard deviation of beach width at transects varies from 7.6 to 39.6 m with maximum and minimum values at GPLS_6 and GPLS_9 respectively. The maximum and minimum value of standard deviation indicates prevalence of frequent and moderate change of beach width at these respective transects. It is noticed that net change in beach width at each transects experienced seaward shifting consistently indicating prevalence of low wave energy impact. The net change in beach width varies from 9.3 to 108.0 m with maximum and minimum seaward movement observed at GPLS_6 and GPLS_9 respectively. Spatial mean of beach width varies from 348.1 to 392.1 m with maximum and minimum values during March, 2022 and October, 2021 respectively. Similarly, standard deviation of beach width varies from 136.1 to 159.5 m with maximum and minimum values during March, 2022 and October, 2021 indicating periods of high and low variability of beach width near the Gopalpur port south beach. Low wave energy helps consistent enhancement of beach width at port south leads the accretional environment.

Temporal mean of beach volume varies from 527.1 to 1926.7 m^3/m with maximum and minimum values at transects GPLS_8 and GPLS_10 respectively. Temporal standard deviation of beach volume during observation periods varies from 24.6 to 105.5 m^3/m with maximum and minimum values at GPLS_8 and GPLS_9 respectively. During the observation period, net change in beach volume are positive at all transects with maximum positive change at GPLS_8 followed by GPLS_6. Net change in beach volume varies from 42.2 to 287 m^3/m with maximum and minimum values at GPLS_8 and GPLS_9 respectively. Spatial mean of beach volume is observed maximum (1170.3 m^3/m) and minimum (1025.8 m^3/m) during March, 2022 and October, 2021 respectively. Standard deviation of beach volume at each transects varies from 495.8 to 561 m^3/m with maximum and minimum values during March, 2022 and October, 2021 respectively. The gain in beach volume and width at port south indicates accretion environment during observation periods due to prevalence low energy monsoonal ocean waves.

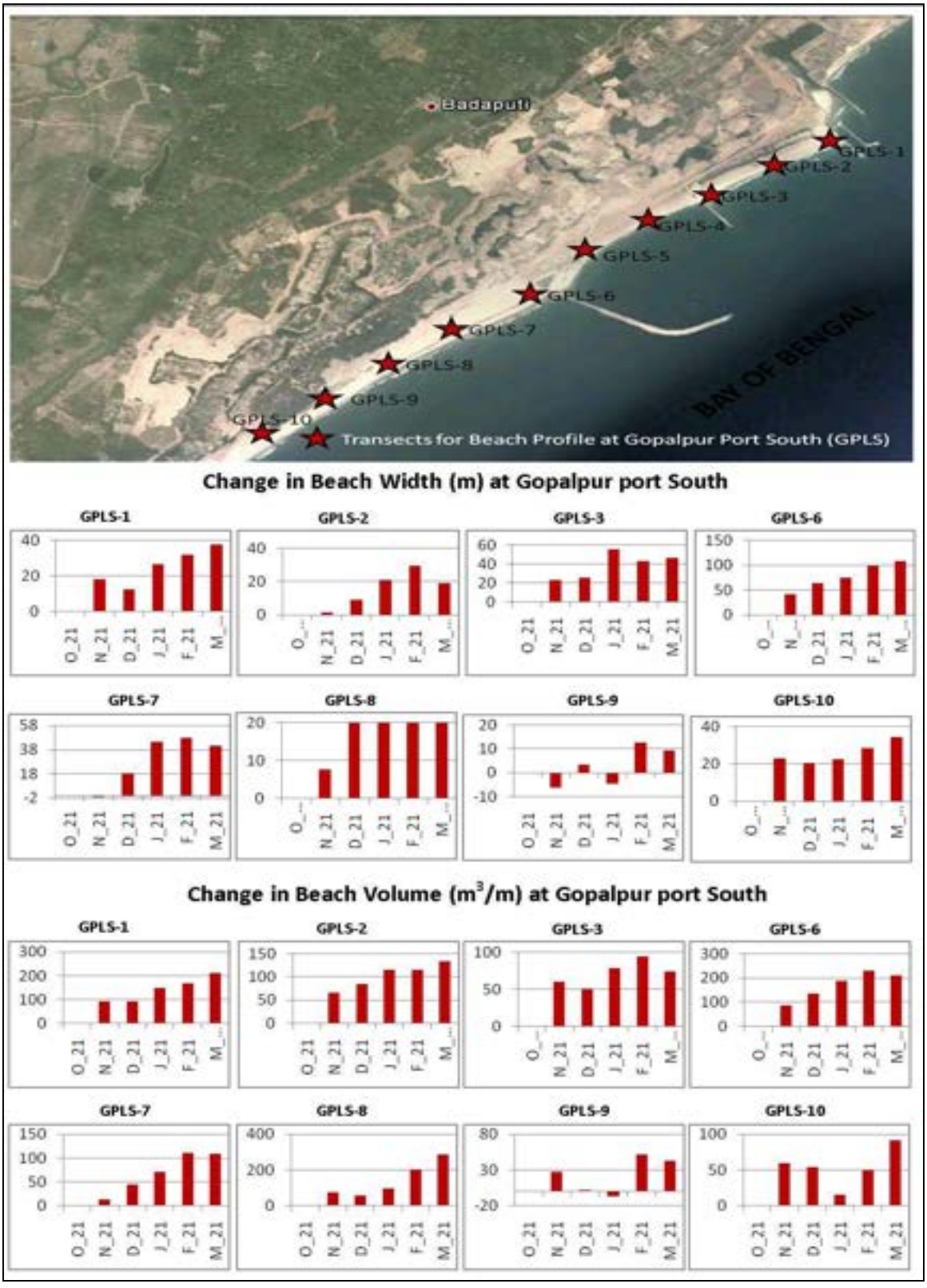


Figure 3.8: Beach width and volume change from October, 2021 to March, 2022 at different locations along Gopalpur Port South with reference to October, 2021.

Table 3.5: Beach width and beach volume statistics along Gopalpur port South during October, 2021 to March, 2022.

Month	GPLS_1	GPLS_2	GPLS_3	GPLS_6	GPLS_7	GPLS_8	GPLS_9	GPLS_10	Mean	STD
Beach Width (m)										
OCT_21	331.0	210.0	275.1	556.3	502.4	436.3	287.2	186.1	348.1	136.1
NOV_21	349.0	211.6	298.5	597.5	500.9	444.1	281.1	208.8	361.4	140.6
DEC_21	343.3	219.2	301.3	618.8	520.6	456.9	290.7	206.2	369.6	148.1
JAN_22	357.5	231.1	330.7	631.3	546.9	473.7	282.5	208.2	382.7	153.0
FEB_22	363.0	239.5	318.6	654.3	549.8	480.4	300.0	214.3	390.0	156.3
MAR_22	368.7	229.0	321.9	664.3	543.4	493.8	296.5	220.1	392.2	159.5
Min	331.0	210.0	275.1	556.3	500.9	436.3	281.1	186.1		
Max	368.7	239.5	330.7	664.3	549.8	493.8	300.0	220.1		
Mean	352.1	223.4	307.7	620.4	527.3	464.2	289.7	207.3		
STD	13.8	11.7	20.2	39.6	22.4	22.2	7.6	11.6		
Net Change	37.8	19.0	46.8	108.0	41.0	57.4	9.3	34.1		
Beach Volume (m^3/m)									**Mean**	**STD**
OCT_21	1032.5	519.5	649.0	1541.1	1355.0	1807.1	820.1	482.1	1025.8	495.8
NOV_21	1122.4	584.8	709.5	1629.4	1367.7	1883.2	847.5	542.0	1085.8	501.0
DEC_21	1122.7	602.4	699.1	1678.5	1400.2	1864.2	821.8	535.9	1090.6	508.9
JAN_22	1179.63	634.4	726.9	1729.845	1426.7	1901.8	812.8	497.2	1113.6	528.2
FEB_22	1200.7	634.1	742.4	1773.4	1465.3	2009.8	871.7	531.5	1153.6	550.6
MAR_22	1242.3	651.7	722.3	1751.6	1463.9	2094.1	862.4	573.7	1170.3	561.0
Min	1032.5	519.5	649.0	1541.1	1355.0	1807.1	812.8	482.1		
Max	1242.3	651.7	742.4	1773.4	1465.3	2094.1	871.7	573.7		
Mean	1150.1	604.5	708.2	1684.0	1413.1	1926.7	839.4	527.1		
STD	73.9	48.2	32.6	87.3	47.1	105.5	24.6	32.9		
Net Change	209.8	132.3	73.3	210.5	109.0	287.0	42.2	91.6		

3.3.2 Gopalpur Port North

Table-3.6 represents the beach width and volume during October, 2021 to March, 2022 for Gopalpur port north beach and their statistical analysis. Beach width and volume are analyzed on space and time scales to understand the erosion/accretion environment. It is observed that temporal mean at each transects varies from 71.2 to 200.9 m with maximum and minimum values at transects GPLN_5 and GPLN_9 respectively. The standard deviation of beach width varies from 5.4 to 17.2 m with maximum and minimum values at GPLN_5 and GPLN_9 respectively. Net change in beach width depicts positive change indicating seaward shifting of beach width at all transects predominantly. The maximum and minimum values of net change in

beach width were observed at GPLN_5 and GPLN_8 respectively. Analysis of beach width shows seaward movement of beach environment at all transects with higher order of accretion near the transects GPLN_5 followed by GPLN_2 compared to other transects. Spatial mean of beach width varies from 103 to 127.8 m with maximum and minimum values observed during March, 2022 and November, 2021. The standard deviation of beach width varies from 41.9 to 47 m with peak value during the month of October, 2021. Beach width analysis shows seaward movement of beach width at entire stretches of port north beach.

During the observation period, temporal mean of beach volume varies from 318.9 to 1219.9 m^3/m with maximum and minimum values observed at GPLN_2 and GLPN_1 respectively. Standard deviation of beach volume observed maximum at GPLN_3 and minimum value at GPLN_10. Net change in beach volume varies from -9.8 to 116.3 m^3/m indicating higher rates of sediment erosion at GPLN_1. The gain in volume at this stretch could be due to low energy of wave. Maximum standard deviation of beach volume near the GPLN_5 indicates higher variability in beach volume compared to other transects. Similarly, spatial mean of beach volume varies from 660.2 to 786.4 m^3/m with maximum value observed during March, 2022 and minimum value observed during November, 2021. The standard deviation of beach volume shows maximum value of 408.6 m^3/m during March, 2022 and minimum of 358.5 m^3/m during November, 2021.

Minimum values of mean and standard deviation of beach volume represents less variability in beach volume during October, 2021 compared to March, 2022. The accretion at port north beach is mainly due to beach nourishment of the port associated with constructional features (i.e groyne field etc).

Table 3.6: Beach width and volume and their statistics during October, 2021 to March, 2022 along Gopalpur port North.

Month	GPLN_1	GPLN_2	GPLN_3	GPLN_4	GPLN_5	GPLN_6	GPLN_7	GPLN_8	GPLN_9	GPLN_10	Mean	STD
	Beach Width (m)											
OCT_21	72.1	145.1	154.1	118.5	193.0	69.6	124.6	84.1	43.7	72.3	107.7	47.0
NOV_21	58.7	120.0	147.9	102.9	199.2	70.3	119.5	79.4	62.8	69.7	103.0	44.9
DEC_21	66.9	130.9	149.6	109.1	200.0	78.1	131.9	84.2	66.1	74.4	109.1	43.8
JAN_22	74.5	128.8	157.0	122.5	200.5	88.8	141.0	78.2	80.6	79.9	115.2	42.3
FEB_22	78.5	137.1	161.7	127.1	209.5	92.4	141.1	88.5	82.8	83.3	120.2	43.1
MAR_22	77.7	149.5	168.9	125.3	203.3	94.9	165.8	107.7	91.4	93.4	127.8	41.9
Min	58.7	120.0	147.9	102.9	193.0	69.6	119.5	78.2	43.7	69.7	--	--
Max	78.5	149.5	168.9	127.1	209.5	94.9	165.8	107.7	91.4	93.4	--	--
Mean	71.4	135.2	156.5	117.6	200.9	82.3	137.3	87.0	71.2	78.8	--	--
STD	7.5	10.9	7.9	9.6	5.4	11.2	16.4	10.8	17.2	8.7	--	--
Net Change	20.5	29.8	20.9	6.0	35.3	13.6	21.6	3.0	7.9	7.2	--	--
	Beach Volume (m^3/m)										Mean	STD
OCT_21	319.2	1226.1	1097.9	646.1	1133.0	324.6	1016.4	459.9	255.2	398.7	687.7	388.2
NOV_21	268.2	1122.8	1050.9	622.0	1082.5	321.0	981.4	457.7	316.9	378.4	660.2	358.5
DEC_21	299.0	1213.7	1073.4	647.9	1150.5	344.6	1003.6	471.1	340.3	409.0	695.3	373.4
JAN_22	305.7	1201.5	1123.0	712.8	1193.8	362.3	1044.4	476.2	363.4	432.1	721.5	379.1
FEB_22	322.1	1257.7	1179.2	734.4	1240.4	386.4	1042.7	487.5	369.6	443.7	746.4	393.1
MAR_22	399.2	1297.4	1297.9	670.9	1256.6	425.7	1143.2	543.9	378.1	450.8	786.4	408.6
Min	268.2	1122.8	1050.9	622.0	1082.5	321.0	981.4	457.7	255.2	378.4	--	--
Max	399.2	1297.4	1297.9	734.4	1256.6	425.7	1143.2	543.9	378.1	450.8	--	--
Mean	318.9	1219.9	1137.1	672.4	1176.1	360.8	1038.6	482.7	337.2	418.8	--	--
STD	43.8	58.8	90.4	43.1	66.6	40.1	56.5	31.9	45.9	28.1	--	--
Net Change	-9.8	89.9	16.1	43.6	116.3	31.3	50.4	15.6	6.7	34.7	--	--

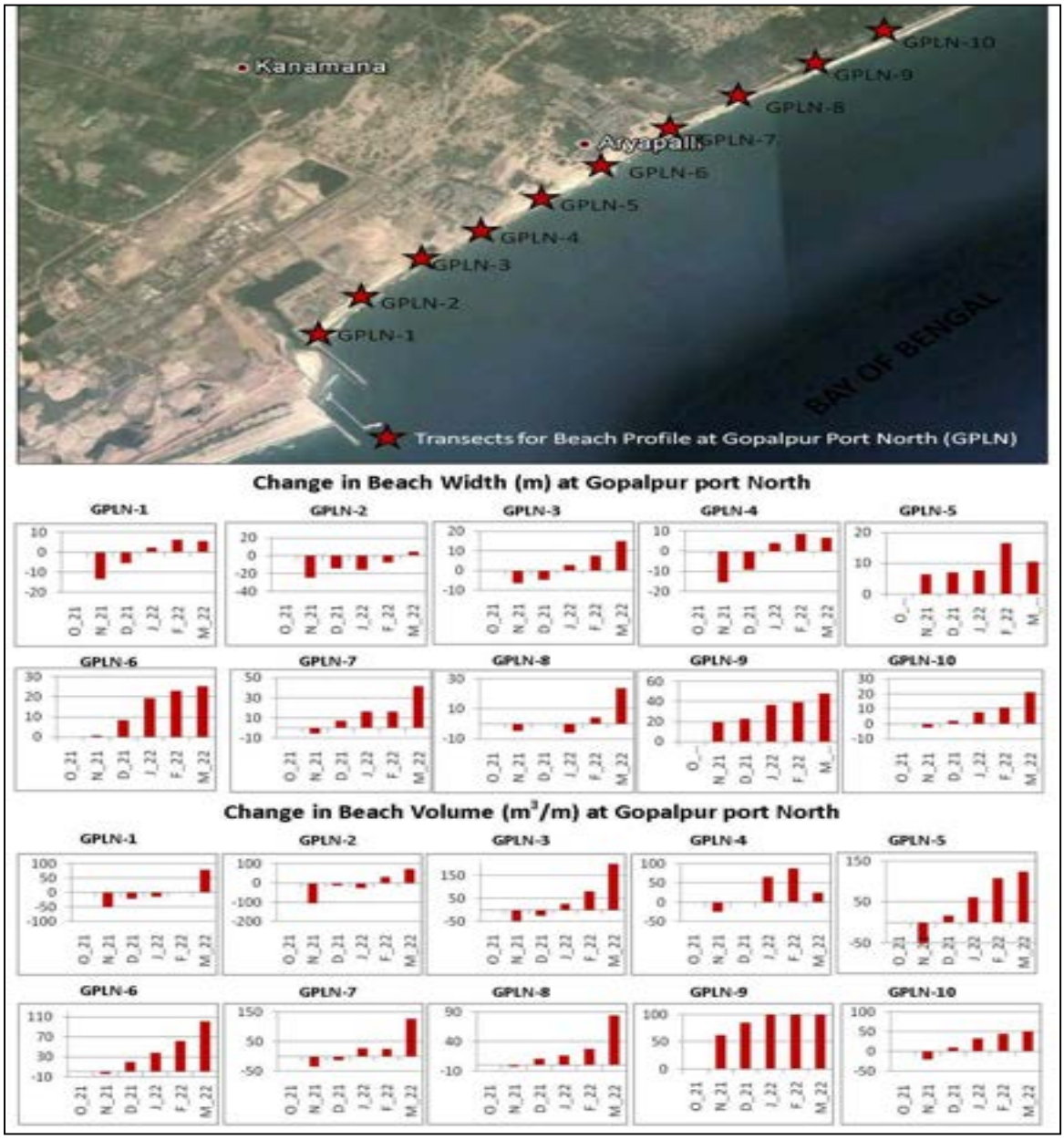


Figure 3.9: Beach width and volume change from October, 2021 to March, 2022 at different locations along Gopalpur Port North with reference to October, 2021.

3.3.3 Gopalpur Tourist Beach

Table-3.7 represents beach width and volume variability during October, 2021 to March, 2022 for Gopalpur tourist beach and its statistical analysis. It is observed that temporal mean of beach width varies from 40.6 to 190.9 m with maximum value at GPB_7 and minimum value at GPB_1. Standard deviation of beach width varies from 2.7 to 19.3 m with maximum value observed at GPB_6 and minimum value observed at GPB_1. Net change in beach width is constantly positive at all transects with maximum positive change observed at transect GPB_6 followed by GPB_5. Change in beach width during the period from October, 2021 to March, 2022

indicates the beach is dynamic to the north of Haripur creek (Table 3.7). Spatial mean of beach width varies from 94.1 to 123.5 m with maximum value observed during March, 2022 and minimum value observed during October, 2021. Standard deviation of beach width observed maximum during March, 2022 while minimum during October, 2021.

Temporal mean of beach volume varies from 70.1 to 821.5 m^3/m with maximum and minimum values near GPB_6 and GPB_4 respectively. Standard deviation of beach volume varies from 4.2 to 41.6 m^3/m with maximum and minimum values observed at GPB_6 and GPB_2 respectively. Net change in beach volume varies from a minimum of 7.2 m^3/m at GPB_2 to a maximum of 113.8 m^3/m observed at GPB_6. Predominantly positive change in beach volume indicates accretional trend during the period of observation. Accretion is more towards north of Haripur creek compared to Gopalpur tourist beach proper. Maximum and minimum values of standard deviation of beach volume indicates higher and lower variability in beach volume. Spatial mean of beach volume varies from 257.6 to 319 m^3/m with maximum and minimum value observed during March, 2022 and October, 2021 indicating accretion of sediments. Standard deviation of beach volume varies from 256.5 to 290.9 m^3/m with maximum and minimum value observed during March, 2022 and October, 2021 indicating higher and lower rate of variability in beach volume during the respective periods. At all the transects the result shows accretion with positive change in beach volume due to the less impact of wave energy.

Table 3.7: Beach width and volume statistics along Gopalpur Tourist Beach during October, 2021 to March, 2022.

Month	GPB_1	GPB_2	GPB_3	GPB_4	GPB_5	GPB_6	GPB_7	Mean	STD
Beach Width (m)									
OCT_21	35.8	38.0	86.5	89.3	95.2	152.4	161.5	94.1	49.3
NOV_21	39.4	36.4	92.0	103.3	112.2	167.9	179.3	104.3	55.8
DEC_21	42.9	43.2	98.1	98.2	109.7	174.8	194.1	108.7	58.5
JAN_22	40.9	46.8	95.5	97.6	123.0	189.4	202.8	113.7	63.4
FEB_22	42.5	48.0	99.3	108.3	131.0	193.5	206.7	118.5	64.3
MAR_22	42.4	45.2	109.4	118.0	143.0	205.5	201.0	123.5	65.9
MIN	35.8	36.4	86.5	89.3	95.2	152.4	161.5	--	--
MAX	42.9	48.0	109.4	118.0	143.0	205.5	206.7	--	--
MEAN	40.6	42.9	96.8	102.4	119.0	180.6	190.9	--	--
STDV	2.7	4.7	7.7	9.9	17.0	19.3	17.4	--	--
Net change	6.6	7.2	22.9	28.7	47.8	53.1	39.6	--	--
Beach Volume (m3/m)								Mean	STD
OCT_21	72.0	96.5	190.2	47.5	212.9	765.1	419.0	257.6	256.5
NOV_21	85.0	96.6	206.2	63.4	250.4	800.0	455.2	279.5	266.5
DEC_21	87.6	100.0	197.7	57.7	246.927	795.7	487.6	281.9	269.5
JAN_22	78.3	106.1	177.1	75.2	271.6	845.6	500.0	293.4	286.0
FEB_22	84.3	104.7	187.5	80.1	278.3	843.4	522.5	300.1	286.1
MAR_22	94.0	103.7	223.7	96.4	321.2	879.0	515.1	319.0	290.9
MIN	72.0	96.5	177.1	47.5	212.9	765.1	419.0	--	--
MAX	94.0	106.1	223.7	96.4	321.2	879.0	522.5	--	--
MEAN	83.5	101.3	197.1	70.1	263.5	821.5	483.3	--	--
STDV	7.6	4.2	16.3	17.5	36.4	41.6	39.4	--	--
Net change	21.9	7.2	33.6	48.9	108.3	113.8	96.1	--	--

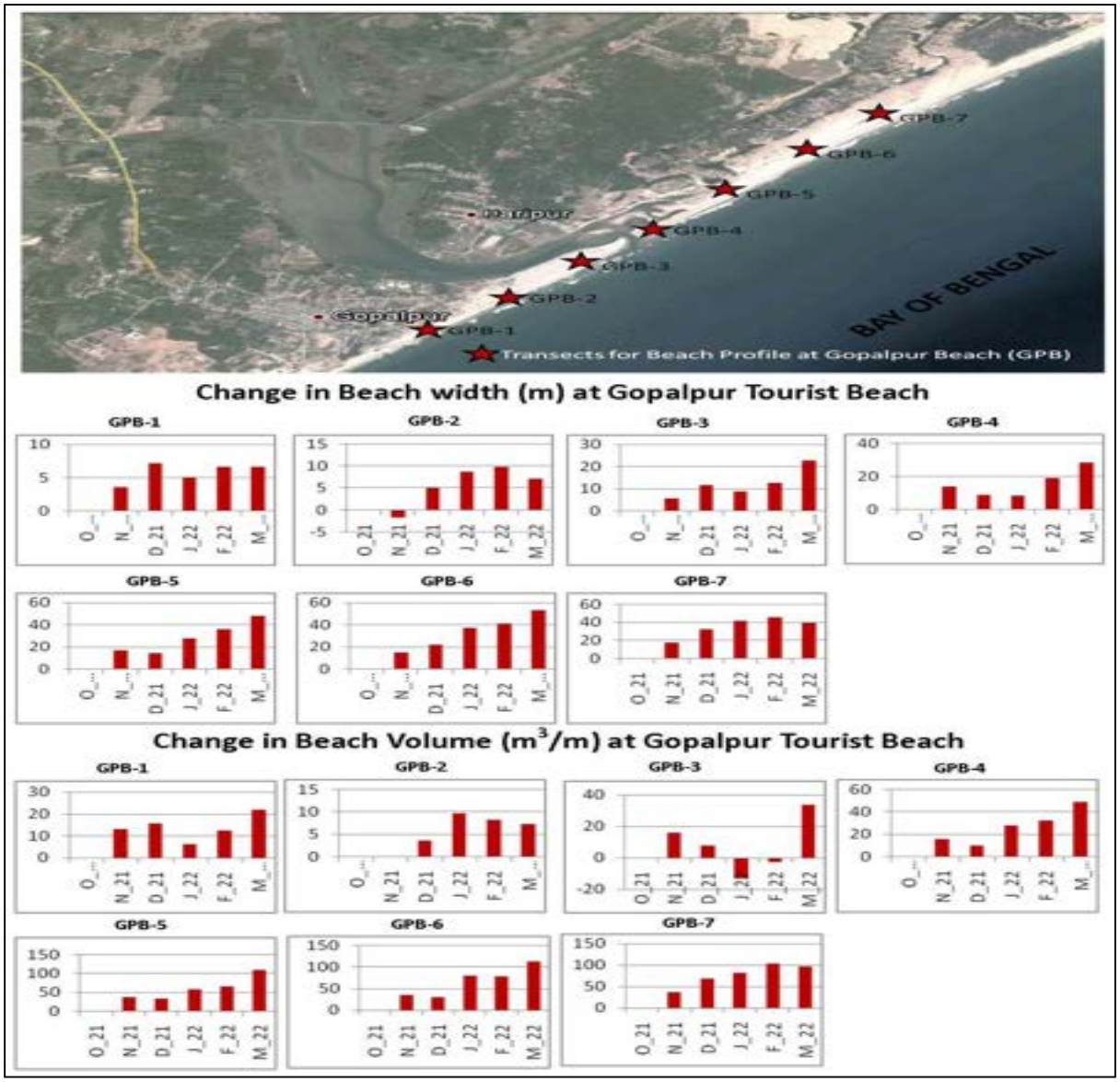


Figure 3.10: Beach width and volume change from October, 2021 to March, 2022 at different locations along Gopalpur Tourist Beach with reference to October, 2021.

3.4 Sediment Characteristics

Sediment characteristics (mean grain size, sorting, skewness and kurtosis) for four stations of Port South (GPLS_1, GPLS_3, GPLS_7 and GPLS_9) and five stations of Port north (GPLN_1, GPLN_3, GPLN_5, GPLN_7 and GPLN_9) beach are presented for the period from October, 2021 to March, 2022. Due to presence of berth, observation at GPLS_5 could not be taken. The distance between each sediment sampling station is maintained at 1km (Only GPLS_3 to GPLS_7 is 2km). Similarly, sediment characteristics for three stations (GPB_2, GPB_4 and GPB_6) of Gopalpur tourist beach and one station of Rushikulya sand spit are presented for the

study period. Sediment samples are collected at backshore (BS), midshore (MS) and foreshore (FS) in each representative transects and later analysed in the laboratory to determine their grain size and other statistical properties.

3.4.1 Gopalpur Port South

Table 3.8 depicts the sediment characteristics (mean, sorting, skewness and kurtosis) of Gopalpur port south beach from October, 2021 to March, 2022.

Table 3.8: Sediment characteristics (mean, sorting, skewness and kurtosis) of Gopalpur Port South beach (BS-back shore, MS-midshore, FS-foreshore)

	GPLS_1 (0 km)			GPLS_3 (1 km)			GPLS_7 (3 km)			GPLS_9 (4 km)		
	BS	MS	FS	BS	MS	FS	BS	MS	FS	BS	MS	FS
Oct_21	M	M	C	C	C	M	C	F	M	M	F	F
	MDS	MWS	MWS	MWS	MWS	MWS	MDS	MDS	MWS	MWS	MDS	MWS
	SYM	SYM	FSK	CSK	SYM	SYM	FSK	CSK	CSK	SYM	SYM	CSK
	MSK	MSK	MSK	PLK	PLK	PLK	PLK	LPK	MSK	LPK	LPK	LPK
Nov_21	M	M	M	M	F	F	F	F	M	M	M	M
	MWS	MWS	MDS	MWS	MDS	MWS	MWS	MWS	MDS	MDS	MWS	MDS
	CSK	SYM	SYM	SYM	SYM	SYM	CSK	SYM	SYM	FSK	SYM	CSK
	MSK	LPK	MSK	MSK	MSK	MSK	MSK	MSK	LPK	LPK	LPK	MSK
Dec_21	C	M	M	M	M	M	M	M	F	M	F	F
	MDS	MDS	MDS	MDS	MDS	MDS	MDS	MWS	MWS	MWS	MWS	WS
	FSK	CSK	CSK	SYM	SYM	CSK	FSK	SYM	SYM	CSK	SYM	SYM
	VPLK	MSK	LPK	PLK	PLK	LPK	LPK	LPK	MSK	LPK	MSK	VLPK
Jan_22	M	M	F	F	M	M	M	VF	C	F	F	F
	MWS	MWS	WS	WS	MWS	MWS	MDS	WS	MWS	MWS	WS	WS
	SYM	SYM	SYM	SYM	CSK	CSK	SYM	SYM	SYM	SYM	SYM	SYM
	LPK	MSK	MSK	MSK	MSK	LPK	LPK	MSK	PLK	MSK	MSK	MSK
Feb_22	M	F	F	M	F	F	F	F	F	M	F	F
	MWS	MWS	MDS	MWS	MWS	MWS	MWS	MWS	MWS	MDS	MWS	MWS
	SYM	CSK	CSK	SYM	SYM	CSK	SYM	SYM	CSK	SYM	SYM	SYM
	LPK	LPK	LPK	LPK	LPK	LPK	LPK	LPK	LPK	MSK	MSK	LPK
Mar_22	M	M	F	F	M	M	M	F	F	F	C	F
	MDS	MWS	MWS	MWS	MDS	MWS	MDS	MWS	WS	MWS	MDS	MWS
	SYM	FSK	SYM	SYM	CSK	SYM	SYM	SYM	SYM	SYM	VFSK	SYM
	LPK	MSK	MSK	LPK	MSK	LPK	MSK	LPK	MSK	MSK	MSK	MSK
Legends:	**Mean:**	**Fine Sand (F)**	**Medium Sand (M)**	**Coarse Sand (C)**	**Very Fine Sand (VF)**							
	Sorting:	**Well Sorted (WS)**	**Moderately Well Sorted (MWS)**	**Moderately Sorted (MDS)**	**Poorly Sorted (PS)**							
	Skewness: Symmetrical (SYM), Coarse Skewed (CSK), Fine Skewed (FSK), VCS-Very coarse skewed											
	Kurtosis:	**Platykurtic (PLK), Leptokurtic (LPK), Mesokurtic (MSK), Very Platykurtic (VPK)**										

The mean grain size of the south beach is mostly medium followed by fine sand while coarse sand is rare during the period from October, 2021 to March, 2022. Percentage distribution indicates, sediments are mostly medium (47.22%) and fine (43.1%). While sorting of the sediments show mostly moderately well sorted (58.33%) followed and moderately sorted (31.9%) and well sorted (9.7%). Most of the fine sands are confined at foreshore region of GPLS_7 during January to March, 2022 because of the sediment trap by southern breakwater. The occurrence of predominantly medium and moderately well sorted sediments at port south beach

could be due to addition of fine sediments associated with constructional features at port south beach. The medium and fine sediments and moderately well sorted are relatively more. Occurrence of fine and moderately well sorted sediments indicates accretion environment in port south beach. Skewness of the sediment indicates that the majority of the sediment samples are symmetrical (65.27%) followed by coarse skewed (25%) in nature. Similarly results of kurtosis of the sediment samples indicate mostly mesokurtic (45.83%) followed by leptokurtic (43.05%) in nature during October, 2021 to March, 2022.

3.4.2 Gopalpur Port North

Table 3.9 depicts the sediment characteristics (mean, sorting, skewness and kurtosis) of Gopalpur port north beach during the period from October, 2021 to March, 2022.

Table 3.9: Sediment (mean, sorting, skewness and kurtosis) analysis along Gopalpur Port North

	Gopalpur Port North														
	GPLN_1 (0 km)			GPLN_3 (1 km)			GPLN_5 (2 km)			GPLN_7 (3 km)			GPLN_9 (4 km)		
	BS	MS	FS	BS	MS	FS	BS	MS	FS	BS	MS	FS	BS	MS	FS
Oct _21	C	M	M	F	M	F	F	M	C	F	M	M	M	M	C
	MDS	MDS	MDS	PS	MWS	PS	MDS	MDS	MWS	WS	MWS	MWS	MWS	MWS	MWS
	SYM	SYM	SYM	FSK	FSK	FSK	SYM	SYM	FSK	SYM	SYM	CSK	CSK	SYM	CSK
	MSK	MSK	MSK	PK	MSK	LPK	MSK	LPK	PLK	MSK	MSK	MSK	PLK	PLK	PLK
Nov _21	M	M	M	M	M	M	M	F	M	M	M	M	M	M	M
	MDS	MDS	MDS	MDS	MDS	MDS	WS	MWS	MWS	MDS	MDS	MWS	MWS	MWS	MWS
	SYM	CSK	CSK	SYM	SYM	CSK	SYM	FSK	SYM	CSK	SYM	SYM	SYM	SYM	SYM
	MSK	MSK	MSK	MSK	LPK	MSK	MSK	MSK	LPK	MSK	MSK	MSK	LPK	LPK	MSK
Dec _21	M	F	F	M	F	F	M	M	M	M	M	C	M	M	M
	MDS	MWS	MWS	MWS	MWS	MWS	MDS	WS	MWS	MDS	MDS	MDS	MDS	MDS	MWS
	SYM	FSK	SYM	SYM	FSK	FSK	SYM	SYM	SYM	SYM	SYM	SYM	SYM	SYM	SYM
	PLK	LPK	LPK	LPK	LPK	MSK	LPK	MSK	LPK	MSK	MSK	MSK	MSK	LPK	MSK
Jan _22	M	M	M	M	F	F	F	F	F	M	F	F	M	F	M
	MWS	MDS	MDS	MWS	MWS	MWS	MWS	MDS	MWS	MDS	MWS	MWS	MDS	MWS	MDS
	CSK	SYM	SYM	SYM	SYM	CSK	SYM	CSK	CSK	SYM	CSK	SYM	SYM	SYM	SYM
	LPK	LPK	MSK	LPK	MSK	LPK	MSK	LPK	LPK	MSK	MSK	MSK	MSK	MSK	MSK
Feb _22	M	M	M	M	M	F	C	M	C	C	M	F	M	M	F
	MDS	MDS	MDS	MDS	MDS	MWS	MWS	MWS	MDS	MWS	MDS	MWS	MDS	MWS	MWS
	SYM	SYM	SYM	SYM	SYM	CSK	FSK	SYM	SYM	FSK	FSK	CSK	FSK	FSK	SYM
	MSK	MSK	MSK	MSK	MSK	MSK	PLK	LPK	PLK	PLK	LPK	LPK	VPLK	PLK	LPK
Mar _22	M	M	M	M	M	M	C	M	M	M	M	M	M	M	C
	MDS	WS	MDS	MDS	MDS	WS	MWS	MDS	MWS	MDS	MDS	MDS	MDS	MDS	MDS
	SYM	VFSK	CSK	SYM	SYM	VFSK	FSK	SYM	SYM	SYM	SYM	SYM	SYM	FSK	SYM
	MSK	MSK	MSK	PLK	LPK	MSK	MSK	LPK	VLPK	LPK	LPK	MSK	MSK	MSK	MSK

Legends: Mean: Fine Sand (F) Medium Sand (M) Coarse Sand (C) Very Fine Sand (VF)

Sorting: Well Sorted (WS) Moderately Well Sorted (MWS) Moderately Sorted (MDS) Poorly Sorted (PS)

Skewness: Symmetrical (SYM), Coarse Skewed (CSK), Fine Skewed (FSK), VCS-Very coarse skewed

Kurtosis: Platykurtic (PLK), Leptokurtic (LPK), Mesokurtic (MSK), Very Platykurtic (VPK)

The mean grain size of the north beach is predominantly medium followed by fine sand. However, sediment textures are rarely coarse type during period of observation. Sediments are predominantly moderately sorted (50%) followed by moderately well sorted (42.2%). Percentage

of well sorted and poorly sorted sediments is rare during period from October, 2021 to March, 2022. Percentage distribution of mean sediment size indicates the of medium sand is higher (67.7%) while fine sediment less than 10% and coarse sediment less than 1% indicates north beach is fully dominated by medium nature. It is observed that fine sediments are associated with either moderately well sorted or sometime moderately sorted type while medium sediments are mainly moderately sorted during observation period. The salient feature of skewness pattern along Gopalpur port north beach indicates symmetrical (64.4%) followed by negligible fine skewed (18.8%) and coarse skewed (16.6%) nature. Kurtosis of the sediment at port north beach is mostly mesokurtic (55.5%) followed by leptokurtic (31.1%). However, platykurtic nature of the sediments (12.2%) found rarely during the period of observation. The result of the present study indicates mostly stable in the port north beach.

3.4.3 Gopalpur tourist Beach

Table 3.10 depicts the sediment characteristics (mean, sorting, skewness and kurtosis) of Gopalpur tourist beach from October, 2021 to March, 2022. The mean grain size of the tourist beach is predominantly medium sand (72.2%). However, fine sand (18%) with rare occurrence of coarse sand (9.26%) indicate accretion environment during the observation period. Sorting distribution indicates the beach is dominated by moderately sorted (48.15%) followed by moderately well sorted (40.74%). However, well sorting nature of the sediment is rare during the observation period. High percentage of medium followed by fine sediments associated with moderately sorted or moderately well sorted sediments indicate good beach condition at the Gopalpur tourist beach which can be visible from profile analysis of Gopalpur beach. Besides, it is observed that coarse sediment are constantly dominated by moderately sorted at few stretches of Gopalpur beach, however it is moderately well sorted at GPB_4. It is noticed that no coarse sediment found in January and March, 2021 indicates the period of accretion. However, predominantly medium sand is found during October, 2021. Symmetrical nature of the sediments (59.3%) followed by fine skewed and coarse skewed (20.37%) are predominantly experienced at Gopalpur tourist beach which indicate low energy environment with unidirectional transport. Most of the symmetrical and negative skewed sediments are confined with medium sand. Kurtosis of the sediment at Gopalpur tourist beach shows mostly mesokurtic (61.1%) followed by leptokurtic (24.1) and platykurtic (14.8) nature.

Table 3.10: Sediment (mean, sorting, skewness and kurtosis) analysis along Gopalpur Tourist Beach from October, 2021 to March, 2022.

	Gopalpur Tourist Beach								
	GPB_2 (1.0 km)			GPB_4 (2.0 km)			GPB_6 (3.0 km)		
	BS	MS	FS	BS	MS	FS	BS	MS	FS
Oct_21	M	M	M	M	M	M	M	M	M
	MWS	MWS	MWS	MWS	MWS	MWS	MDS	MWS	MWS
	SYM	SYM	SYM	CSK	SYM	FSK	FSK	FSK	SYM
	MSK	MSK	MSK	MSK	PLK	MSK	MSK	LPK	MSK
Nov_21	M	M	F	M	M	M	C	M	M
	MWS	MWS	MDS	MWS	MDS	MDS	MDS	MWS	MDS
	SYM	SYM	FSK	SYM	SYM	FSK	SYM	SYM	SYM
	LPK	MSK	VLPK	MSK	PLK	MSK	MSK	LPK	MSK
Dec_21	M	M	F	M	M	F	C	M	M
	MWS	MWS	MWS	MDS	MWS	MDS	MDS	MDS	MDS
	CSK	SYM	SYM	SYM	SYM	VCSK	VFSK	CSK	CSK
	MSK	LPK	LPK	LPK	LPK	LPK	PLK	MSK	MSK
Jan_22	M	M	F	F	F	M	F	F	M
	MDS	MDS	MWS	MDS	WS	MWS	MWS	WS	MDS
	SYM	SYM	SYM	CSK	FSK	SYM	SYM	SYM	SYM
	MSK	MSK	MSK	LPK	LPK	MSK	MSK	MSK	MSK
Feb_22	M	C	M	C	C	M	M	M	M
	MDS	MDS	PS	MDS	MWS	MDS	MDS	MDS	PS
	CSK	CSK	CSK	SYM	SYM	SYM	CSK	CSK	SYM
	MSK	PLK	PLK	PLK	PLK	MSK	MSK	MSK	PLK
Mar_22	M	M	M	F	M	F	M	M	M
	MDS	MDS	PS	MWS	MDS	MWS	MDS	MDS	PS
	FSK	SYM	SYM	SYM	FSK	FSK	FSK	SYM	SYM
	MSK	LPK	MSK	MSK	MSK	MSK	VLPK	MSK	MSK

Legends: Mean: Fine Sand (F) Medium Sand (M) Coarse Sand (C) Very Fine Sand (VF)

Sorting: Well Sorted (WS) Moderately Well Sorted (MWS) Moderately Sorted (MDS) Poorly Sorted (PS)

Skewness: Symmetrical (SYM), Coarse Skewed (CSK), Fine Skewed (FSK), VCS-Very coarse skewed

Kurtosis: Platykurtic (PLK), Leptokurtic (LPK), Mesokurtic (MSK), Very Platykurtic (VPK)

3.4.4 Rushikulya sand spit

Table 3.11 depicts the sediment characteristics (mean, sorting, skewness and kurtosis) of Rushikulya sand spit for the period from October, 2021 to March, 2022. The mean grain size of the sand spit at backshore, midshore and foreshore are predominantly medium type. However, fine sediments are observed at foreshore during October, 2021 and at midshore during March, 2022. Sediments are almost characterized by predominantly moderately sorted followed by moderately well sorted while poorly sorted sediment is rare in nature at the study area. Association of medium sand with moderately sorted sediment leads to development of south Rushikulya sand spit. Skewness of sediment at Rushikulya sand spit is mostly symmetrical followed by coarse skewed and occasionally fine skewed. Kurtosis of the sediment indicates

mostly mesokurtic followed by platykurtic while leptokurtic nature of the sediment is very rare during the study period.

Table 3.11: Sediment grain size (mean, sorting, skewness and kurtosis) analysis along Rushikulya Sand spit

	Rushikulya Spit (SPIT_A)		
	BS	**MS**	**FS**
Oct_21	M	M	F
	MWS	MWS	MWS
	SYM	SYM	SYM
	LPK	MSK	MSK
Nov_21	M	M	M
	MDS	MDS	MDS
	SYM	SYM	SYM
	LPK	PLK	LPK
Dec_21	M	M	M
	MDS	MDS	MDS
	CSK	SYM	CSK
	PLK	MSK	PLK
Jan_22	M	M	M
	MDS	MDS	MDS
	CSK	CSK	SYM
	PLK	MSK	MSK
Feb_22	M	M	M
	PS	MWS	MDS
	SYM	SYM	CSK
	PLK	LPK	MSK
Mar_22	M	F	M
	PS	MWS	MWS
	SYM	SYM	FSK
	MSK	LPK	MSK
Legends: Mean: Fine Sand (F) Medium Sand (M) Coarse Sand (C) Very Fine Sand (VF)			
Sorting: Well Sorted (WS) Moderately Well Sorted (MWS) Moderately Sorted (MDS) Poorly Sorted (PS)			
Skewness: Symmetrical (SYM), Coarse Skewed (CSK), Fine Skewed (FSK), VCS-Very coarse skewed			
Kurtosis: Platykurtic (PLK), Leptokurtic (LPK), Mesokurtic (MSK), Very Platykurtic (VPK)			

3.5 Littoral Environment Observation (LEO)

Table 3.12 depicts the Littoral Environment Observation (LEO) at the Gopalpur Tourist Beach, Gopalpur port (south) and Rushikulya mouth area from October, 2021 to March, 2022. Ocean wave breakers are either plunging or spilling type at beach and port area. However, predominantly spilling breakers are found at tourist beach. Similarly plunging breakers are predominant at spit area except March, 2022. Breaker angle are predominantly from the direction bounded between north and north north east direction at all the sectors during observation period. The breaker height varies between 0.5 to 1.78 m with temporal mean of 1.20 m at beach area, 0.6 to 1.62 m with temporal mean of 1.24 m at port area and 1.02 to 1.65 m with temporal mean 1.42 m at mouth area. The wave periods are ranging from 6.21 to 10.86 sec

at beach area with maximum value during January, 2022. However, at port region, it is ranging from7.63 to 11.53 sec and at Rushikulya it is from8.08 to 10.91 sec. Ocean waves are predominantly from ESE (112.5^0) to SSE (157.5^0). The surf zone width ranges from 95 to 120 m at the tourist beach, 110 to 120m at port and 90 to 98 m at mouth area. Uprush/Swash velocities are greater than backwash velocities in all the three sectors during the period of observation. Swash and backwash velocities for different period for three sectors are almost same or differ very little.

Table 3.12: Littoral Environmental Conditions along Gopalpur Coast from October, 2020 to March, 2021.

Month	Breaker type	Breaker height (m)	Breaker angle (deg)	Wave period (sec)	Wave direction	Uprush (m/s)	Backwash (m/s)	Surf zone width(m)
Gopalpur Tourist Beach								
Oct_21	Spilling	1.78	20	9.06	SE	1.15	0.99	95
Nov_21	Spilling	1.19	-10	6.29	ESE	1.11	0.94	110
Dec_21	Spilling	1.36	-20	9.19	ESE	1.10	0.97	100
Jan_22	Spilling	0.5	5	10.86	SE	1.0	0.70	110
Feb_22	Spilling	1.08	10	8.73	SSE	1.27	1.16	120
Mar_22	Spilling	1.28	25	6.21	SSE	1.18	1.01	105
Gopalpur Port								
Oct_21	Plunging	1.62	15	9.02	SE	1.08	0.95	115
Nov_21	Spilling	1.49	5	7.63	SE	1.26	1.08	115
Dec_21	Plunging	1.48	-5	9.54	ESE	1.15	1.20	110
Jan_22	Spilling	0.6	7	11.53	SE	1.13	1.05	115
Feb_22	Plunging	1.10	15	10.61	SE	1.04	0.91	120
Mar_22	Plunging	1.14	20	9.69	SSE	1.00	0.89	115
Rushikulya Spit								
Oct_21	Plunging	1.65	18	9.86	SSE	1.31	0.96	90
Nov_21	Plunging	1.62	-5	8.08	ESE	1.41	1.15	95
Dec_21	Plunging	1.53	-10	10.91	ESE	1.10	1.00	95
Jan_22	Plunging	1.02	10	10.24	SSE	1.19	1.00	98
Feb_22	Plunging	1.18	10	8.47	SSE	1.28	1.15	95
Mar_22	Spilling	1.52	15	10.20	SE	1.29	1.00	90

3.6 Monitoring of Terrestrial Environment

Ambient air quality (PM_{10}, $PM_{2.5}$, SO_2 and NO_2) and noise level were monitored around the Port premises at four points, two in the windward and two in the leeward sides (Figure 3.11) from October, 2021 to March, 2022. The coordinates of the four stations of air quality monitoring are; A (19^0 17' 18.69''N, 84^0 56'41.82''E), B (19^0 17' 48.1''N, 84^0 57' 03.3''E), C (19^0 18' 29.0''N, 84^0 57' 41.1''E) and D (19^0 18' 50.09''N, 84^0 58'09.12''E) (Figure 3.11).The four points of monitoring are fixed in such a way that the impact of the port on air quality can be assessed up to a distance in down wind direction (both during strong sea breeze and land breeze time) where maximum ground level concentration is anticipated. Table-3.13, 3.14, 3.15 and 3.16 depict the air quality values and the noise level monitored for the study period at the four points within the port premises along with the national ambient air quality standard (NAAQS) norms stipulated by MoEFCC.

The maximum PM_{10} (112.59 µg/m^3) and $PM_{2.5}$ value (48.34 µg/m^3) was recorded during the month of December-2021 and March-2022 respectively at station 'C' due to large number of vehicular emission and road dust whereas the minimum PM_{10} (64.28 µg/m^3) was recorded during the month of October-2021 at station 'B' and the minimum $PM_{2.5}$ (22.38 µg/m^3) was recorded during the month of March-2022 at station 'D'. The maximum SO_2 (9.13 µg/m^3) and NO_2 (8.91 µg/m^3) was recorded during the month of November, 2021 at station 'D' and station 'B' respectively due to high vehicular emission. Whereas the minimum SO_2 (1.08) was recorded at station 'A' during the month of February, 2022 and the minimum NO_2 (1.58) was recorded at station 'B' during the month of March, 2022. The maximum average noise level (75.23) was recorded at station 'C' where the maximum construction activities are under progress and the minimum noise level was recorded at station 'A'.

The average value of the all ambient air quality monitored parameters at the four points within the port premises from October, 2021 to March, 2022 are well within the NAAQ threshold limit stipulated by CPCB. Further, sound level monitored during the day time is also well within the NAAQ thresholds stipulated by MoEFCC for industrial (75dB) and commercial (70dB) zones during day time. Thus, the ongoing port operational activities are not detrimental to the air quality and noise level in the terrestrial environment.

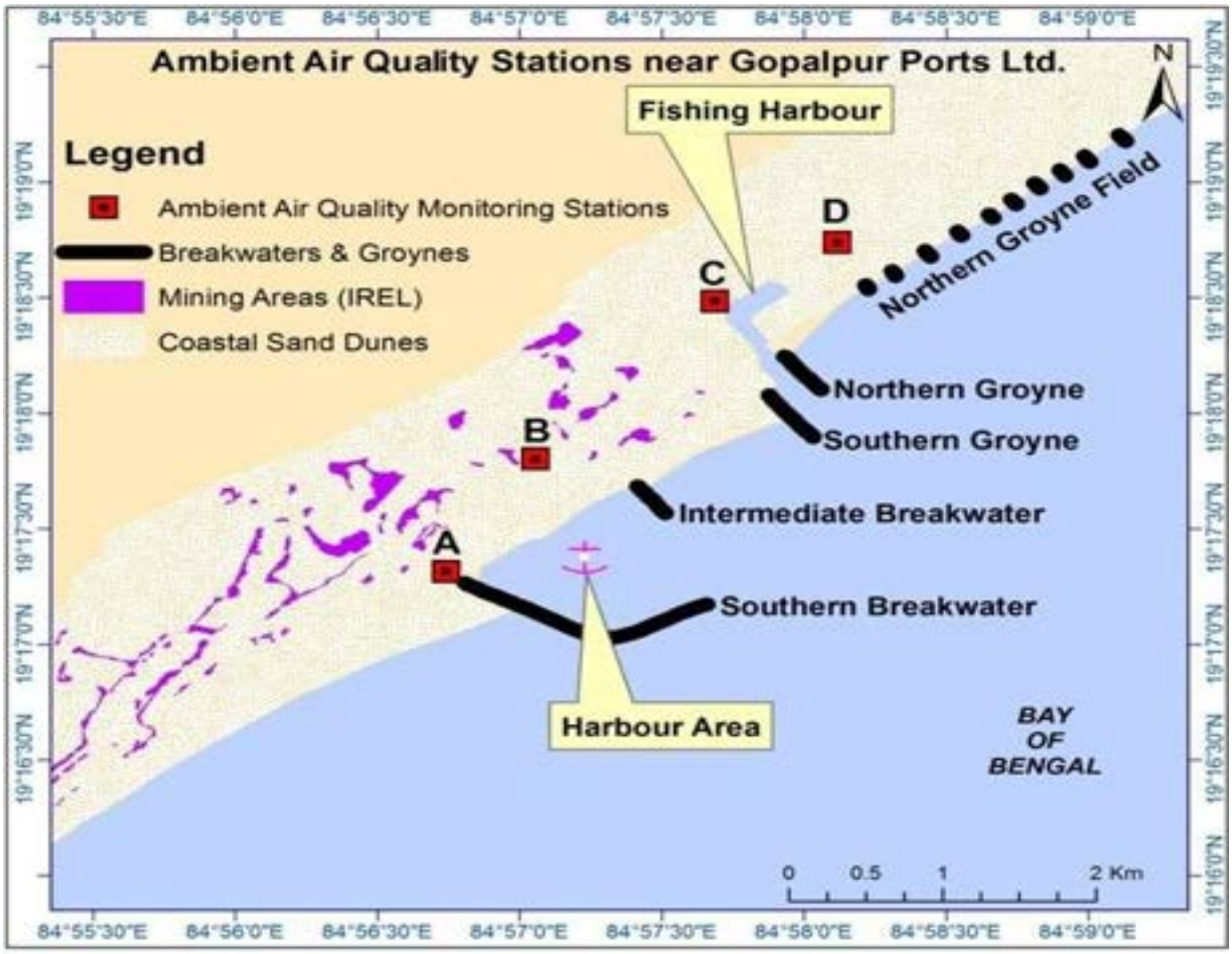


Figure 3.11 Location of air quality monitoring stations within the Gopalpur Port area

Table 3.13: Ambient Air Quality and Noise level within Gopalpur Port premises (A)

STATION-A	Date	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	SO_2 (µg/m³)	NO_2 (µg/m³)	Noise level (dB)
Oct_21	03.10.2021	88.35	35.91	6.81	6.34	72
	04.10.2021	81.62	34.28	7.5	6.52	71.68
	10.10.2021	92.37	31.65	6.35	7.08	73.51
	11.10.2021	81.91	28.91	7.15	7.16	68.56
	17.10.2021	79.37	34.61	6.92	8.05	69.34
	18.10.2021	88.52	28.34	7.08	6.81	67.25
	25.10.2021	82.38	31.05	6.51	7.29	69.57
	26.10.2021	76.81	30.64	6.82	6.58	67.59
Nov_21	03.11.2021	92.65	36.25	7.35	6.84	82.56
	04.11.2021	85.61	33.52	6.94	6.94	77.92
	08.11.2021	88.94	28.97	7.08	7.28	79.82
	09.11.2021	87.28	30.58	7.55	6.82	98.38
	16.11.2021	91.53	35.61	6.82	7.22	65.94
	17.11.2021	74.65	27.53	6.33	7.56	71.62
	22.11.2021	79.58	38.75	6.7	6.99	76.38
	24.11.2021	72.98	26.38	7.09	6.38	68.11
Dec_21	01.12.2021	89.35	28.35	4.38	5.82	78.91
	02.12.2021	84.62	31.52	6.28	4.29	80.15
	07.12.2021	88.91	36.57	5.91	4.38	82.64
	08.12.2021	92.67	34.83	4.67	5.12	71.68
	15.12.2021	89.37	37.29	6.15	5.34	72.51
	16.12.2021	99.59	34.91	6.22	4.83	70.91
	22.12.2021	91.64	30.59	5.82	5.44	64.81
	23.12.2021	88.37	29.47	6.08	5.94	78.54
Jan_22	04.01.2022	92.34	42.35	3.24	3.42	69.46
	05.01.2022	97.43	38.38	2.16	3.58	68.34
	10.01.2022	82.14	34.75	4.92	2.64	65.28
	11.01.2022	89.34	40.61	2.84	3.16	67.46
	17.01.2022	91.25	32.61	4.62	3.67	69.82
	18.01.2022	97.43	42.91	3.95	2.92	68.49
	25.01.2022	90.42	38.16	5.16	3.49	65.82
	27.01.2022	87.34	31.54	4.29	5.16	68.43
Feb_22	03.02.2022	87.64	38.91	2.61	3.07	68.56
	04.02.2022	86.37	39.29	2.91	2.64	65.92
	10.02.2022	80.72	42.62	1.08	2.08	66.82
	11.02.2022	79.67	37.61	2.59	2.94	72.91
	17.02.2022	82.81	30.95	3.16	2.66	68.37
	18.02.2022	86.19	33.64	3.07	2.09	70.19
	23.02.2022	90.58	38.29	3.44	3.18	67.34
	24.02.2022	88.64	37.29	3.72	4.28	70.68
March_22	03.03.2022	89.61	26.59	1.09	2.16	61.38
	04.03.2022	85.26	34.82	1.95	2.35	66.29
	14.03.2022	78.34	39.16	2.58	2.38	59.46
	15.03.2022	76.54	27.34	2.64	3.05	70.61
	21.03.2022	80.49	29.81	3.05	3.16	49.28
	22.03.2022	74.38	30.18	2.94	2.67	67.38
	28.03.2022	81.59	32.61	2.62	2.52	68.29
	29.03.2022	88.64	35.28	3.45	2.91	72.91
Mean (Range)		86.13 (72.98-99.58)	34.00 (26.38-42.91)	4.80 (1.08-7.55)	4.69 (2.08-8.05)	70.62 (49.28-98.38)
Reference value(NAAQS,2009)		**100**	**60**	**80**	**80**	**70-75 (Env. Protection Act, 1986)**

Table 3.14: Ambient Air Quality and Noise level within Gopalpur Port premises (B) (PM-Particulate matter, SO_2-Sulphur dioxide, NO_2-Oxides of nitrogen

STATION-B	Date	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	SO_2 (µg/m³)	NO_2 (µg/m³)	Noise level (dB)
Oct_21	03.10.2021	78.52	33.52	7.28	7.08	87.38
	04.10.2021	72.59	35.68	7.38	7.67	72.62
	10.10.2021	85.37	31.28	7.16	8.28	78.64
	11.10.2021	89.28	30.29	6.91	6.24	77.92
	17.10.2021	90.15	28.67	6.28	6.15	71.52
	18.10.2021	75.68	29.51	5.27	6.27	80.19
	25.10.2021	71.35	33.18	8.08	6.05	81.67
	26.10.2021	64.28	28.37	7.92	6.42	76.29
Nov_21	03.11.2021	82.52	28.61	9.06	8.91	86.38
	04.11.2021	88.38	30.29	8.56	7.68	82.94
	08.11.2021	75.39	29.64	7.94	7.29	80.49
	09.11.2021	77.95	34.29	7.09	8.15	76.38
	16.11.2021	84.38	30.58	652	6.75	68.75
	17.11.2021	89.66	26.82	6.94	7.29	83.91
	22.11.2021	78.35	29.84	7.09	7.06	76.81
	24.11.2021	72.66	31.59	8.15	6.38	82.67
Dec_21	01.12.2021	77.29	25.83	6.28	6.22	88.37
	02.12.2021	81.62	27.34	5.46	6.59	82.53
	07.12.2021	79.37	26.51	5.49	7.15	91.53
	08.12.2021	84.61	28.37	3.51	7.61	78.38
	15.12.2021	88.28	32.86	6.49	6.54	77.29
	16.12.2021	79.37	32.59	6.22	6.37	68.24
	22.12.2021	84.51	31.84	5.83	5.52	72.68
	23.12.2021	89.37	28.64	7.06	6.73	84.37
Jan_22	04.01.2022	80.16	32.67	4.35	4.61	67.49
	05.01.2022	76.29	34.82	4.32	3.59	68.28
	10.01.2022	81.34	29.61	3.62	5.16	65.58
	11.01.2022	86.52	28.76	4.12	4.37	64.38
	17.01.2022	81.67	34.82	2.92	4.67	67.29
	18.01.2022	78.61	29.82	3.16	5.79	58.46
	25.01.2022	91.52	30.54	2.54	4.67	62.81
	27.01.2022	83.28	32.49	3.64	4.78	53.94
Feb_22	03.02.2022	73.94	30.95	3.99	2.37	72.38
	04.02.2022	81.67	32.64	3.49	2.92	71.92
	10.02.2022	72.91	35.19	4.06	2.33	65.84
	11.02.2022	75.68	33.51	4.19	3.49	68.37
	17.02.2022	84.61	40.62	2.37	3.51	70.16
	18.02.2022	88.67	29.53	2.67	2.82	67.34
	23.02.2022	86.97	38.49	1.09	2.73	51.28
	24.02.2022	80.94	30.53	2.55	3.16	48.37
Mar_22	03.03.2022	78.91	30.95	3.16	2.33	68.33
	04.03.2022	84.61	32.64	2.94	2.58	69.51
	14.03.2022	81.37	35.19	2.67	2.16	58.42
	15.03.2022	73.27	33.51	3.16	2.37	55.22
	21.03.2022	65.29	40.62	409	1.58	67.91
	22.03.2022	71.38	29.53	3.58	2.94	48.38
	28.03.2022	77.65	38.49	2.67	1.83	53.73
	29.03.2022	79.28	30.53	1.94	2.99	55.72
Mean (Range)		80.36 (64.28-91.52)	31.27 (25.83-40.62)	26.91 (1.09-9.06)	5.13 (1.58-8.91)	71.02 (48.37-91.53)
Reference value (NAAQS,2009)		**100**	**60**	**80**	**80**	**70-75(Env. Protection Act,1986)**

Table 3.15: Ambient Air Quality and Noise level within Gopalpur Port premises (C) (PM-Particulate matter, SO_2-Sulphur dioxide, NO_2-Oxides of nitrogen

STATION-C	Date	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	SO_2 (µg/m³)	NO_2 (µg/m³)	Noise level (dB)
Oct_21	05.10.2021	89.35	42.68	6.22	7.16	92.37
	06.10.2021	91.67	38.61	6.92	6.82	88.61
	13.10.2021	78.62	40.92	7.08	6.91	76.28
	14.10.2021	80.53	42.67	7.28	7.08	90.34
	19.10.2021	92.64	44.64	6.53	7.34	86.51
	21.10.2021	68.37	32.46	7.61	6.28	82..37
	27.10.2021	91.28	42.92	7.38	6.81	78.18
	28.10.2021	99.82	40.91	6.85	7.37	72.94
Nov_21	05.11.2021	90.58	39.51	7.95	8.37	87.29
	06.11.2021	98.69	42.56	8.09	7.61	91.67
	12.11.2021	87.61	44.38	7.62	7.29	94.28
	13.11.2021	82.67	38.29	6.83	6.73	83.19
	18.11.2021	84.38	36.89	8.16	8.11	94.26
	19.11.2021	81.9	44.82	8.29	7.64	90.81
	25.11.2021	94.38	40.29	7.99	7.09	84.67
	26.11.2021	97.29	42.38	7.08	7.82	88.59
Dec_21	03.12.2021	94.61	38.15	6.57	7.12	75.38
	04.12.2021	108.37	41.59	7.24	6.28	68.76
	10.12.2021	105.82	38.66	6.84	5.49	80.49
	11.12.2021	94.93	34.28	6.28	6.18	76.28
	17.12.2021	96.18	32.18	7.59	6.75	79.51
	18.12.2021	112.59	42.59	6.72	7.38	80.76
	24.12.2021	108.73	38.46	7.09	7.08	88.49
	26.12.2021	97.42	34.29	7.38	5.92	76.57
Jan_22	06.01.2022	97.56	42.62	4.72	3.46	66.49
	07.01.2022	94.46	39.57	4.26	4.27	62.73
	13.01.2022	98.72	32.61	5.34	3.68	59.64
	15.01.2022	89.67	40.46	3.48	5.42	61.49
	19.01.2022	98.46	42.91	4.16	4.29	65.38
	20.01.2022	99.82	44.86	3.84	3.67	67.82
	28.01.2022	94.64	37.28	4.62	4.58	64.86
	29.01.2022	94.37	35.76	5.46	4.33	68.57
Feb_22	07.02.2022	92.37	45.38	3.16	3.16	70.56
	08.02.2022	88.97	41.06	3.81	3.07	67.29
	14.02.2022	92.67	43.29	3.33	2.91	60.19
	15.02.2022	94.73	38.72	2.16	4.08	71.67
	19.02.2022	94.83	42.68	3.07	3.16	69.39
	21.02.2022	96.82	46.37	4.61	2.99	62.29
	25.02.2022	94.38	48.34	2.19	3.18	64.18
	26.02.2022	84.92	38.49	3.46	3.42	64.45
Mar_22	07.03.2022	84.62	45.38	2.99	2.54	69.46
	08.03.2022	94.38	41.06	3.16	3.06	72.46
	16. 03.2022	91.28	43.29	2.85	3.18	66.49
	17. 03.2022	87.61	38.72	3.46	3.53	68.19
	24.03.2022	94.38	42.68	2.59	2.85	68.27
	25.03.2022	99.27	46.37	3.19	2.63	70.16
	30.03.2022	76.59	48.34	4.29	3.11	72.38
	31.03.2022	84.37	38.49	3.11	2.91	74.99
Mean (Rang)		**92.67 (68.37-112.59)**	**40.83 (32.18-48.34)**	**5.44 (2.16-8.29)**	**5.25 (2.54-8.37)**	**75.23 (59.64-94.28)**
Reference value, (NAAQS, 2009)		**100**	**60**	**80**	**80**	**70-75(Env. Protection Act,1986)**

Table 3.16: Ambient Air Quality and Noise level within Gopalpur Port premises (D) (PM-Particulate matter, SO_2-Sulphur dioxide, NO_2-Oxides of nitrogen

STATION-D	Date	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	SO_2 (µg/m³)	NO_2 (µg/m³)	Noise level (dB)
Oct_21	05.10.2021	78.34	27.62	7.52	6.65	80.37
	06.10.2021	69.53	28.37	8.38	6.82	75.62
	13.10.2021	68.46	31.5	6.38	7.09	66.59
	14.10.2021	71.92	26.85	7.28	6.28	81.09
	19.10.2021	70.61	28.62	8.08	7.42	66.28
	21.10.2021	83.27	31.28	7.64	7.28	67.28
	27.10.2021	84.29	33.28	7.92	6.92	77.29
	28.10.2021	81.38	30.86	8.14	6.11	72.54
Nov_21	05.11.2021	82.67	29.61	8.09	7.79	88.59
	06.11.2021	76.28	34.67	7.29	7.64	84.56
	12.11.2021	88.37	25.82	6.55	6.76	90.18
	13.11.2021	84.61	30.08	7.83	7	77.38
	18.11.2021	91.67	33.55	7.07	7.16	76.18
	19.11.2021	78.38	32.67	8.95	6.84	77.91
	25.11.2021	77.64	29.61	9.13	7.49	84.62
	26.11.2021	84.57	28.77	8.64	6.58	76.24
Dec_21	03.12.2021	82.64	26.81	5.27	6.73	79.43
	04.12.2021	88.93	29.37	6.18	5.29	84.37
	10.12.2021	76.58	31.59	6.38	4.15	89.46
	11.12.2021	91.67	37.24	6.72	7.82	86.19
	17.12.2021	97.38	28.34	7.08	6.49	94.28
	18.12.2021	88.72	26.49	6.91	7.07	89.37
	24.12.2021	79.61	39.18	5.84	6.13	79.27
	26.12.2021	91.53	37.52	6.88	7.66	82.49
Jan_22	06.01.2022	78.62	24.67	2.46	3.86	63.49
	07.01.2022	84.59	34.56	3.82	2.64	65.82
	13.01.2022	87.46	28.67	2.94	2.57	67.64
	15.01.2022	90.18	42.81	3.04	3.16	64.28
	19.01.2022	89.37	37.63	3.56	4.79	59.51
	20.01.2022	92.81	39.48	4.24	3.57	64.29
	28.01.2022	86.49	34.72	2.79	4.29	54.64
	29.01.2022	92.76	36.71	3.54	2.82	64.24
Feb_22	07.02.2022	88.37	30.91	3.16	3.08	72.61
	08.02.2022	85.62	25.37	3.58	2.64	67.39
	14.02.2022	86.91	24.95	2.69	4.16	68.16
	15.02.2022	90.73	22.38	3.46	3.09	72.92
	19.02.2022	94.61	28.61	2.88	3.43	69.48
	21.02.2022	92.82	30.64	4.59	3.52	72.61
	25.02.2022	99.72	28.33	2.64	3.22	69.64
	26.02.2022	91.66	38.94	3.16	2.86	65.38
Mar_22	07.03.2022	82.61	30.91	2.92	2.88	61.95
	08.03.2022	88.46	25.37	3.28	3.16	62.38
	16. 03.2022	75.68	24.95	2.58	3.49	60.49
	17. 03.2022	86.37	22.38	2.67	2.91	55.29
	24.03.2022	91.67	28.61	2.92	2.04	61.38
	25.03.2022	85.16	30.64	3.09	1.92	71.94
	30.03.2022	91.67	28.33	3.58	2.66	68.27
	31.03.2022	88.62	38.94	4.07	2.59	63.58
Mean (Rang)		**85.28 (68.46-99.27)**	**30.82 (22.38-42.81**	**5.29 (2.46-9.13**	**4.97 (1.92-7.82)**	**72.81 (54.64-94.28)**
Reference value (NAAQS, 2009)		**100**	**60**	**80**	**80**	**70-75(Env. Protection Act, 1986)**

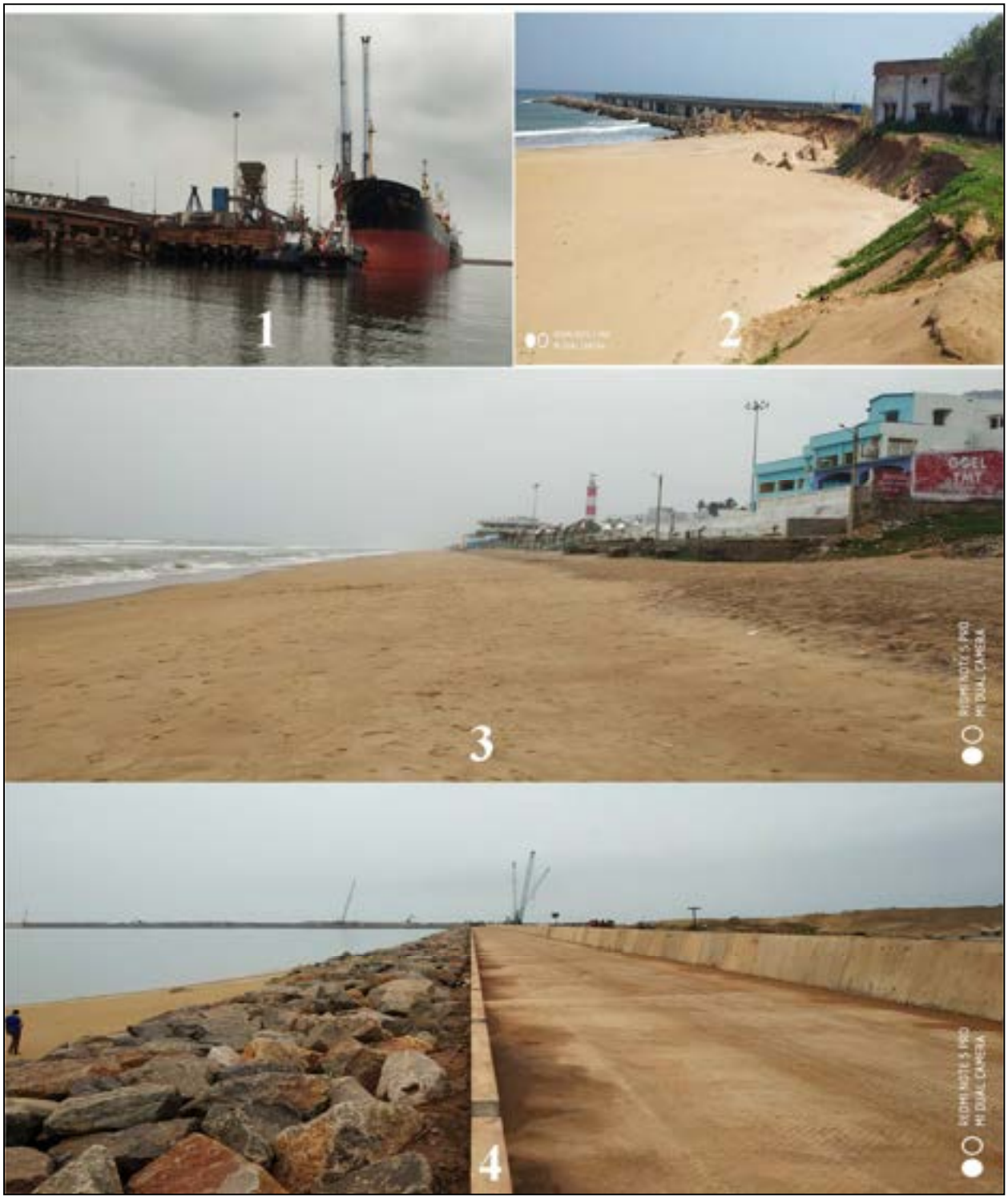


Plate1. Shipping activities near berth of Gopalpur port.
Plate2. Beach condition at north of Gopalpur port (GPLN_1).
Plate3. Accreted environment at Gopalpur tourist beach.
Plate4. Fully developed southern breakwater at south of Gopalpur port.

PART-II

WATER, SEDIMENT, SOIL AND BIOLOGICAL ENVIRONMENT

Chapter-4

WATER, SEDIMENT, SOIL AND BIOLOGICAL ENVIRONMENT

4. Water, sediment and Biological parameters

Water and sediment samples were collected from port berth area (19^0 17′ 21″ N, 84^0 56′ 55″ E) for determination of their physico-chemical and biological properties. Due care was taken to avoid error during sampling. The chemical and biological properties of water and sediment samples were measured adopting prescribed methods by Indian Standards. The detail observed/analysed parameters and their threshold values are provided below.

4.1 Water Quality

Water quality parameters such as pH, dissolved oxygen (DO), color and odour, fecal coliform, biological oxygen demand (BOD), salinity, electrical conductivity (EC), Total dissolved solids (TDS), total suspended matter (TSM), phosphate, nitrate, chloride, Sulphate, lead, mercury, hexavalent chromium and petroleum hydrocarbon for the period from October,2021 to March, 2022 of Gopalpur port harbour area are presented in Table 4.1.

From Table 4.1 it is evident that most of the parameters are well within the permissible limit/standard. During the observation period it is noticed that pH of water ranged from 6.87-7.83 with mean value of 7.36 representing alkaline nature of the harbour area. Salinity ranged from 30.62-33.42 PSU with minimum and maximum values during October and November, 2021 and February, 2022 respectively. The Dissolved Oxygen ranged from 6.39-7.34mg/l with average value of 7.05 mg/l for last six month. The BOD value ranged from 1.94-3.13 with average value of 2.61 mg/l. The minimum value found during the month of December while the maximum value found during the month of October. The TDS and TSM value ranged from 27.38-35.67 and 0.792-1.061 gm/l with average value of 31.61 and 0.92gm/l respectively. These parameters are indicators of turbidity of coastal water and the values suggest that turbidity is at the minimum level. EC ranged from 48.37-48.64 ms/cm with average value of 52.58 ms/cm. Phosphate concentration was observed <0.01mg/l from November, 2021 to March, 2022 while during the month of October, 2021 it was recorded 0.05 mg/l. Nitrate concentration ranged between 0.62 to 1.93 mg/l with with average value of 1.04 mg/l. the maximum value recorded during the month of October, 2021 while the minimum value recorded during the month of November, 2021. Sulphate values ranged between 188-1255 mg/l with average value of 998.17 mg/l for last six month. Fecal coliform values ranged from 30-2000 CFU/ml with average value of 416.67 CFU/ml.

Chloride level of sea water varied from 1089-13400 mg/l with mean value of 8085.3 mg/l. The level of petroleum hydrocarbon was very less as compared to the standard during the observation and it ranged between 0.11-0.19 mg/l with average value of 0.14 mg/l. The level of lead varied from 0.001-0.007 mg/l with average value of 0.004 mg/l. The levels of mercury value recorded 0.001 during all the month while the hexavalent chromium were varied from 0.001 to 0.02 mg/l with average value of 0.014 mg/l.

From the analysis of water quality parameters, it can be stated that the water quality of harbour area is good as almost all parameters are well within the permissible limits.

Table 4.1: Water Quality parameters during October, 2021 to March, 2022 from Gopalpur port harbour area

Water parameters	Oct_21	Nov_21	Dec_21	Jan_22	Feb_22	Mar_22	Range	Mean	Standard	Methods
pH	6.87	6.87	7.63	7.43	7.31	7.62	6.87-7.83	7.36	6.5-9[1]	Microprocessor based pH system Model 1012
DO	6.39	7.1	7.09	7.06	7.29	7.34	6.39-7.34	7.05	>3 mg/l [1]	Winkler's Titration method, Grasshoff et al (1999)
Colour & Odour	BO	BO	BN	BO	BO	BO	--------			-------
Fecal coliform	170	140	2000	30	50	110	30-2000	416.67	--	APHA, 1999
BOD	3.13	2.59	1.94	2.38	2.73	2.91	1.94-3.13	2.61	< 5 [1]	Winkler's Titration method, Grasshoff et al. (1999)
Salinity	30.62	30.62	31.56	32.68	33.42	32.97	30.62-33.42	31.98	--	Mohr-Knudsen Argentometric titration method
EC	49.43	49.43	48.37	52.91	58.64	56.68	48.37-48.64	52.58	--	Hanna HI 98194 portable multi parameter water quality meter
TDS	33.27	33.27	35.67	30.67	29.42	27.38	27.38-35.67	31.61	--	Hanna HI 98194 portable multi parameter Water Quality meter
TSM	1.061	1.061	0.873	0.884	0.861	0.792	0.792-1.061	0.92	--	Filtration method (Vacuum pump filtration unit)
Phosphate	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	------		0.1 mg/l[2]	APHA 4500 PD
Nitrate	1.93	0.62	0.86	0.96	0.92	0.92	0.62-1.93	1.04	1.0 mg/l [2]	APHA 4500 NO_2 E
Sulphate	188.0	1255.0	1072	1138	1144	1192	188-1255	998.17	--	APHA 4500 SO_4^{2-}E
Chloride	13400	8527	9683	6537	9276	1089	1089-13400	8085.3	--	APHA 4500 CL^- B
PHC	0.12	0.11	0.13	0.19	0.12	0.15	0.11-0.19	0.14	10 mg/l[1]	EPA 3510
Lead	0.005	0.007	0.006	0.001	0.001	0.001	0.001-0.007	0.004	0.1 mg/l[3]	APHA 311 B.C
Mercury	0.001	0.001	0.001	0.001	0.001	0.001	0.001-0.001	0.001	0.01 mg/l[3]	APHA 5500 Hg
Hexavalent Chromium	0.02	0.01	0.01	0.02	0.02	0.001	0.001-0.02	0.014	0.1 mg/l[3]	APHA 3500 Cr B

Units (Parameter): **Mg/l (BOD, TSM, Phosphate, Nitrate, Sulphate, Chloride, PHC, Lead, Mercury, Hexavalent Chromium), CFU/ml (Fecal coliform), mS/Cm (EC), PPT (TDS)**

Legends: **Bluish & Odourless- BO; Bluish and no odour- BN**

Source of standards: **[1]Primary water quality criteria for class SW-IV waters (Harbour) as per EPA, 1986**
[2]Guidelines for coastal water quality, Dept. of Environment, Govt. of India, General notice no 620 of 1999.
[3]Central Pollution Control Board, Pollution Control Acts, Rules and Notifications, Fourth Edition, Ministry of Environment and Forests, 2001, 897pp.

4.2 Sediment Quality

Bed Sediment texture and chemical parameters are analysed after collecting samples from Gopalpur Port harbour area. Mean grain size analysis of sediment indicates that sediments are predominantly fine followed by either medium or coarse. Sorting analysis of the sediment indicates predominantly moderately well sorted followed by moderately sorted and occasionally well sorted. Sediments skewness is predominantly symmetrical in nature. Results of Kurtosis show that the sediments are predominantly mesokurtic followed by occasionally leptokurtic or platykurtic in nature. Sediment pH varied from 6.67 to 7.37 with mean value of 6.98 indicating prevalence of alkali medium within the sediment environment. Sodium level in sediment varied from 676-964 mg/kg with mean value of 773.5 mg/kg. Maximum values were observed during October, 2021 and minimum during December, 2021**.** Phosphate level was <0.2 mg/kg throughout the observation period (i.e October, 2021 to March, 2022). Sulphate level was observed maximum during October, 2021 while it was minimum in the month of November, 2020. Level of petroleum hydro carbon (PHCs) was observed as very low (<0.01µg/L) during the period of observation indicating no contamination of sediment environment with the PHCs. Level of lead varied from 0.14 to 1.22 mg/kg with highest value during December, 2021 and lowest value during January, 2022, which shows higher level of lead presence in sediment. Levels of hexavalent chromium (<0.2 mg/kg) and mercury (<0.01 mg/kg) were observed very low during the period of observation. Percentage of organic carbon varied from 0.03 to 0.12 % with maximum and minimum values during December, 2021 and February, 2022 respectively.

Table 4.2 Sediment parameters during October, 2021 to March, 2022

Sediment parameters	Oct_21	Nov_21	Dec_21	Jan_22	Feb_22	Mar_22	Range	Mean	Methods
Texture (Mean, sorting, skewness, kurtosis)	F MWS SYM MSK	F MWS SYM MSK	C MDS SYM PLK	M MDS SYM MSK	F MWS SYM LPK	F WS SYM MSK	.....	.....	Sieve Analysis method using RETSCH AS 200
pH	7.07	7.08	7.37	6.89	6.67	6.82	6.67-7.37	6.98	Potentiometric method
Sodium (mg/kg)	964	752	676	791	689	769	676-964	773.50	Flame photometry
Potassium (mg/kg)	19.8	15.8	21.4	21.64	17.3	24.6	15.8-24.6	20.09	Flame photometry
Phosphate (mg/kg)	0.07 (BDL)	0.05 (BDL)	BDL (0.08)	0.07	0.06	0.04	0.04-0.08	0.04	Methods of analysis of soil by HLS Tandon*
Chlorides (mg/kg)	879	226	428	567	315	462	226-879	479.50	USDA:1954 US -affirmed 2010
Sulphates (mg/kg)	249	61.3	142	98.6	92.6	118.3	61.30-249	126.97	Methods of analysis of soil by HLS Tandon*
PHC (µg/L)	0.007 (BDL)	0.008 (BDL)	BDL (0.006)	0.005	0.004	0.007	0.004-0.008	0.01	UNEP 1992
Lead (mg/kg)	0.26	0.19	1.22	0.14	0.17	0.21	0.14-1.22	0.37	EPA 3050 B
Mercury (mg/kg)	0.004 (BDL)	0.006 (BDL)	BDL (0.005)	0.004	0.003	0.008	0.003-0.008	0.01	EPA 3050 B
Hexavalent chromium (mg/kg)	0.05 (BDL)	0.07 (BDL)	BDL (0.08)	0.06	0.04	0.05	0.04-0.08	0.06	Methods of analysis of soil by HLS Tandon*
Organic carbon (%)	0.11	0.08	0.12	0.08	0.03	0.04	0.03-0.12	0.08	Methods of analysis of soil by HLS Tandon*

*Methods of analysis of Soils, Plants, Waters, and Fertilizers by HLS Tandon published by FDCO, New Delhi, 1993.

Legend for texture statistics are as per Table 3.8.

BDL: Below Detection Level

4.3 Soil Quality

Surface soil from an active port operational area (near the berth) was collected and analyzed for its chemical characterization. To understand annual variability of soil characteristics, once a year, soil analysis has been carried out. Sample was collected during March, 2022. Detail of soil chemical characteristics is provided for the assessment of soil property within the port premises (Table 4.3).

Table 4.3: Physico-chemical property of surface soils during March, 2022

Soil Parameters	Testing Method	Analysis Result
pH	IS:2720(P-26):1987	7.28
Electrical Conductivity (µs/cm)	IS:14767:2000	2716
Available Nitrogen (%)	Methods of analysis of soil by HLS Tandon*	<1.4
Available Phosphorus (mg/kg)		0.76
Available Potassium (mg/kg)	VCSPL/SOP/SOIL/15	12.24
Alkalinity (mg/kg)	Methods of analysis of soil by HLS Tandon*	33
Chloride (mg/kg)		2087
Sulphate (mg/kg)	IS:2720(P-27):1987	312
Magnesium (%)	Methods of analysis of soil by HLS Tandon*	0.22
Organic Matter (%)	VCSPL/SOP/SOIL/05	<0.02
Iron (mg/kg)	EPA 3050B, 7000B	11.26
Copper (mg/kg)	EPA 3050B, 7000B	8.7
Manganese (mg/kg)	EPA 3050B	89.5
Zinc (mg/kg)	EPA 3050B, 7000B	31.4
Total Chromium (mg/kg)	EPA 3050B	37.2
Lead (mg/kg)	EPA 3050B	5.73
Nickel (mg/kg)	EPA 3050B, 7000B	8.6
Arsenic (mg/kg)	EPA 3050B, 7000B	BDL (0.04)
Cadmium as Cd (mg/kg)	EPA 3050B, 7000B	BDL (0.1)
Mercury (mg/kg)	EPA 3050B, 7000B	BDL (0.007)

BDL- Below Detectable Limits: Arsenic<0.5 (mg/kg), Mercury <0.01(mg/kg), Organic Matter <0.02 %, Available Nitrogen <1.4%.

*Methods of analysis of Soils, Plants, Waters, Fertilizers and organic manures by HLS Tandon published by FDCO, New Delhi, 1993.

4.4 Biological Parameters

Biological parameters such as chlorophyll, primary productivity, phytoplankton and zooplankton, macrobenthos and meiobenthos samples were collected and analysed on quarterly basis for the year 2021-22. Quarter 3 (Q3) represents for months October to December, 2021 and Quarter 4 (Q4) represents for January to March, 2022.

4.4.1 Chlorophyll, Primary Productivity and light penetration

The chlorophyll value was recorded as high (3.59 mg.m-3) during Q3 and low (2.11mg.m-3) during Q4. Similarly, the primary productivity value was recorded as high (0.057g.C.m-3.hr-1) during Q3 and low (0.03 g.C.m-3.hr-1) during Q4. Light penetration is recorded as high during Q4 and low during Q3.

4.4.2 Phytoplankton

The phytoplankton community represented by 17 species belonging to class Bacilariophyceae (14 species), Cyanophyceae (2 species) and filamentous algae (Table 4.4). Species richness was high during Q4 (13 species) than Q3 (12 species). However, abundance was high during Q3 (627 cells.l-1) than Q4 (700 cells.l-1).

Table 4.4. Phytoplankton community (No. of cells.l^{-1}) of Gopalpur Port during quarter 3 (October to December, 2021) and quarter 4 (January to March, 2022)

Sl. No.	Species	Class	Q3	Q4
1.	*Rhizosolenia intricata*	Bacilariophyceae	20	20
2.	*Lauderia* Sp.		20	-
3.	*Pleurosigma* sp.		-	20
4.	*Navicula* sp.		20	60
5.	*Thalassiosira* sp.		-	20
6.	*Chaetoceros* sp.		28	-
7.	*Thalassionema* sp.		28	-
8.	*Coscinodiscus* sp.		244	200
9.	*Protoperidinium* sp.		28	-
10.	*Ceratium* sp.		100	120
11.	*Ditylum* sp.		-	20
12.	*Biddulphia* sp.		28	20
13.	*Thalasiothrix* sp.		11	20
14.	*Nitzschia* sp.		60	40
15.	*Oscillatoria* sp.	Cyanophyceae	-	20
16.	*Trichodesmium* sp.		-	20
17.	Filamentous algae		40	120
Total number of cells.*l*$^{-1}$			627	700

4.4.3 Zooplankton

The zooplankton sample was represented by bivalve larva, copepod, Polychaete larva, fish egg, tintinid, nauplius and nematode (Table 4.5). Species diversity was high during Q3 but low during Q4. The zooplankton sample was dominated by Copepode during Q3 and Q4.

Table 4.5. Zooplankton community (No. of organisms.l^{-1}) of Gopalpur Port during quarter 3 (October to December, 2021) and quarter 4 (January to March, 2022)

Sl. No.	Zooplankton	Q3	Q4
1.	Bivalve larva	0	1
2.	Copepod	36	24
3.	Polychaete larva	02	01
4.	Fish egg	06	06
5.	Tintinid	08	03
6.	Nauplius	03	1
7.	Nematode	05	02
Total		**60**	**39**

4.4.4 Macrobenthos

The macrobenthic community was represented by polychaetes, nematodes, mysis, amphipods and isopods (Table 4.6). Abundance of macrobenthos was high during Q3 due to dominancy of polychaetes.

Table 4.6 Macrobenthic community (No. of organisms. m^{-2}) of Gopalpur Port during quarter 3 (October to December, 2021) and quarter 4 (January to March, 2022)

Sl. No.	Macrobenthos	Q3	Q4
1.	Polychaete	23933	8533
2.	Nematod	400	533
3.	Mysis	467	1133
4.	Amphipod	-	67
5.	Isopod	33	-
Total		**24833**	**10267**

4.4.5 Meiobenthos

The meiobenthos community was represented by nematode and polychaetes. Polychaete dominated the meiobenthic community during both the quarters and their abundance was significantly high during Q3 (Table 4.7).

Table 4.7. Meiobenthic community (No. of organisms. m^{-2}) of Gopalpur Port during quarter 3 (October to December, 2021) and quarter 4 (January to March, 2022)

Sl. No.	Meiobenthos	Q3	Q4
1.	Nematode	2667	8400
2.	Polychaete	39733	14400
Total number of individuals per m^2		**42400**	**6000**

5. Conclusion

The general oceanographic conditions during October, 2021 to March, 2022 along the coastal stretches from Gopalpur lighthouse to Rushikulya mouth are predominantly of swell waves with spilling breakers followed by plunging breakers. During the observation, spilling breakers at beach area, both spilling/plunging breakers at port area and predominant plunging breakers at Rushikulya mouth is experienced. Breaker heights are varied from 0.5 to 1.78 m along Gopalpur coastal environment. Angle of wave breakers varied from -20 to 20 degree. Directions of waves approach varied from ESE (112.5^0) to SSE (157.5^0) at all the sectors with predominant direction of wave approach as south-east direction along the entire stretch of Gopalpur coastal environment. The wave periods vary from 6.21 to 11.53 sec along Gopalpur, indicating dominance of swell waves along the entire stretches of Gopalpur coastal environment from October, 2021 to March, 2022. The surf zone widths varied from 90 to 120 m along the entire stretch of coastal environment with maximum value near port and beach area. Uprush velocities are always higher than backwash velocities during the period of observation at three sectors.

At Gopalpur tourist beach, net shoreline change is uniformly seaward with maximum at GPB_6 which is 2.5 km north of the light house. Analysis of shoreline position depicts higher variability also at GPB_6 while minimum is observed at GPB_1. Maximum variability in shoreline position is observed during February, 2022 while minimum variability observed during October, 2021. Net change in beach width is consistently positive from GPB_4 to GPB_7 with maximum change observed at transect of GPB_6. Maximum and minimum variability in beach width for tourist beach was observed during March, 2022 and October, 2021. Similarly, net change in beach volume is predominantly positive at all transects. Maximum positive change in beach volume is noticed at GPB_6 followed by GPB_5. Month of March, 2022 and October, 2021 is noticed as the periods of maximum and minimum Variability in beach volume at each transects. From the above analysis, it can be inferred that the shoreline at Gopalpur tourist beach experienced seaward movement and also had positive change in beach volume. The positive change could be attributed to low wave energy. Beach profile during the period of observation showed either steep or gentle slope at Gopalpur tourist beach. The mean grain size of the tourist beach is predominantly medium sand (72.2%) followed by fine sand (18%) with rare occurrence of fine sand (9.3%) during the

observation period. Sediments are mostly moderately sorted (48.2%) followed by moderately well sorted (40.7%). Skewness and Kurtosis indicate symmetrical and mesokurtic nature of the sediments at Gopalpur tourist beach.

At Gopalpur port south, net change in shoreline position is predominantly seaward with rarely landward movement. The magnitude of shoreline is maximum at 2.5 Km followed by at 3.0 Km. Maximum and minimum variability in shoreline position is observed during January, 2022 and February, 2022 respectively. Net change in beach width is observed seaward at all transects with maximum change at GPLS_7 and minimum change at GPLS_2. Month of March, 2022 and November, 2021 are observed as the periods of maximum and minimum spatial variability in shoreline change. Positive net change in beach width and volume is observed at all transects with maximum change towards south of southern breakwater (GPLS_6). Month of March, 2022 and October, 2021 are regarded as period for maximum and minimum variability in beach width and volume respectively. Beach profiles on port south beach are wide and mostly plane type at most of the transects while concave topography is visible at some transects. Bermline at most of the transects are very prominent while its moderate oscillation is visible at rest of transects. Slope of the profiles are gentle while it is steep at GPLS_1,2 and 9. The mean grain size of the south beach is mostly medium followed by fine sand and coarse sand during observation from October, 2021 to March, 2022. The sediments are mostly moderately well sorted (58.3%) followed by moderately sorted (31.9%) while poorly sorted sediments is rare. The sediments at Gopalpur port south are mostly symmetrical and mesokurtic in nature.

At the port north beach, shoreline has moved consistently seaward with maximum seaward movement at 3.0 Km while maximum landward movement is observed at GPLN_1 responding beach nourishment activities. Maximum and minimum variability of shoreline position is observed at transect GPLN_1 and GPLN_4 respectively. Month of December, 2021 is observed as maximum variability in shoreline position while minimum variability is observed during November, 2021. Net change in beach width is observed predominantly positive with maximum at GPLN_5 while minimum at GPLN_8. Variability in beach width is observed maximum at GPLN_9 and minimum at GPLN_5. October, 2021 and March, 2022 are found to have high and low variability in beach width. Spatial mean in beach width shows maximum development during March, 2022 and minimum during November, 2021. The

Maximum beach width at GPLN_5 could be due to beach nourishment activity by Port authority. Net change in beach volume is also positive at all the transects except at GPLN_1 with maximum change at GPLN_5 followed by GPLN_2. Maximum and minimum variability in beach volume are observed at transect GPLN_3 and GPLN_8 respectively. March, 2022 and November, 2021 are noticed as the period of maximum and minimum variability in beach volume. Beach profiles indicate distinct variation of sediment in midshore/foreshore region compared to the backshore. Maximum width profile is observed at middle of port north beach (GPLN_5). Beach width and beach volume gradually enhanced from October, 2021 to March, 2022 at all transects. This could be due to impact of north east monsoon when the wave energy is very low. Slope of beach profiles are gentle type at most of the transects except at GPLN_1,3 and GPLN_4. The sediment texture of port north beach is predominantly medium sand followed by fine type. Sediments are predominantly moderately sorted (50%) followed by moderately well sorted (42%). Skewness of beach sediment at north beach is predominantly symmetrical while kurtosis of the beach sediment is mostly mesokurtic in nature.

The geomorphology of sand spit at Rushikulya mouth is ephemeral due to interaction of coastaline with high energy waves and river discharge. During the period of observation from October, 2021 to March, 2022, sand spit showed very little variability in its area, peremeter and length. Area of the spit varied from 0.74 to 1.27 km^2 while peremeter and length of the spit varied from 12.53 km to 13.50 km and 5.60 km to 6.30 km respectively. The mean grain size of the sand spit at backshore, midshore and foreshore are predominantly medium type. However, fine sediments observed at foreshore during October, 2021 and at midshore during March, 2022. Sediments are characterized by moderately sorted, symmetrical and mesokurtic type.

Ambient air quality such as PM_{10}, $PM_{2.5}$, SO_2, NO_2 were monitored twice weekly at the four points within the port premises from October, 2021 to March, 2022. The values observed are well within the NAAQ norms stipulated by MoEFCC and Environment (protection) Act, 1986. The maximum PM_{10} and $PM_{2.5}$ was recorded during dry season at station 'C' compared to all other stations due to large number of vehicular emission and road dust near the station C. Further, sound level monitored during the day time is within the permissible limits stipulated by CPCB for industrial (75dB) and commercial (70dB) zones during day time. Thus,

the ongoing port activities at present are not detrimental to the air quality and noise level and indicates a pollution free terrestrial port environment.

Water quality parameters of port harbour area monitored for the period October, 2020 to March, 2021 include, pH, DO, colour and odour, Fecal Coliform, BOD, Salinity, EC,TDS, TSM, Phosphate, Nitrate, Sulphate, Chloride, PHC, lead, mercury and Hexavalent chromium. All the parameters are well within the standard limit and suggest prevalence of good water quality in the harbour area.

Sediment quality of port harbour area was assessed by examining sediment texture (mean grain size, sorting, skewness and kurtosis), pH, sodium, potassium, phosphate, chloride, sulphate, PHC, lead, mercury, organic carbon and hexavalent chromium. Sediment grain size is predominantly fine and only medium type during January, 2022 and coarse during December, 2021. Sediment is alkaline in nature while phosphate, PHC, mercury, organic carbon and hexavalent chromium are present in trace amount. Organic carbon content ranges between 0.03-0.12% and is in agreement with predominantly fine grain. Soil chemical characteristics is examined for the assessment of soil property which shows well within the permissible limits at port premises.

Among the biological parameters both chlorophyll and primary productivity were higher in Q3 (October-December, 2021) compared to Q4 (January-March, 2022). Similarly in phytoplankton, both abundance and biodiversity were higher in Q3 compared to Q4. There is a clear dominance of class Bacilariophyceae observed in the study area during the entire sampling period. Higher value of chlorophyll and primary productivity can be attributed to the phytoplankton abundance during the study period. The zooplankton Species diversity was high during Q3 but low during Q4. The Zoo plankton sample was dominated by Copepode during Q3 and Q4. The meiobenthos community was represented by nematode and polychaetes. Polychaete dominated the meiobenthic community during both the quarters and their abundance was significantly high during Q3 while the nematode abundance was higher during Q4.

★★★ *End of the Report* ★★★