Report on EIA/EMP and modelling studies for the sand mining clusters in the rivers of Goa

Report on Zuari Estuary

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EXECUTIVE SUMMARY

Zuari is regarded as the longest river in the state of Goa with a total length of 145 kms of which 42 kms is in Saline Zone. This tidal river originates in the Western Ghats. It is located between the latitudes (15°20'N and 15°30'N) and longitudes (73°45'E and 74°10'E). The water of Zuari flushes out into the Arabian Sea at Cabo Aguada, a common point where Zuari meets the Mandovi river. The present study was undertaken to study the following aspects of the Zuari estuary: Hydrodynamic modelling of flow dynamics; Numerical modelling of replenishment and recharge related aspects / issues of clusters - including dynamics of accretion and erosion; hydrological study of the area under consideration; the diversity and abundance of phytoplankton, zooplankton, benthos and fish diversity to evaluate the impact of sand extraction on the estuarine ecology and biodiversity and to calculate the biodiversity index of the estuary.

The results of all the above aspects have been incorporated in various chapters of this report. The higher phytoplankton abundance was found predominantly at the upstream freshwater region, whereas moderate and low abundance were detected at the mouth and mid-stream regions respectively. The clear gradient in phytoplankton community composition was observed with the dominance of diatom species (*Pleurosigma*, *Navicula*, *Nitzschia*, *Cyclotella*, *Surirella*, *Coscinodiscus* etc.) near mouth and other midstream-upstream regions of the estuary. Biomass estimation of the zooplankton community structure showed a decresing trend from mouth to upstream regions of the estuary. The present report also revealed that the peripheral region of Zuari estuary was rich in macrofauna, meiofauna as well as foraminiferal diversity, while their abundance decreased gradually towards the upper stream area. The central stations of the estuary found less faunal diversity due to the continuous dredging in the estuary. Ecological quality status assessment carried out by biotic indices (AMBI and Bentix), based on the benthic polychaete diversity and abundance, assigned most of the sampling sites near mouth and mid-stream regions as moderately to slightly disturbed, whereas stations towards the upper stream areas showed poor ecological status. Commercially important fish varieties such as sardines, mackerels, mullets, catfish, sharks, seerfish, cuttlefish, prawns, crabs and other shellfishes were found in Zuari. Furthermore, Zuari estuary supported a variety of reptiles (crocodiles, snakes, turtles) and mammals (otters, dolphins, finless porpoise etc.). Intertidal mudflats, sandy beaches and rocky beaches of the Zuari estuary provided suitable feeding ground for waders and other aquatic birds. Other than wader, surrounding mangroves and nearby grass and mangrove associated plants also hosted habitat to forest and grassland birds such as Kingfisher, herons, bee-eaters, munias, prinias and birds of prey. A total of eight mangrove species and nine mangrove associate species recorded from the Zuari estuary. The

detailed flora and faunal species list are given in Chapter 3. The overall biological results suggest moderate to poor conditions, possibly several parts of the estuary impacted due to cumulative activities in the region. Some regions of the lower reaches of the estuary show good growth of mangroves in 2021 which were not present in 2010. On the other hand, mangrove covers have been cleared from some areas for structures such as buildings, bridges and roads. Land Use Land Cover images along the Zuari estuary depicted that although agriculture land, salt pan and aquaculture pond were in use in 2010. However, presently they were in inusitation due to salt water intrusions. The intrusion of saline water could be due to poor maintenance of existing bunds/embankments, breach in embankments, erosion of mudflats or shift in mangrove area to the landward side as well as excavation of sand which in turn increases the water depths and the water breaches the embankments making it saline. There is no noticeable change in the river except near the mouth region undergoing development.

Considering the physical baseline parameters, modelling studies have been carried out. The Hydrodynamic simulations are carried out using MIKE21 Flow Model FM. The MIKE 21 Flow Model FM is a modelling system based on a flexible mesh approach providing the hydrodynamic basis for the Sediment Transport Module. The modelling system is based on the numerical solution of the two-dimensional shallow water equations i.e., depth-integrated incompressible Reynolds Averaged Navier-Stokes equations. The Sediment transport module calculates the resulting transport of non-cohesive materials based on the flow conditions found in the hydrodynamic calculations. The model output consists of bed level changes, amongst other parameters. The comparisons of the current speed between Case 1 (present scenario) and Case 2 (scenario after mining) at sections A to F are also studied. The comparisons of the bed level changes between Case 1 and Case 2 are presented in the morphology model results.

Major observations are given below:

- Considering the results of the baseline, Zuari estuary has been influenced by cumulative anthropogenic activities and natural riverine and costal processes.

- Over the years, many pits and deep gorges are formed at many stretches of the river/estuary.

- The lower stretches of the estuary are influenced by higher salinity regime thus the adjacent banks have been protected by traditional embankments. These embankments allow the locals to carry out agriculture- predominantly paddy. These traditional embankments consistently face the problem of saline water intrusion and require continuous repair and maintenance. There are several reasons for the damage of embankments viz; high tidal surges, subsidence of land, removal of sand/sediment from the river bed, non-maintenance of embankments and flooding due to rainfall and upstream water flow.

- The salinity intrusion has also changed the land use, converting many paddy fields and riparian zones and mudflats into unproductive areas or mangrove areas.

- Based on the baseline data and the prevailing site conditions (cumulative impacts herein), sand extraction at unregulated rates or in the sensitive area will have negative impacts on the environment. Therefore, minimum areas recommended as per SSMG (2016) & Hon'able NGT are to be followed. Accordingly, certain areas in the stretches of the river have been demarcated where sand extraction from the river bed requires restrictions.

- The bed level changes for the post-mining scenario are mostly around -0.2 m to 0.5 m based on the studies covering monsoon (July-November, 2020) and non-monsoon period (November, 2020 - June, 2021). The changes in bed morphology in the post-mining scenario at different sections of the river are highly dynamic and patchy in nature.

Following are the recommendations:

- The sand extraction has to be conducted by traditional (manual) method only. No mechanized boats or machinery to be operated. The activity shall be restricted to the available areas only and the depth of extraction should not exceed 3m from the existing baseline profiles.

- Once the lease areas are issued, the delineated "Environmental Conservation and Management Plan" needs implementation. The plan also describes the team/committee which should be capable to address, execute and monitor all the aspects of the plan. Furthermore, the team/committee should appoint sub-teams, SHG's, Village committees on requirement basis as per the plan.

CHAPTER 1: INTRODUCTION

1.1 Sand Mining Scenario in the State of Goa

Sand is available in three forms in the State of Goa. They are ordinary sand, silica sand and beach sand. The ordinary sand is brought by the river originating from the Western Ghats and flowing west to join the Arabian Sea. The process of weathering helps the deposition of sand. Sand is extracted mainly from the river Mandovi, Zuari, Terekhol, Chapora and its tributaries. Where the water column is deep, sand is extracted with the help of canoes and buckets attached to bamboos. Sand is mostly used in construction activities.

The extraction of sand is a traditional activity being carried out in Goa before the Portuguese regime. There are some communities who are dependent on sand extraction for livelihood. Post-Portuguese regime Goa, Daman and Diu Minor Minerals Extraction and Removal Rules, 1974 were in force and after that, the Goa Minor Mineral Concession Rules, 1985 were notified. In 1979 various references are available in the form of application from traditional extractors, letters from cart owners, village panchayats etc.

The extraction of sand from the rivers beds in Goa is governed by the Goa Minor Mineral Concession Rules, 1985 and permission was granted yearly. However, after the Coastal Regulation Zone (CRZ) Notification dated 6th January, 2011, no permission for sand extraction was granted after 2011-2012 onwards as it was declared a non-permissible activity in CRZ. Subsequently some states including Karnataka requested the Ministry of Environment, Forests & Climate Change, Government of India for permission to remove sand bars naturally formed in rivers by manual methods by traditional communities and an Office Memorandum dated 8th November, 2011 of the Dy. Director, Ministry of Environment, Forests & Climate Change was issued which carved out an exception to the CRZ notification. To facilitate the grant of sand permits in Goa, the State Government has constituted two District Committees under the Chairmanship of the respective District Collectors to deal with the grant of licence for extraction of sand. The said committees are notified in the Official Gazette Series II no. 37 dated 13th December, 2012. Based on studies conducted by the committees certain zones/stretches were identified in Terekhol, Chapora & Mandovi in North Goa and Dudhsagar, Ragada, Kushavati, Ugvem, Zuari & Sal River in South Goa wherein manual extraction by traditional communities could be permitted. Prior Environment Clearance was obtained by the respective District Collectors vide 3-181-2010/STA-DIR/159 dated 1st October, 2015, 3-181-2010/STA-DIR/158 dated 1st October, 2015 and 3-181-2010/STA-DIR/184 dated 14th December, 2015 from the Goa State Environment Impact Assessment Authority. It was unanimously decided in a meeting held on

02/12/2015 with District Magistrate, North Goa, (letter no. 39/8/13-MAG/DC-Sand-Ext-NG/9486 dated 4th December, 2015) that Directorate of Mines & Geology can issue the permits for extraction of sand by local communities through traditional method. Similar decision was recorded in the meeting held on 11/12/2015 by District Magistrate, South Goa. 458 Sand permits were issued by the Directorate starting 2015 onwards for the year 2017-18 and 333 permits were renewed for the period 1 October 2017 to 31st May 2018. As per one of the conditions in the Environmetal Clearance, sand extraction is banned from 1st June to 30th September due to monsoon. The sand permit holders for the year 2017-18 are being assessed for payment of royalty and non-filling of monthly returns which is a violation of Goa MMCR. Recovery is being carried and penalties imposed as per rules. On 3rd May 2018 a PIL Writ petition (14 of 2018) was filed in Hon'ble High Court of Bombay at Goa by Federation of Rainbow Warriors regarding Sand Extraction in Goa. Subsequently as per High Court Order dated 3rd October 2018 the learned Advocate General submitted that the State is in the process of examining various conditions and permits will be renewed/ granted after consideration of the same. However, as per para 9 of the High Court Order dated 23rd October 2018 the Hon'ble Court has not passed any restraint order against issuance of permits. Further affidavit was filed by the State Environment Impact Assessment Authority (SEIAA) on 31/10/2018, wherein at para no. 4 of the Hon'ble High Court's order various lacunae are pointed out and has made further observation. Subsequently, a note was forwarded by the office of the Learned Advocate General for seeking extension of the time cited in the order of Hon'ble High Court dated 31st October 2018 for the State Government to take a decision on renewal of sand permits as well as seeking modification of the order as approved by the State Government. MCA application was filed before the Hon'ble High Court seeking a time frame of 8 weeks as the Directorate of Environment was in the process of finalizing the studies to be conducted as required under Sustainable Sand Mining Management Guidelines 2016 and MOEFF notification no So. 141(E) and Directorate of Mines and Geology are working out modalities such as stacking point of sand, installation of weigh bridges, etc. Subsequently, in the order dated 4th April 2019, eight weeks were granted to the State Government to decide on renewal of sand permits. The directorate of Environment has agreed to incorporate Environment Management Plan for an individual cluster to capture all possible externalities before the renewal of the licences. A proposal for the Environmental Management plan is sent for cabinet approval. Hon'ble High Court gave its Judgment in PIL WP No. 14 of 2018 on 18th December 2019. The Environment Department accorded the work to CSIR - NIO, Dona Paula. This report presents the EIA/EMP and modelling studies for the sand mining in the Zuari Estuary.

1.2 Zuari Estuary

Out of nine major rivers in the state of Goa, Zuari is regarded as the longest river and has second largest basin. Being a tidal river, Zuari originates at Hemad-Barshem hills of the Western Ghats escarpments in Karnataka and follows a zigzag stretch of about 145 km. It is located between the latitudes (15°20'N and 15°30'N) and longitudes (73°45'E and 74°10'E). Zuari river is a fifth order stream flowing through Quepem, Sanguem, Salcete, Ponda, Tiswadi and Mormugao talukas and finally opens up into the Arabian Sea at Mormugao – Dona Paula point (Figure 1.1). The Kushavati river joins the Zuari at about 38 km from the mouth near Sanvordem. The upstream stretch of Zuari above Sanvordem is known as Sanguem and it has two tributaries at the head known as Uguem and Guloli rivers (Shetye et al., 2007). The average depth of the estuary is about 5 m. The estuary can be broadly divided into two regions: a wide bay region of ~ 5 km of width at the mouth, extending from mouth to ~ 12 km upstream and a narrow channel of barely 50 m wide at the upstream station (Sanvordem) located at about 45 km from the mouth (Sundar et al., 2015).

The Zuari estuary is classified as monsoonal estuary, which receive an abundant river discharge during south-west (SW) monsoon, with the peak rainfall occurring throughout the month of July that cascades down the slope and floods this estuary (Vijith et al., 2009). The freshwater flow of Zuari refers to combined flow from Kushavati, Uguem and Guloli tributaries, which account to 2.1 x 10^9 m^3 yr^{-1} (Water Resources Department, Goa). During SW Monsoon this large freshwater influx due to heavy rainfall and land runoff results in partial stratification of the estuary which is more pronounced near the mouth. A funnel shaped bay (width: 5 km and area: 50 km^2) in estuarine region stimulates salt–water intrusion roughly 40 km upstream with semi-diurnal tides (tidal range 1.5 –2.3 m), which together corresponds to strong vertical mixing especially during post and premonsoon seasons (Sundar et al., 2015). After monsoon, the freshwater discharge at the head decreases and the estuary starts recovering gradually to its original pre-monsoon condition. During the dry season, the tidal influence is present as far as from 1 to 8 km upstream stretches of all the branches of Zuari (RRC, 2019). The fresh water discharge of Zuari is regulated by the Selaulim Dam with ~ 0.25 x 10^9 m^3 yr^{-1} freshwater storage capacity and has a significant impact on the flow of Zuari. After monsoon when natural runoff declines, dam water is released in a controlled manner to ensure greater runoff in dry months. The river flows steeply down the Western Ghats across the lowlying coastal plains, which are mainly composed of heavily weathered rocks and covered by laterites. Due to low elevation of the coastal plains, the tidal effect is observed ~45 km inland and it is forced out seawards during the monsoons by high amounts of river discharge (Shetye et al. 2007).

As part of the Mandovi–Zuari estuarine system, the Zuari river is connected with Mandovi (another major river of the state Goa) by Cumbarjua canal. The Zuari estuarine network is extensively used for transport of goods (mainly iron ore), for fishing, dumping domestic and industrial waste. The waters of Mandovi and Zuari both flush out into the Arabian Sea at Cabo Aguada, a common point where Zuari meets the Mandovi river. The Zuari has the catchment area of 973 km^2 with an average runoff of 2247.4 MCM. A stretch of 28 km of the river is in the saline zone from Curchorem to Marcaim Jetty and this stretch has in all 8 outfalls bringing the domestic untreated sewage causing the main source of the pollutants (RRC, 2019). The reconnaissance survey was conducted along with the polluted stretch as well as the upstream side (till bridge on Dharglim Road) during the month of January and February, 2019 by Goa State Pollution Control Board. The stretch of river Zuari from Curchorem to Marcaim Jetty having a length of 28 kms is categorized as Priority V by the Central Pollution Control Board (CPCB). The prime cause of concern is high levels of Fecal Coliform, while other parameters such as dissolved oxygen (DO) and biological oxygen demands (BOD) are well within the CPCB prescribed standards on majority of occasions.

CHAPTER 2: METHODOLOGY

2.1 Water sample collection and processing

Based on the project objectives, similar to previously sampled other estuaries of Goa, the Zuary estuary was also thoughtfully sampled at every 2 km distance between near mouth to upstream. Samling was conducted during the high tide of 25th & 26th Feb & on 1st March 2021 to understand the hydrography and productivity pattern on a spatial scale based on biological parameters such as chlorophyll-*a* concentration and analyses of phytoplankton and zooplankton composition (see below). These parameters form the bases of an aquatic food web. Since minerals govern phytoplankton production, nutrients such as nitrate, phosphate, and silicic acid were also simultaneously measured.

Sample collection, preservation, and processing were done following the standard protocol (as detailed in the project proposal). The samples were collected from near mouth to upstream region stations (Stns): Z1, Z2, Z3, Z4, Z5, Z6, Z7, Z8, Z9, Z10, Z11, Z12, Z13, Z14, Z15, Z16, Z17, Z18, Z19 and Z20 (Figure 2.1) and analysed for taxonomic identification and enumeration of plankton. Sampling was also carried out along the riverbanks at a few representative locations to study spatial variations across the river width (not shown in the study map).

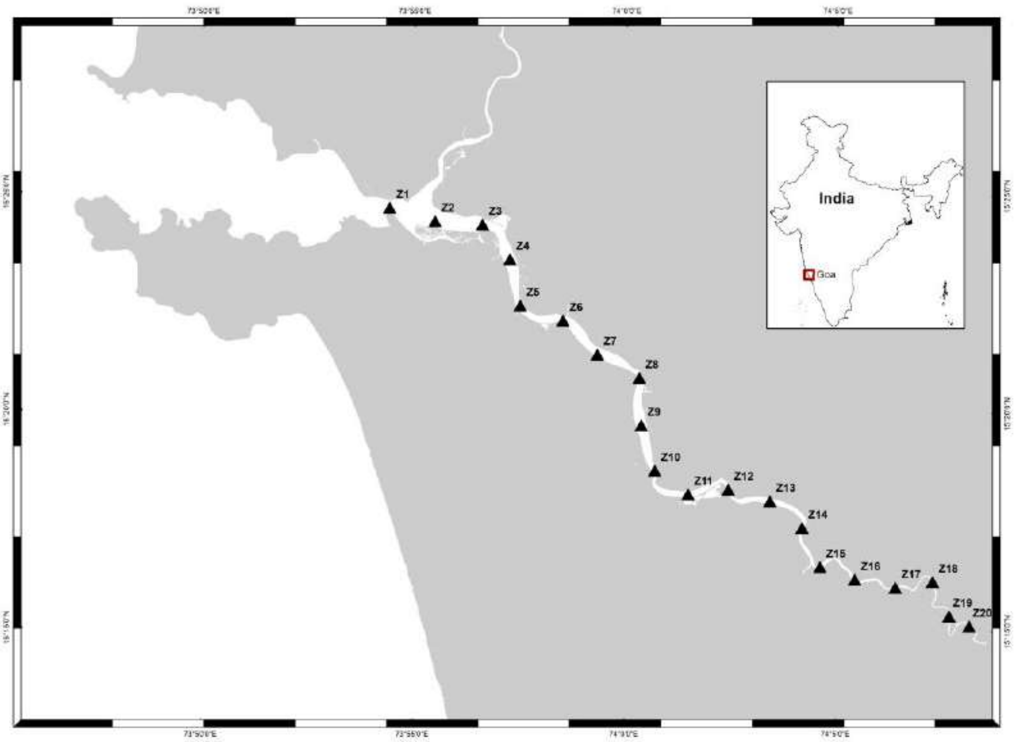


Figure 2.1: Map showing sampling stations in the Zuari estuary

Table 2.1: Sampling locations, coordinates, depth and sediment texture of Zuari estuary				
Station	Location		Depth (m)	Sediment texture
	Lattitude (N)	Longitude (E)		
Z1	15°24.673'	73°54.417'	4	Shell debris
Z2	15°24.368'	73°55.484'	6.5	Silty clay
Z3	15°24.315'	73°56.612'	--	Clay silt
Z4	15°23.506'	73°57.264'	--	Clayey
Z5	15°22.440'	73°57.510'	4.6	No data
Z6	15°22.101'	73°58.525'	6	Clayey sand
Z7	15°21.390'	73°59.387'	4.5	Sandy
Z8	15°20.895'	73°00.237'	7.5	No data
Z9	15°19.707'	74°00.380'	3	Sandy
Z10	15°18.692'	74°00.704'	6.5	Sandy
Z11	15°18.124'	74°01.492'	2.5	Sandy
Z12	15°18,244'	74°02.442'	3	Sandy
Z13	15°17.979'	74°03.434'	4	Sandy
Z14	15°17.363'	74°04.193'	5	Pebbles
Z15	15°16.464'	74°04.648'	2	Gravel
Z16	15°16.209'	74°05.630'	4.5	Clayey
Z17	15°16.003'	74°06.401'	4.3	Gravel
Z18	15°16.141'	74°07.288'	3.6	Gravel
Z19	15°15.354'	74°07.680'	4.6	Gravel
Z20	15°15.115'	74°08.155'	6.15	Gravel

Plate 2.1: Study area of Zuari estuary

2.2 Sediment sample processing

2.2.1 Sample Collection

The sediments from the margins of the estuary were manually collected from 1 m deep waters, by scrapping the top 2 cm of the sediments with a spatula. The surface sediments from the middle of the estuary were collected by using a grab sampler. The top 2 cm of the grab sediment was scrapped with a sterile spatula and transferred to zip-lock bags. A part of the sediment was transferred to plastic containers and immediately stained with ethanol Rose Bengal solution (2 g Rose Bengal in 1 L of 70% ethanol) to identify the living benthic foraminifera. The samples were stored in cool-dry storage boxes. The surface water samples were collected in clean sterile plastic containers for the total suspended matter measurements.

2.2.2 Sample Processing

For grain-size analysis, sediments were freeze-dried, weighed and washed by using 63 µm sieve. The material retained on the sieve (sand, coarse fraction) was dried and stored in plastic vials. The water passing through the sieve containing the clay and silt fraction was collected. The fine fraction solution volume was made to 1000 ml in a glass measuring cylinder, stirred vigorously and left undisturbed for a pre-determined duration, as per the ambient temperature. After the passage of pre-determined time, 25 ml of the solution was siphoned and transferred to pre-weighed glass beakers and dried. The beaker with dried clay was weighed again to get the clay weight. The silt weight was estimated by subtracting the weight of the sand plus clay from the weight of the dry sediment. A part of the freeze dried sediment was powdered and used for total carbon, nitrogen and inorganic carbon analysis. The total carbon and nitrogen was analysed by using a CN analyser and the inorganic carbon was measured by coulometer. The organic carbon was estimated by subtracting the inorganic carbon from the total carbon.

The stained sediments were stored for a couple of weeks for proper staining. The sediments were then directly washed by using a 63 µm sieve. The material retained on the sieve was stored in plastic vials.

2.3 Meiofauna

The sediment samples were collected from 60 stations across the Zuari Estuary. Sampling was carried out from a mechanized boat between 25th, 26th February and 1st of March 2021 using an acrylic core of 4.5 cm in diameter. The sampling stations were represented as ZA and ZB indicating the peripheral regions of Zuari estuary and stations were located at the centre of the Zuari estuary were labeled as Z. Extraction of sand was done in the centre of the estuary while the peripheral regions generally contain sensitive areas like mangroves and embankments. The samples were collected in duplicates at the stations. Samples were not retrived at stations Z1, Z14, Z15, Z17, Z18, Z19, Z20, Z20A and Z20B due to hard substratum. All samples were preserved in mixture of 10% buffered formalin and Rose Bengal solution and stored in polythene bags.

2.3.1 Laboratory analysis

The meiobenthos samples were sieved thoroughly on a 0.3 mm mesh to remove larger macrofauna and then through a 0.04 mm sieve for smaller fauna. The fauna retained on the 0.04 mm mesh was considered as meiofauna which was collected in a 100 ml sample container and preserved in 5% buffered formalin. The fauna was enumerated and taxonomically identified up to the group level under the stereo-zoom microscope (Nikon SMZ18 and Nikon eclipse Ci) using the taxonomic identification guide (Higgins and Thiel, 1988).

2.4 Macrofauna

Total 60 stations were sampled for benthic study from Zuari Estuary. The sampling stations were represented as Z, ZA and ZB. Central stations are represented as Z where there is extraction of sand and peripheral stations were represented as ZA and ZB where there is mangrove area and other sensitive area. Sampling was carried out on a mechanized boat using van Veen grab for the central station and metal quadrant for the peripheral station of the river. All the sediment samples were washed through 300 µm nylon mesh in the field and collected in the polythene bags and preserved in 5% formaldehyde containing Rose Bengal stain. However, sediment samples were recovered from only 51 stations. Sediment could not be retrieved from station Z5, Z8, Z13, Z14, Z15, Z17, Z18, Z19 and Z20 and due to hard substratum. The sand texture at the central region was sandy whereas at the peripheral region it was silty clayey.

2.4.1 Laboratory analysis

In the laboratory, all samples of macrobenthos were once again washed on 300µ sieve. All the fauna were sorted and preserved in 5 % formaldehyde in plastic vials. The fauna was enumerated and identified upto family/genus level under stereo microscope (Nikon SMZ 18) and compound microscope (Nikon Eclipse C*i*). Faunal abundance was calculated as ind. m^{-2}. Polychetes were identified to the highest taxonomic level using available identification keys (Day, 1967; Fauvel, 1953; Fauchald, 1977). Abundance of other fauna such as Oligochaeta, Crustacea, Bivalvia, Gastropoda, Platyhelminthes, Nemertea, Nematoda, Bryozoans, Chironomidae larvae, Fish juveniles, Ophiuroidea were recorded group-wise. Station wise biomass (wet weight) was done and expressed as g m^{-2}.

2.4.2 Benthic Polychaetes Amphipods (BPA) index

To study the pollution status of the marine environment and to access the ecological quality status of the area, biotic indices like Benthic Polychaetes Amphipods (BPA) index was analysed. This index is mainly based on the ratio of sensitive amphipods to other fauna like annelids (polychaetes). The Benthic Polychaetes Amphipods (BPA) index was determined by the lack of sensitive species among polychaetes from the study area. Amphipods are the second abundant fauna of the estuarine area and marine soft-bottoms and they are sensitive to polluted sediments. They mainly disappear from benthic communities which is impacted by pollution and will reappear when the environmental condition recover (Ré et al., 2009; de-la-Ossa-Carretero et al., 2012).

The Benthic Polychaetes Amphipods (BPA) ratio index is given as:

$$BPA = \log10\ [fp/(fa+ 1)+ 1]$$

Where *f*p was the polychaete frequency and *f*a is the amphipod frequency and +1 used to prevent a total absence of amphipods and the other +1 used to prevent a total absence of opportunistic polychaetes. This index corresponded to the total number of polychaetes (annelida) and total number of amphipods divided by the overall abundance accounted in a station sample. Thresholds for establishing the Ecological Quality status by each index, the valves ranged as 0.025-0.130 (Good status), 0.130-0.199 (moderate status), 0.199-0.255 (poor status).

2.4.3 Diversity indices

All the raw data was initially processed using Microsoft Excel. Further processing of the ecological data was done using the PRIMER (Plymouth Routine in Multivariate Ecological Research) software package (Clarke and Warwick, 1994) after square root transformation. The univariate measures such as number of individuals or specimens (N), number of species (S), Shannon- Wiener diversity index (H'), Margalef species richness (d), Pielou's eveness (J') and Simpson index (1-lambda') were calculated using log2 scale at each station (Clarke & Gorley, 2001).

2.4.4 Shannon-Wiener index of diversity

Shannon-Wiener diversity index a measure derived from information theories developed by Shannon & Wiener (1949), which is used by ecologists when a system contains many individuals for each to be identified and examined. The index is the ratio of the number of species to their importance values (e.g. biomass or productivity) within a trophic level or community. This normalizes the Shannon diversity index to a value between 0 and 1. The lower values indicate more diversity while higher values indicate less diversity. Specifically, an index value of 1 means all groups has the same frequency.

2.4.5 Simpson's Diversity Index

Simpson's Diversity Index (D) is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. As species richness and evenness increase, so diversity increases. The value of Simpson's Diversity Index ranges between 0 and 1. 1 represents infinite diversity and 0 denotes no diversity.

2.4.6 Biotic indices

Biotic indices are developed based on indicator species, used as a guide to the level of a particular abiotic factor. For example, the presence of certain invertebrate groups in aquatic ecosystem can be awarded a score that indicates the quality of the water. Indices like AZTI Marine Biotic Index (AMBI), Multivariate AMBI (M-AMBI) and Bentix index are specialized case of a diversity index generally considered an important means for assessment of water-pollution, and ecosystem stability.

2.4.7 AMBI index

The AZTI Marine Biotic Index (AMBI) is software developed by AZTI- Tecnalia for assessing the quality of benthic macro-invertebrates assemblages by calculating the homonymous index. It was developed in order to establish the ecological quality of European coasts and estuaries. This index explores the response of soft-bottom communities to natural and man-induced changes in water quality, integrating long-term environmental conditions. AZTI Marine Biotic Index (AMBI) relies on the calculation of the biotic coefficient (BC), which is, in turn, based on the proportion of disturbance-sensitive taxa and is expressed on a continuous scale ranging from 0 (best status) to 6 (worst status). The AMBI approach follows a model (Glémarec & Hily, 1981; Grall & Glémarec, 1997) which categorises benthic invertebrates into five ecological groups (EGs), depending on their dominance along a gradient of organic enrichment and oxygen depletion. The software includes near 8,000 taxa from all seas, representative of the most important soft-bottom communities presents at estuarine and coastal systems, from the North Sea to the Mediterranean, North and South America, Asia etc.

2.4.8 M-AMBI index

M-AMBI ('Multivariate AMBI', Bald et al., 2005; Muxika et al., 2007) is a multimetric index for assessing the ecological quality status of marine and transitional waters. It is based on benthic macro invertebrates and integrates AMBI, a biotic index based on species sensitivity/tolerance, with diversity and richness, making it compliant with the European Water Framework Directive. It adopts a multivariate (trivariate) approach, integrating the response of three selected metrics, i.e. species richness, Shannon diversity index (Shannon & Weaner, 1949) and biotic index AMBI (Borja et al., 2000). The success of AMBI paved the way for the introduction of M-AMBI; which was subsequently incorporated into the regulations of several European countries. The M-AMBI algorithm integrates the metrics by means of factor analysis (FA).

2.4.9 BENTIX index

The Bentix index (Simboura and Zenetos, 2002) is a marine biotic index based on the concept of indicator species and was developed for the purpose of the ecological status classification of the marine environment using the macroinvertebrates quality element. The index is designed for the assessment of the impact caused by general stress factors and does not discriminate among natural and anthropogenic disturbance. It has been tested successfully in a variety of Hellenic benthic ecosystems (Simboura and Zenetos, 2002) and areas subject to organic pollution such as the Athens or Saronikos gulf (Simboura et al., 2005), to oil spills accidents (Zenetos et al., 2004) and is currently tested in other Mediterranean areas within the framework of the EU Water Framework Directive inter calibration exercise (EC, 2003).

BENTIX Index (Simboura and Zenetos, 2002):

BENTIX considers sensitive (GS) and tolerant (GT) taxa based on the reduction of five EG's (as per AMBI) to two EG's, i.e. EG-I, II as EG-I and EG-III, -IV, -V as EG-II for BENTIX. For BENTIX computation, a newly developed add-in BENTIX v.09 (beta version) software package was used.

2.4.10 AMBI and M-AMBI index

AMBI relies on the abundance-weighted average disturbance sensitivity of the macrobenthic species in a sample (Borja et al., 2000). Each species was distributed in five ecological groups (EG) as per their sensitivity to an increasing stress gradient as summarized by AZTI's classification (Grall and Glémarec 1997).

EG I: species sensitive to organic enrichment and present only under unpolluted conditions.

EG II: species indifferent to enrichment, present in low densities with non-significant variations.

EG III: species tolerant to high organic matter enrichment.

EG IV: second-order opportunistic species.

EG V: first-order opportunistic species, able to withstand high disturbance.

The index calculation was done by the software provided at AZTI's software, following the guidelines of Borja and Muxika, (2005). The index generates a final score on a continuous scale from 1 to 6 (7 in azoic sediments) and the thresholds used to define benthic community health were <1.2 (undisturbed), 1.2–3.3 (slightly disturbed), 3.3–5 (moderately disturbed), 5–6 (heavily disturbed) and >6 (extremely disturbed) (Borja et al., 2000) which were then condensed to a high, good, moderate, poor and bad status respectively. The multivariate AMBI (M-AMBI) combines with AMBI values in a factor analysis multivariate approach (Table 2.2).

Table 2.2: Threshold limits used for ecological status of AMBI and M-AMBI index

	AMBI	M-AMBI
High	0.0-1.2	>0.77

Good	1.2-3.3	0.53-0.77
Moderate	3.3-5.0	0.35-0.53
Poor	5.0-6.0	0.20-0.38
Bad	6.0-7.0	<0.2

2.5 Methodology for physical parameters and numerical modelling

2.5.1 Methodology for physical parameters measurement

This section comprises of the physical measurements carried out at Zuari Estuary for the validation of numerical model. The deployment locations (Figure 2.2), duration and various instruments used for measuring different parameters, are given in Table 2.3. Current and water level measurements (WLM) (ZC1 and ZC2) were done in the Zuari Estuary. During monsoon, current and water level measurements were carried out at ZC1 while during non-monsoon, current and water level measurements were carried out at ZC2. Current measurements at mid-depth were carried out using self-recording current meters (RCM). Watch-keeping boats were engaged for guarding the same. The current meter was hanged from the watch keeping boat. Water level measurement at ZL1, also carried out. CEESCOPE portable echosounder was used to measure the water depths along the cross sections of Zuari estuary during January, 2021. The water depth measurement track is shown below (Figure 2.3).

Table 2.3: Table showing instruments used and deployed locations

Location ID	INSTRUMENT	POSITION (Latitude and longitude)	Measurement Period	Water depth at Current measuring point (m)
ZC1	RCM9	15°15'59.6"N 74°06'08.6"E	21/7/2020-20/8/2020	5
	SeaGuard		21/7/2020-3/8/2020	
ZC2	RCM9	15°24’36.2” N 73°53’46.00” E	25/3/2021-25/4/2021	3.6
	SeaGuard		25/3/2021-25/4/2021	
ZL1	SeaGuard	15°15'17.1"N 74°07'40.8"E	21/7/2020-25/4/2021	4

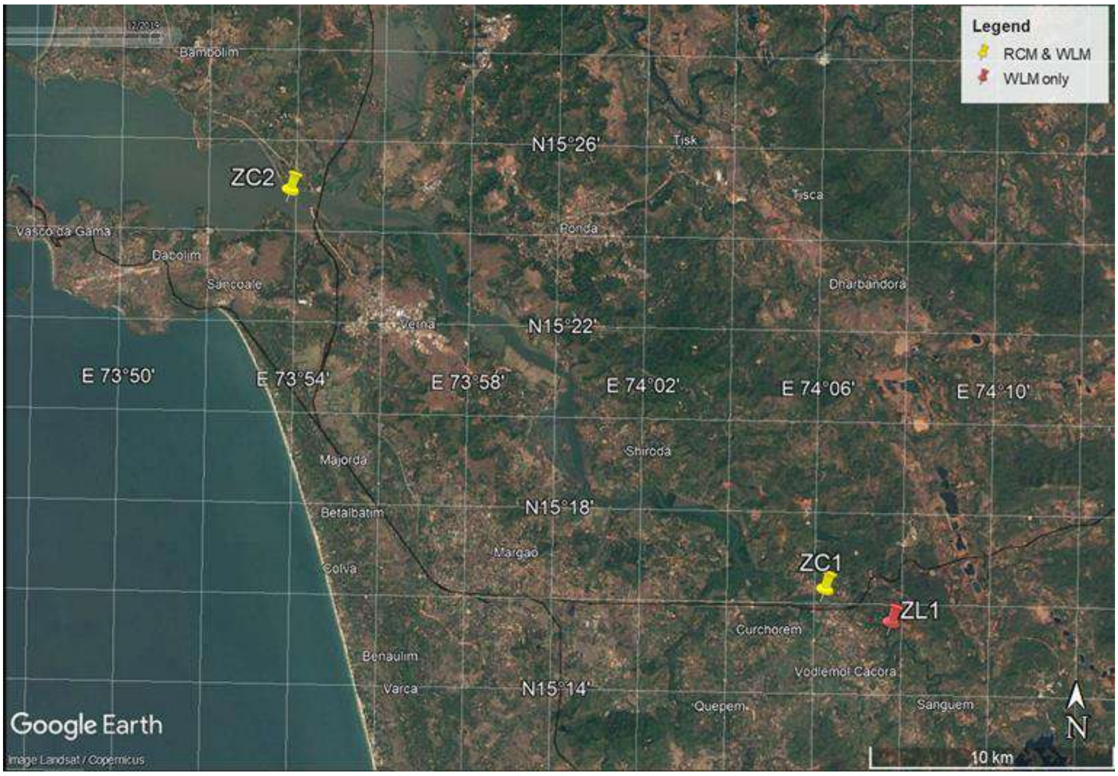


Figure 2.2: Locations of current and water level measurements in the Zuari estuary

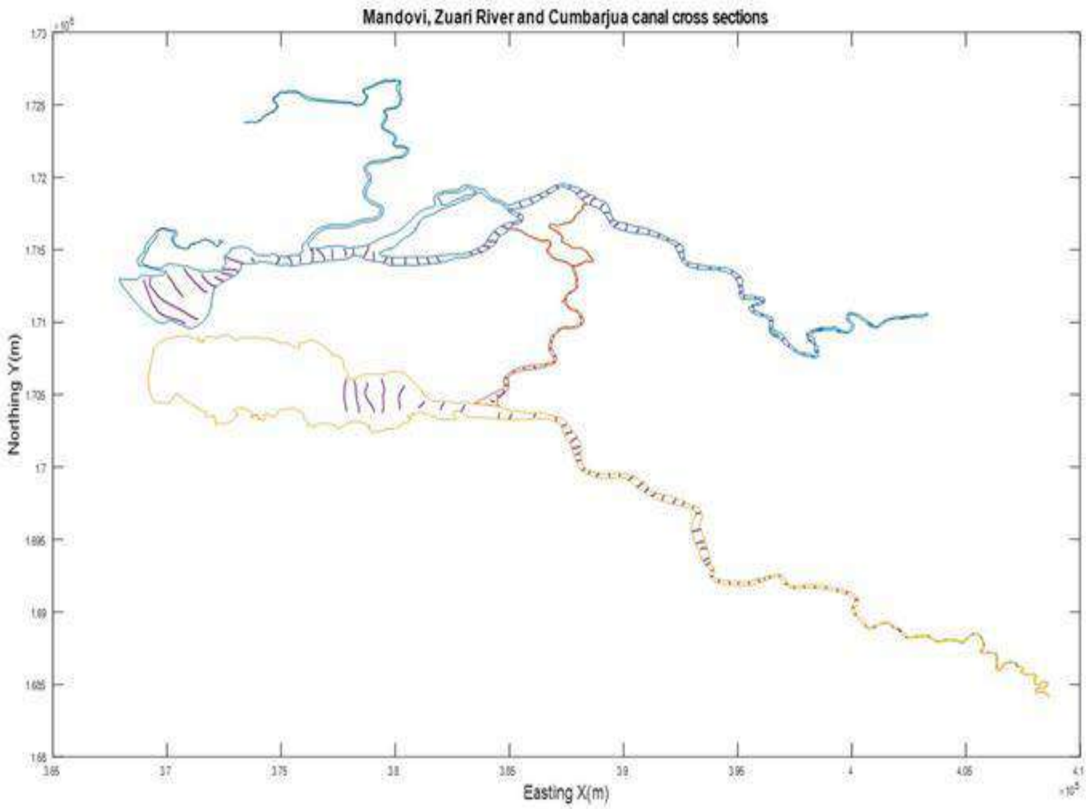


Figure 2.3: Water depth measurement track

2.5.2 Methodology for Numerical Modelling Studies

The main inputs considered to the numerical model are river topography and water level. The water depth information of Zuari estuary was collected during January-February, 2021 using an echosounder. Then the collected water depth information is processed and used for numerical modelling. The base case scenario (Case-1) is with measured water depth information. The second scenario (Case-2) is the modified bathymetry by deepening 3m uniformly at 6 locations (A-F), as in Figure 2.4 of Zuari estuary.

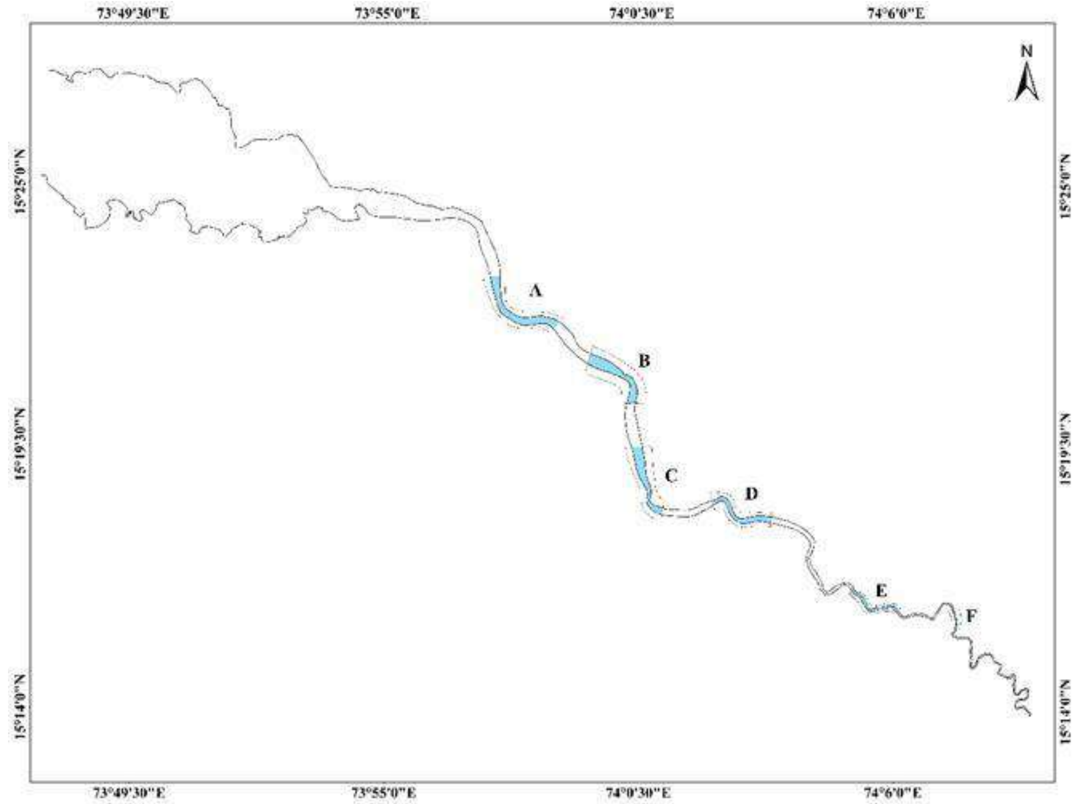


Figure 2.4: Figure showing six different sections (A-F)

The numerical model is setup for various scenarios initially to ascertain the validity of the model for the study region. In order to test the validity of the model, purely tidal forcing is given to the model during non-monsoon. However, during monsoon, measured water level data at the upstream model boundary of Zuari estuary, is given to the model and the hydrodynamic results are compared.

In this study, the effects of the deepening of the river at A-F sections on the hydrodynamics and morphology are studied by comparing with the base case scenario. The Case-1 (base case) scenario model therefore provides a basis for comparison with the modified bathymetry model simulations. In this study, after testing the validity of the model, the numerical model is simulated for July-

November, 2020 (during monsoon period) and November, 2020 -June, 2021 (during non-monsoon period) of Zuari estuary.

2.5.3 Assessment of mining

Based on the modelling of the hydrodynamics or flow conditions of the region, possible impacts due to the Case-2 scenario of this work are reported in terms of (i) changes in flow or hydrodynamics impact, and (ii) bed level change or morphological impact. The difference between the base case (Case-1) and modified bathymetry case (Case-2) are studied to ascertain the changes in flow patterns and bed morphology changes. The variations of current speed and bed level changes for each of the scenarios are also compared for each section A-F, in the study region.

2.5.4 Hydrodynamic impact

Any change in existing bathymetry, results in changes in the local hydrodynamics till such time equilibrium is attained. Till then the local hydrodynamics would be in dynamic mode adjusting to the new and changing conditions. The extent of change in the hydrodynamics can be ascertained through comparison of flow conditions between the base case (Case-1) and modified bathymetry case (Case-2). In this study, the hydrodynamic impact assessment is carried out through numerical modelling of flow conditions. This is ascertained by studying the differences between the validated model results for the base case and the modified bathymetry case.

2.5.5 Morphological impact

The activity of sand mining would modify the local bottom topography which in turn changes the local hydrodynamics. The impact of the change in bottom topography is studied through numerical modelling of the bed level changes. Modelling the morphology changes using the sediment transport model provides the bed level changes. The changes in the bed morphology for the base case, as well as the modified bathymetry scenario, are carried out.

CHAPTER 3: PHYSICO-CHEMICAL AND BIOLOGICAL PARAMETERS

3.1 Introduction

Estuaries are specialized ecosystems with contrasting biogeochemical regimes linking two ecosystems, riverine and marine, with distinct biological communities and the structuring processes. It is well known that estuaries receive a substantial contribution of carbon and nitrogen, more so from the terrestrial region that can at times lead to the uncontrolled growth of some organisms, such as harmful algal blooms. Furthermore, consequent to death-decay and sinking of blooming/swarming organisms can lead to hypoxia (/anoxia) beginning from the near bottom, altering the ecosystem's health. Therefore, reducing sediment and the water column (near the bottom) can significantly facilitate N (and C) transformation consequent to microbial activities, more so in the tropical regions.

The Mandovi – Zuari, the two primary rivers in the state of Goa described as the lifeline of Goa. These tropical monsoonal estuaries of India, undergoes extreme change in salinity regime seasonally. Owing to its geographical set up the estuarine systems receives enormous precipitation during wet season and run-off from a large catchment area. In contrast, during dry season, negligible riverine discharge leads to seawater domination and formation of a prominent salinity gradient. Thus, the estuarine sediments have a vital role to play in ecosystem functioning/health, such as preventing an estuarine system from being nutrient-limited by giving out nutrient and, on the other side, can avoid being eutrophic by acting act as a nutrient trap. Thus, any uncontrolled disturbance to the benthic ecosystem, including sand mining, is likely to disturb the benthic life which is expected to percolate into the food chain bringing imbalance in the whole ecosystem. Our aim of this project is to address the impact of sand mining on different ecosystem gradients to facilitate appropriate ecosystem management.

3.2 Physico-chemical parameters

3.2.1 Temperature and Salinity

During the sampling period, the station depths of the Zuari estuary varied between 3 and 8m (avg. 5m), with a deeper zone at the near mouth region, the deepest point at station Z8 (Figure 2.1). Similar to the other estuaries of Goa, the Zuari estuary is also influenced by the tidal currents influencing hydrography. The Secchi disk values indicated the shallow part of the estuary to be well illuminated in the upstream region (Stn Z11-Z20) (see Figure 3.1).

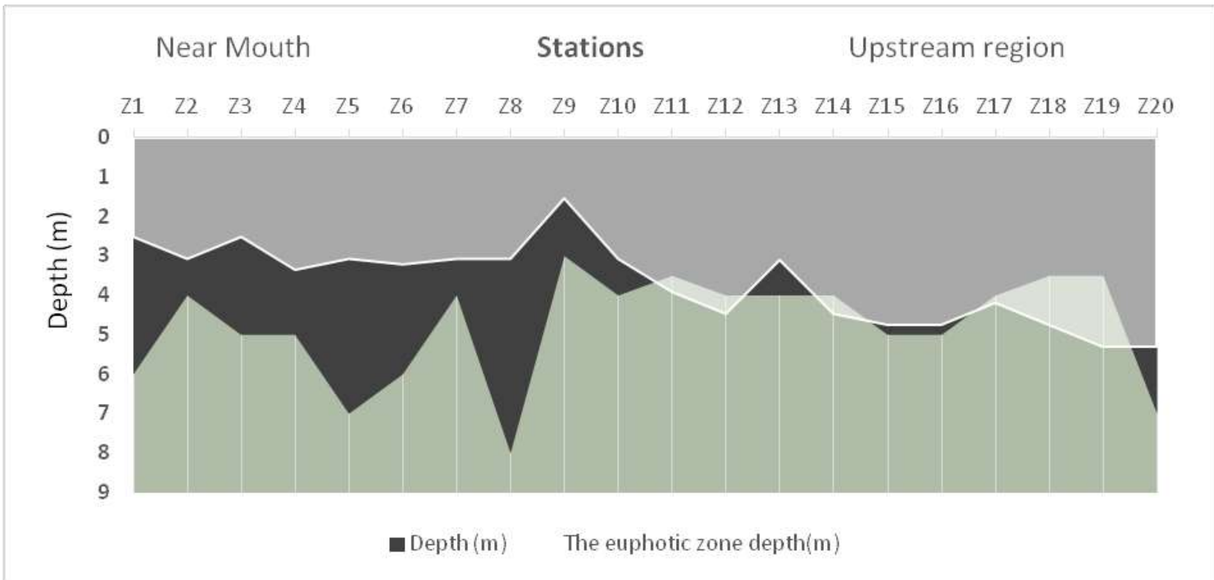


Figure 3.1: Sampling station depths (m) and the depth of euphotic zone (m) in the Zuari estuary

In general, salinity (PSU) profiles depicted large variations (0.0-24.0) than that of temperature (°C) which varied narrowly (29.0- 30.7; avg. 29.83) (Figure 3.2, 3.3). The relative water with higher temperature (>29°C) was restricted to the near mouth region (avg. 30.34°C), while lower temperature waters prevailed in the middle (<29.74°C) and upstream region (29.37°C; Figure 3.2). Likewise, freshwater dominated the upper part of the estuary beyond station Z14; saline water (20-25) influenced the near mouth region (stns Z1-Z8) while the region in between experienced brackish water (Figure 3.3).

Thus, hydrographic feature characteristically divides the river into three zones, Zone-1: region under the influence of seawater (stns Z1-Z8), Zone-2: transitional zone (stns Z9-Z13) and Zone- 3: region influenced by the freshwater (stns Z14-Z20).

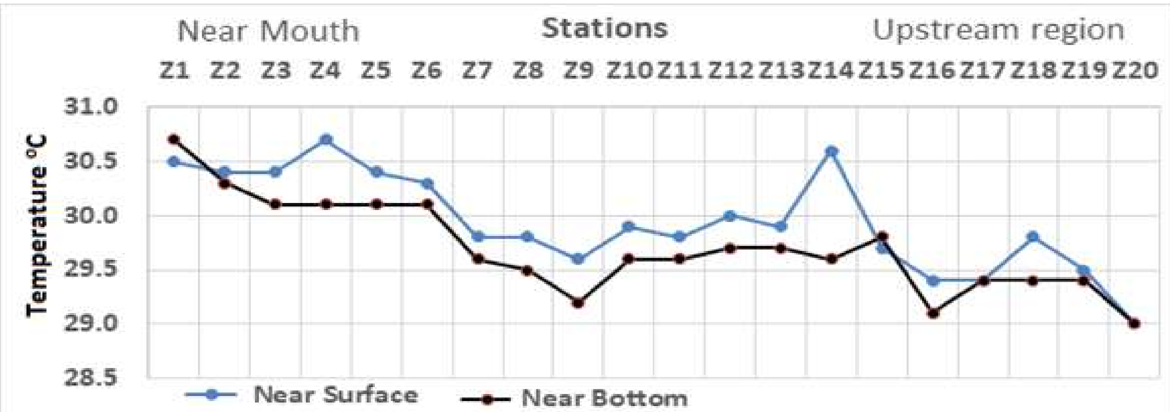


Figure 3.2: Spatial variations of temperature (surface and bottom) in the Zuari estuary (Z1-near mouth and Z20-upstream region)

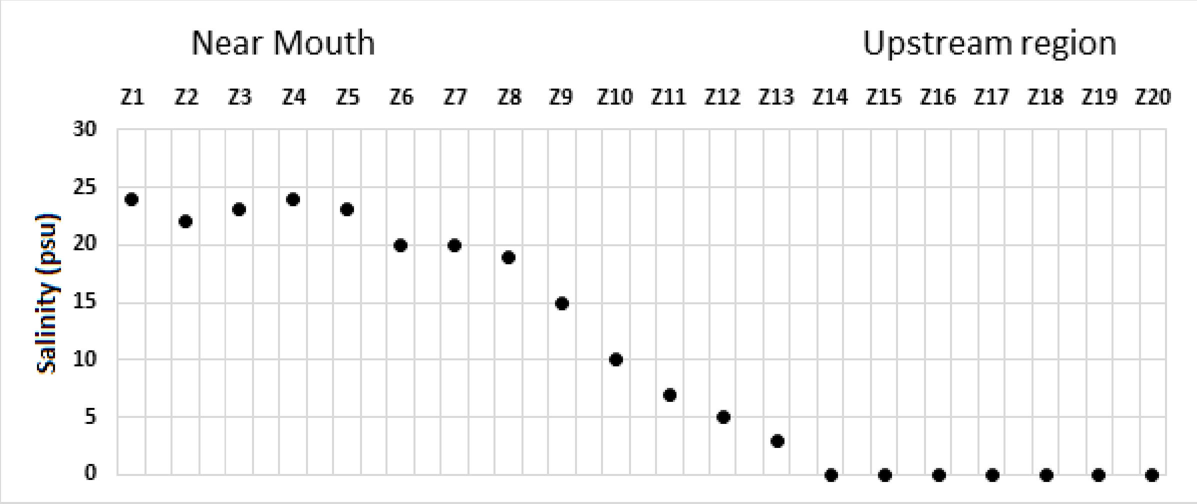


Figure 3.3: Spatial variations of salinity (surface) in the Zuari estuary (Z1-near mouth and Z20-upstream region)

3.2.2 Dissolved oxygen and nutrients

From near mouth to upstream region, the Zuari waters found well saturated with O_2 varying from 2.75 to 4.85 ml L^{-1} (avg. 3.61 ml L^{-1}) with an increasing trend towards upstream. Interestingly, the prevailed near-bottom waters above the hypoxic level (O_2 > 1.4 ml L^{-1}) indicated a healthy environment for aquatic organisms (Figure 3.4).

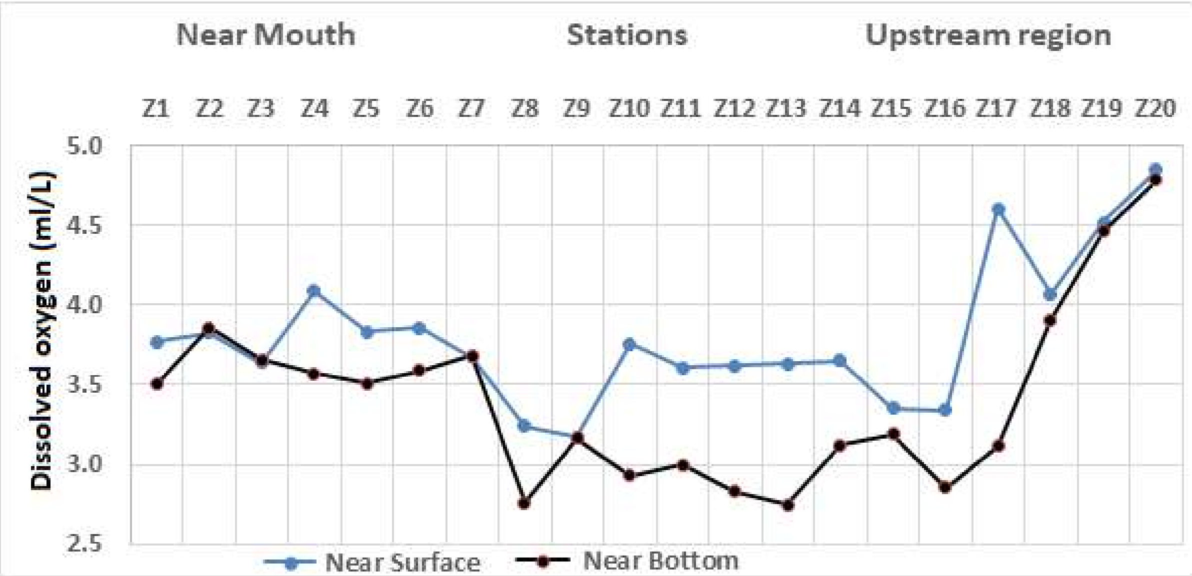
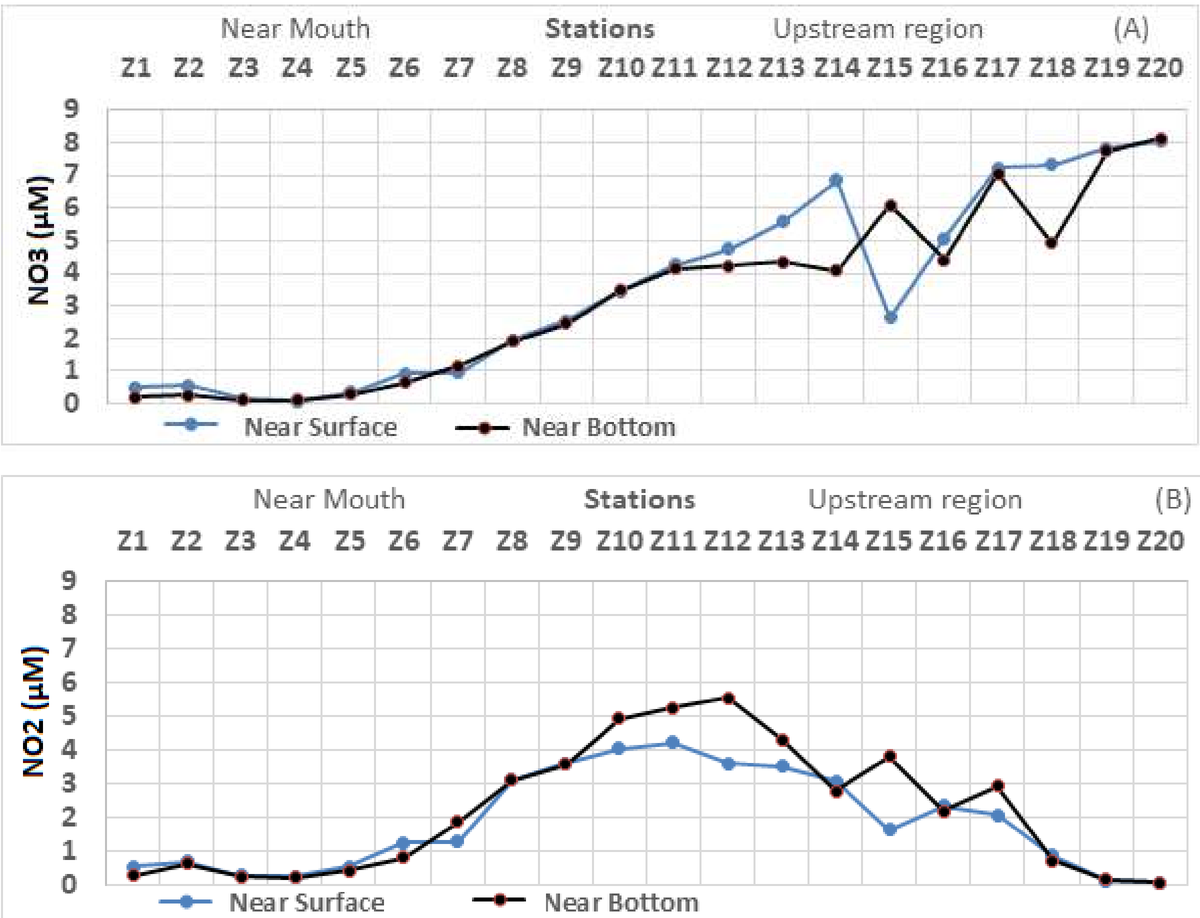


Figure 3.4: Spatial variations (surface and bottom) of dissolved oxygen in the Zuari estuary (Z1-Near mouth and Z20-upstream region)

The distribution of nutrients in the Zuari estuary is shown in Figure 3.5. The nitrate level in the study region varied from 0.08 to 8.12 µM (avg: 3.42), with a lower concentration at the near mouth that increased gradually towards the upstream region. Likewise, silicate concentrations that varied from 11.72 to 80.3 µM (avg: 42.43) also showed higher values in the upstream region. On the contrary, phosphate concentration changed from 0.08-0.89 µM (avg. 0.31) showed a decreasing trend from near mouth to upstream region. A single sizeable mid-estuarine maximum was prominent in nitrite levels (stn Z11/Z12) and two peaks in Ammonium levels at stn Z9 and Z18.

In general, nitrite concentration, which varied from 0.07 – 5.57 µM (avg. 2.03), showed a clear decreasing trend (<1 µM) towards the mouth and the upstream region. Near undetectable levels of ammonium (<0.1 µM) were recorded only at stations Z12-Z13. It is remarkable to see the influence of freshwater in the Zuari estuary, mainly up to the stn Z14 from the riverine end and after that seawater penetration, influencing the concentrations of O_2 and nutrients.



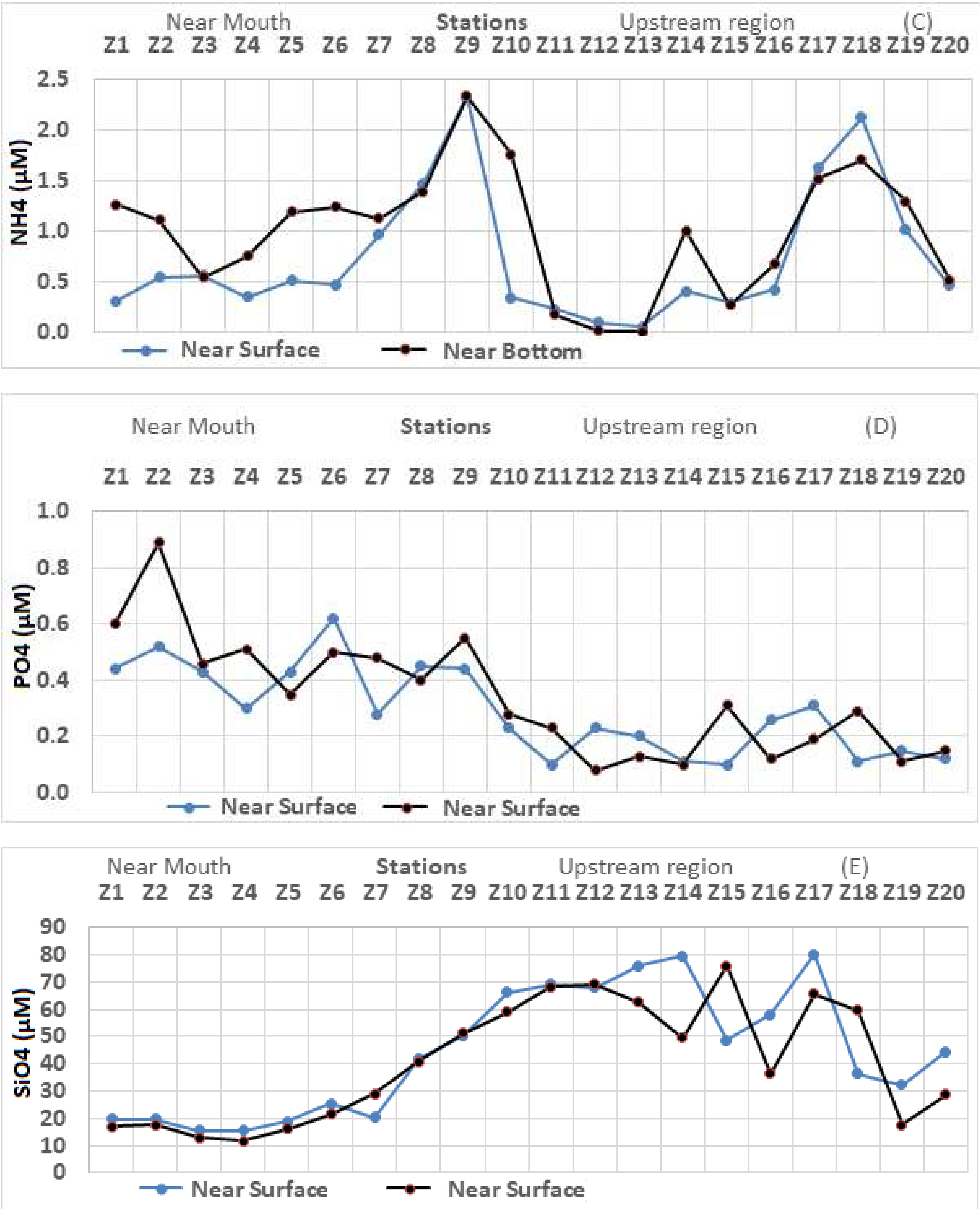


Figure 3.5: Spatial variations of (A) nitrate (NO_3), (B) nitrite (NO_2), (C) ammonium (NH_4), (D) phosphate (PO_4) and (E) silicate (SiO_4) in the Zuari estuary (Z1-river mouth and Z20-upstream region)

3.2.3 pH

The pH is the degree of concentration of hydrogen ions in a substance or solution. The lower the pH value, the higher the acidity, while solutions with high pH are basic (= alkaline). Before the Industrial Revolution, the average ocean pH was about 8.2. The pH measurements were made using a calibrated pH sensor.

In the Zuari estuary, water pH was generally low (6.39-7.36; avg. 7.38) even at the near mouth stn Z1 (with a salinity influence of 24). Vertically in the water column, relatively higher values were recorded in the near-bottom than near-surface measurements. Spatially, more acidic conditions (<6.9) prevailed in the riverine end (Figure 3.6).

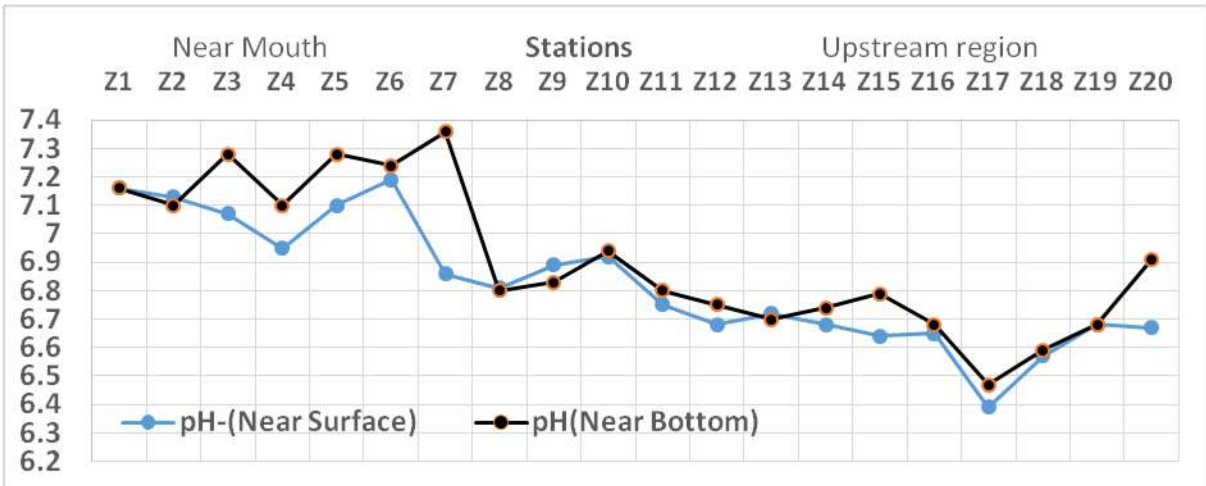


Figure 3.6: Spatial variations (surface and bottom) of pH in the Zuari estuary (1-river mouth and 21-upstream region)

3.2.4 Turbidity

Turbidity is the measure of intensity of light transmitted through different layers of water. The water columns can contain significant amounts of suspended sediment (called turbidity/napheloid layer), which generally forms due to resuspension of bottom sediments caused by tidal currents/ anthropogenic activities, including mining. The turbidity layer can scavenge organic particles from the water column into the sediment.

In the Zuari estuary, turbidity values varied between 5.7 and 70.0 NTU (Avg. 22.6), with higher values near bottom depth. Noted peak values (>50) at stns Z2, Z9, and Z16 indicate possible sites of anthropogenic disturbances (Figure 3.7).

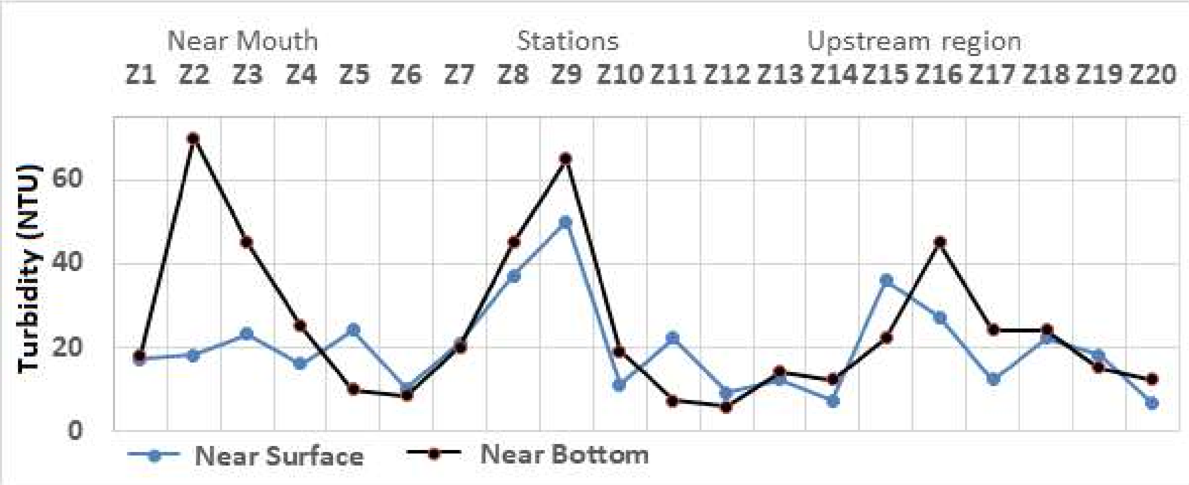


Figure 3.7: Spatial variations (surface and bottom) of turbidity (NTU) in the Zuari estuary (Z1-Near mouth and Z20-upstream region)

3.3 Biological parameters

Planktonic organisms such as phytoplankton and zooplankton drift in the water at the mercy of water current are an essential food resource of aquatic ecosystems. They are influenced by various physico-chemical variables reflecting the environmental status. Thus, plankton serves as an integrator of hydroclimatic forcing and provides information on an aquatic ecosystem's state.

3.3.1 Phytoplankton

Chlorophyll *a* (Chl *a*)

One of the most widely used proxies of phytoplankton biomass is the total Chl *a* (mg m^{-3}) concentration measured fluorometrically. Their values showed spatial variation with an increasing trend towards the upstream region, similar to dissolved oxygen concentration. Biomass that varied between 0.64 and 3.05 (avg. 1.57) showed the lowest concentration in the mid-stream region, particularly at stn Z8, also showed variations in the water column vertically. Generally, the near-surface waters were found to be more productive, especially upstream region, while well mixed near mouth region (Stns Z1-Z9) was comparatively less productive (Figure 3.8).

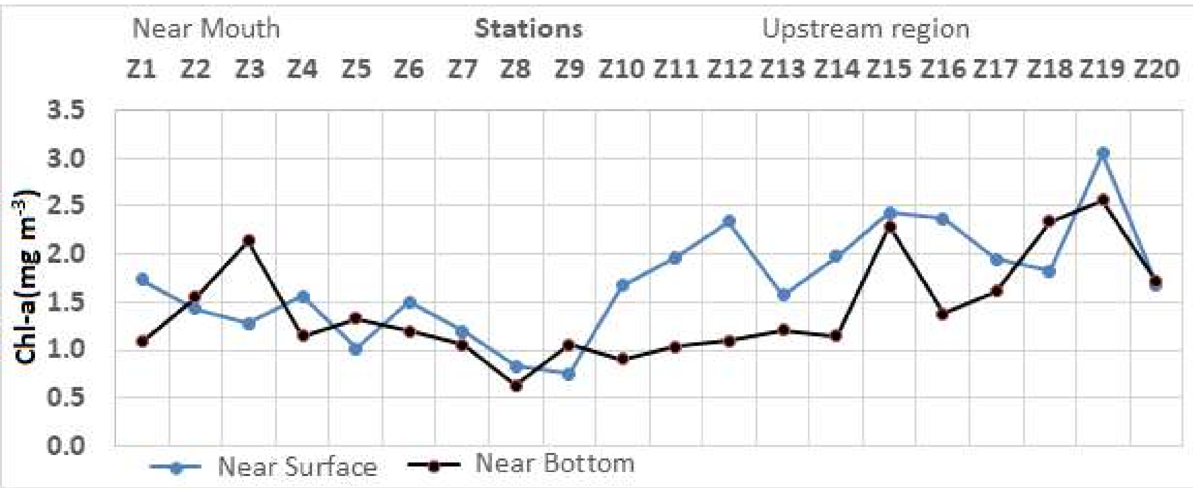


Figure 3.8: Spatial variations (surface and bottom) of surface water Chlorophyll *a* (mg m^{-3}) in the Zuari estuary (Z1-near mouth and Z20-upstream region)

Likewise, sedimentary chlorophyll *a* biomass also showed variability (0.03 and 1.7 mg g^{-1}; avg 0.30) with higher concentration mainly in the midstream region and consistently lower values (< 0.06 mg g^{-1}) in the near mouth area (Figure 3.9).

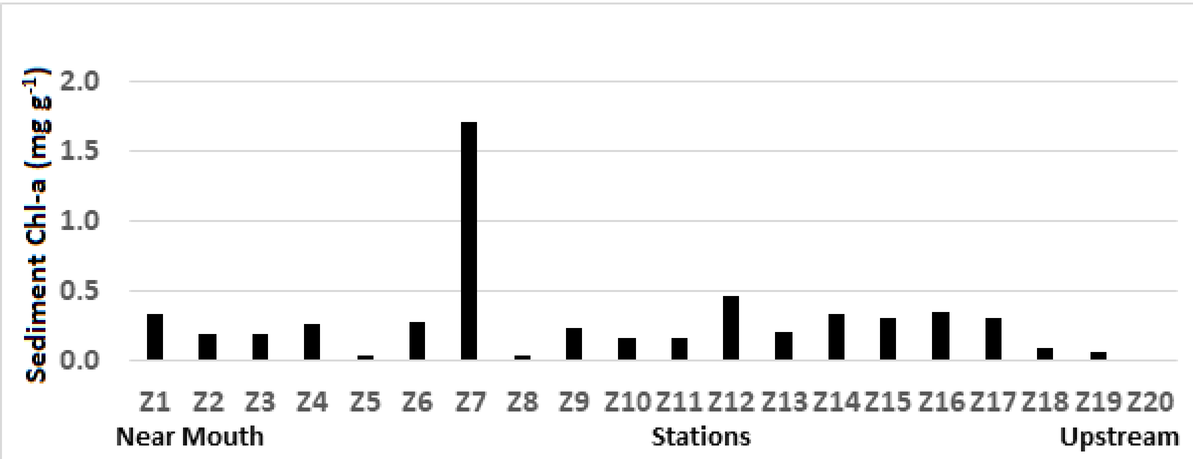


Figure 3.9: Spatial variations of sedimentary Chlorophyll *a* (mg g^{-1}) in the Zuari estuary (1-river mouth and 21-upstream region)

Species composition and abundance of phytoplankton

Phytoplankton composition and its numerical abundance studied from the Zuari river following microscopic technique (>10um in size) showed diverse forms (Genera: 102; Table 3.1). These forms representing the phytoplankton community are grouped broadly into nine phyla: (i) Bacillariophyta, (ii) Dinoflagellata/Myzozoa, (iii) Charophyta, (iv) Cryptophyta, (v) Chlorophyte, (vi) Cyanobacteria, (vii) Euglenozoa, (viii) Ochrophyta and (ix) Cryptophyta. Bacillariophyta was comprising diatoms with predominantly centric forms (centric: 25 genera and pennate: 21 genera), while Dinoflagellata, was characterized by 15 genera. Other phyla such as were less diverse, Charophyta (represented by 20 Genera), Cyanobacteria (6 Genera), and Chlorophyta (9 Genera) and 1 each of Ochrophyta and Euglenozoa. The clear gradient in phytoplankton community composition was also observed in this river with the dominance of diatoms near the mouth and others in the midstream-upstream regions. Amongst the genera *Pleurosigma*, *Navicula*, *Nitzschia*, *Gymnodinium*, *Cymbella*, *Thalassiosira*, *Cyclotella*, *Scrippsiella*, *Surirella*, *Staurastrum*, *Coscinodiscus*, *Chaetoceros*, *Thalassionema*, *Synedra*, *Amphiprora*, *Cryptomonas*, *Amphora*, *Pseudo-nitzchia*, *Pinnularia* majorly dominated the community.

Numerically, phytoplankton abundance varied within the water column (3.7-262.2 10^3 L^{-1}; avg. 51.1) showed spatial variation along the river length (Figure 3.10). The higher population was found chiefly at the upstream freshwater region (stns Z19 & Z20), whereas moderate and low abundance were detected at the mouth and mid-stream regions respectively. An increasing trend of numerical abundance at the upstream location was due to freshwater species of phytoplankton belonging to Cyanobacteria, Chlorophyta and Charophyta. Interestingly, Cryptophyta proliferated in the middle part of the estuary (Stns Z11 to Z13) (Figure 3.11).

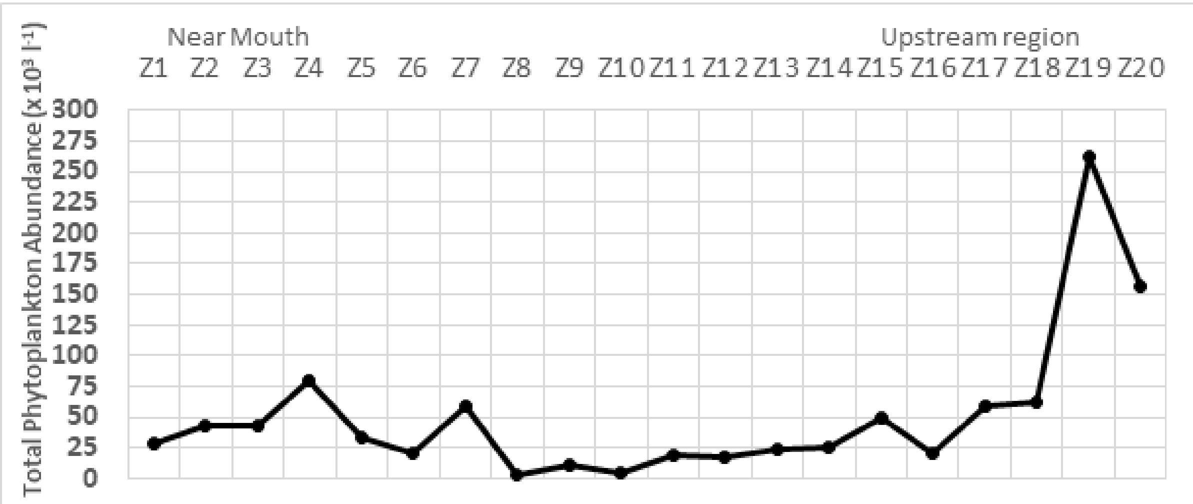


Figure 3.10: Spatial variations of phytoplankton abundance (average) in the Zuari estuary (Z1-Near mouth and Z20-upstream region)

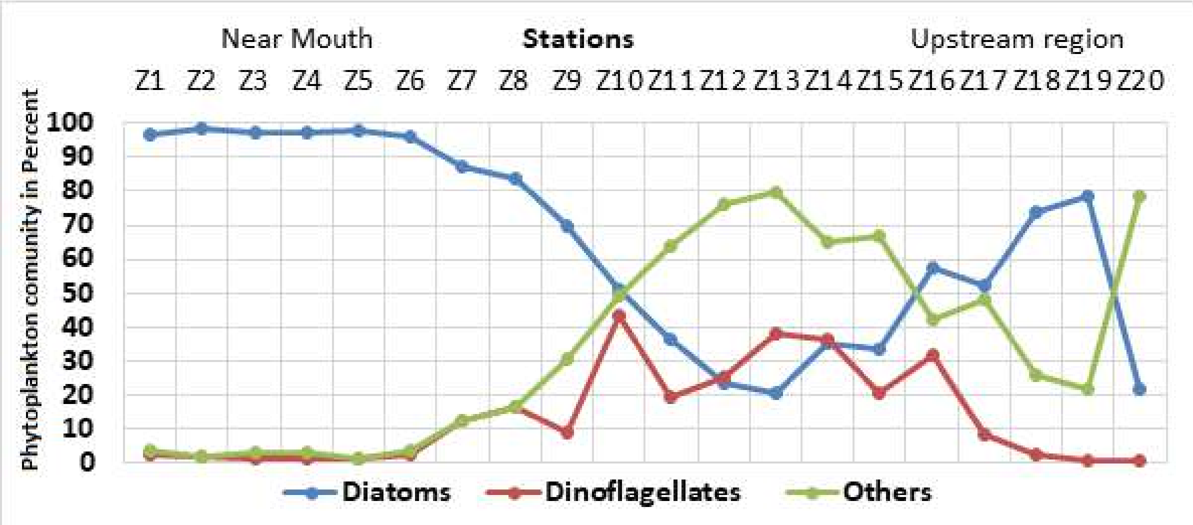


Figure 3.11: Percent contribution of Bacillariophyta, Dinoflagellata and other forms (Cryptophyta, Cyanophyta, Charophyta, Chlorophyta, Ochrophyta and Euglenozoa to the phytoplankton abundance (average) in the Zuari estuary (Z1-near mouth and Z20-upstream region)

Table 3.1: Spatial variation of phytoplankton composition and abundance in the Zuari estuary

Phytoplankton Abundance and Composition (Average abundance of surface and near bottom samples)	<--- Near Mouth				Stations									Upstream --->						
Phyllum: Bacillariophyta																				
DIATOM (Centric)	**Z1**	**Z2**	**Z3**	**Z4**	**Z5**	**Z6**	**Z7**	**Z8**	**Z9**	**Z10**	**Z11**	**Z12**	**Z13**	**Z14**	**Z15**	**Z16**	**Z17**	**Z18**	**Z19**	**Z20**
Actinoptychus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	111	-	-
Arthrospira filaments	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	330	-	-
Aulacodiscus spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4868	2464	11980	15800	153458	13914
Aulacoseira spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	878	825	9359	1420
Bacteriastrum sp.	1004	581	4070	2329	3216	500	296	-	-	-	-	-	-	-	-	-	-	-	-	-
Bellerochea spp.	3252	6654	4880	2390	4140	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cerataulina sp	-	268	220	1100	288	-	-	218	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros spp.	10749	11582	7979	16338	7114	3682	15757	565	108	209	22	232	-	-	-	102	-	-	-	-
Coscinodiscus spp.	360	268	-	1992	480	-	2296	-	-	110	-	255	1500	1010	-	2576	5445	1665	2755	-
Cyclotella spp.	-	250	220	2268	384	-	508	-	714	873	1570	1755	-	1616	1530	1259	4660	8880	1208	3450
Dactyliosolen sp	2175	1125	4430	-	3264	1740	2428	-	-	-	-	-	400	-	-	-	-	-	-	-
Ditylum sp	-	-	-	-	-	240	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eucampia spp	-	625	1105	165	774	1225	286	-	-	27	-	-	-	-	-	-	-	-	-	-
Guinardia sp.	30	156	-	1450	72	-	160	-	-	-	-	-	-	101	-	-	-	-	-	-
Hemiaulace sp.	-	-	60	358	48	265	160	-	-	-	-	-	-	-	-	-	-	-	-	-
Hyalotheca sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10368
Leptocylindru sp.	845	-	900	-	-	-	-	-	-	-	-	143	-	101	-	-	-	-	-	-
Melosera spp.	-	670	-	1100	496	-	-	-	40	-	81	-	-	-	-	-	-	74	149	36
Odontella spp.	-	-	-	228	84	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Panktonella sol	121	-	-	-	-	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhizosolania spp.	1290	1518	773	1077	1532	900	-	33	-	-	-	-	-	-	-	-	-	-	-	-
Skeletonema spp.	-	-	-	-	-	-	-	-	-	-	1800	-	-	-	-	-	-	-	-	-
Stephanodiscus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	188	112	-	4125	-	-
Surirella spp.	-	929	3280	1250	-	400	767	-	-	109	-	85	-	202	102	-	242	2885	3631	223
Thalassiosira spp.	967	1068	180	-	1050	500	3312	354	60	165	600	170	892	505	141	-	-	-	1400	122
DIATOM (pennate)																				
Achnanthes sp.	-	-	-	-	-	-	-	-	-	220	-	-	-	-	-	-	-	-	-	-
Amphora spp.	-	-	330	228	252	1200	128	-	-	-	-	255	-	-	290	784	-	554	336	108
Amphiprora spp.	-	250	275	114	42	150	-	-	-	-	-	-	348	101	251	224	1924	2488	4271	-
Bacillaria spp.	-	-	3070	2280	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cymbella spp.	121	1322	460	2884	336	-	1280	-	1310	-	1560	615	1500	1020	5156	1164	847	111	436	122
Cylindrotheca sp.	-	-	-	330	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diploneis spp.	-	-	550	-	420	680	-	-	-	-	242	475	-	-	-	224	-	-	-	-
Fragillaria spp.	-	-	-	55	-	-	-	-	-	-	-	-	-	-	1122	-	-	56	-	-
Gomphonema spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	218	-	1199	-
Gyrosigma spp.	-	31	173	-	84	-	-	109	30	-	-	93	-	-	-	-	-	-	165	-
Licmophora spp.	-	-	165	-	-	50	-	-	120	-	-	-	-	-	-	-	-	-	-	-
Monoraphidium spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1755	5535	6164	1530
Navicula sp.	193	2722	72	5009	545	392	2572	20	167	88	-	34	80	568	783	274	385	776	1644	314
Nitzschia spp.	2608	7158	3632	10764	2436	2660	12665	98	72	88	-	85	-	489	132	426	307	374	240	73
Pinnularia sp.	-	-	550	-	1008	-	765	-	480	-	-	-	-	424	102	95	363	-	4905	324
Pleurosigma spp.	643	1137	1287	18781	1728	633	1021	33	397	182	400	32	100	1481	1442	2302	1501	962	8385	194
Pseudo-nitzschia sp.	121	1072	2540	2810	1044	2480	508	327	-	110	-	-	-	-	-	-	-	333	-	-
Synedra sp.	-	634	605	-	84	-	573	-	952	164	-	-	-	1111	141	112	236	-	2160	291
Tabellaria sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	327	-
Telmemorus spp.	2057	518	-	880	-	-	255	-	-	-	-	-	-	-	-	-	-	330	-	1080
Thalassionema sp.	785	1599	715	1389	1680	1440	6515	1357	3099	55	600	-	-	-	-	56	-	-	-	-
Phyllum: Dinoflagellata																				
Alexandrium spp.	-	250	-	-	-	-	-	-	-	110	-	-	-	424	-	-	-	-	-	-
Ceratium sp.	-	67	-	110	-	30	191	264	268	-	-	-	-	-	-	-	-	-	-	-
Dinophysis sp.	-	-	-	114	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gonyaulax spp.	-	-	-	-	-	-	1143	-	-	-	-	-	-	202	-	-	-	-	-	-
Gymnodinium sp.	-	197	600	279	-	60	3306	-	60	1264	1082	1278	397	5362	4175	1481	1211	1108	112	61
Gyrodinium spp.	-	-	-	-	168	-	1150	-	-	440	-	-	196	1222	94	-	-	-	-	-
Noctiluca spp.	-	-	-	-	-	-	127	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxytoxum sp.	-	-	-	-	-	-	-	-	-	-	560	-	-	-	-	-	-	-	-	-
Phacus sp.	-	-	-	-	-	-	64	49	-	-	240	-	-	-	47	112	-	443	-	-
Prorocentrum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Protoperidinium spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	763	-	448	-
Peridinium spp.	-	-	-	220	-	-	-	294	360	-	605	-	-	-	2014	1062	2507	-	-	610
Pyramimonas spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	218	-	-	-
Scrippsiella spp.	603	268	-	-	288	360	1270	-	240	218	1210	2850	8350	1888	3674	190	-	-	-	-
Woloszynskia spp.	-	-	-	-	-	-	-	-	-	-	-	380	-	-	-	3800	-	-	560	-
Phyllum: Charophyta																				
Arthrodesmus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	366
Cylindrocystis spp.	-	-	-	342	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorogonium spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	218	-	-	-
Costratum spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	306	-	218	-	-	-
Crucigenia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	94	-	-	-	-	-
Cymalopleura sp.	-	-	550	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Desmidium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1120	-
Gloeocapsa sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	436	-
Gymnozyga sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17812
Micractinium spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	218	-
Micrasteias spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	244
Opephora sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	102	-	-	-	-	-
Cosmarium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	443	112	486
Closterium spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	109	-
Coelastrum colonies	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	888	-	864
Sphaerozosma sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	42928	80244
Sphaerodinium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	109	-	-	-
Staurastrum sp.	-	-	-	18	-	-	43	-	119	9	50	54	66	-	133	283	217	111	888	661
Roya anglica sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	110	-	-
Spondylosium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	278	-	5724
Phyllum: Cryptophyta																				
Chromulina spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	218	-
Cryptomonas sp.	-	-	-	-	-	-	192	-	180	-	8400	9170	9673	2650	18140	238	21092	2424	-	108
Chlamydomonas sp.	-	-	-	-	-	-	-	-	-	257	-	-	98	4409	170	855	73	3256	-	-
Rhodoonas spp.	360	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phyllum: Chlorophyta																				
Actinostrum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	448	648
Actinotaenium spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	336	-	-	109	-
Actinastrum spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	981	854
Ankistrodesmus spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	273	2937	728	1458
Tribonema sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	282	504	-	-	-	793
Ulothrix strands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	188	-	763	-	-	-
Xanthidium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	110	-	-
Elakatothrix spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1110	109	-
Scenedesmus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	770	-	-
Phyllum: Cyanobacteria																				
Cyanobacteria strands	-	-	-	1140	-	-	-	-	-	-	-	-	-	-	-	-	-	110	-	108
Lyngbya spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	888	-	-
Gloeotrichia spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	439	-
Chlorella spp.	-	-	-	-	-	300	-	-	2040	-	-	-	-	-	-	112	484	-	-	540
Chroococcus spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	336	-
Amphanizomenon sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2040	-	-	-	-	-
Phyllum: Euglenozoa																				
Euglena spp.	-	-	-	110	192	-	-	-	-	-	-	-	-	-	972	-	109	330	-	-
Phyllum:Ochrophyta																				
Dinobryon colonies	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	218	888	4857	11414

Phytoplankton Diversity

Statistical analysis of phytoplankton data in the Zuari estuary is given in Table 3.2. Overall, the total number of species (S) decreased from the mouth and upstream regions towards the midstream region. However, vertically in the water column 'S' did not vary much spatially (data not shown here). On the contrary, species richness (d) varied from 0.82-2.43 (avg. 1.7). The higher values of 'd' at the mouth and upstream regions were predominantly due to the numerical dominance of diatoms that accounted for > 80% of total phytoplankton. Similarly, evenness (J') and Diversity index (H') ranged from 0.46-0.86 (avg. 0.67) and 1.34-2.52 (avg. 1.94) respectively.

Table 3.2: Distribution of number of species (S), total abundance (N), species richness (d), evenness (J') and diversity (H') of phytoplankton in the Zuari estuary

Stations	S	N	d	J'	H'(log_e)
Z1	19	158788	1.52	0.46	1.34
Z2	29.5	220173	2.33	0.60	2.02
Z3	25	162870	2.00	0.64	2.03
Z4	32	363622	2.43	0.53	1.83
Z5	24	140184	1.94	0.61	1.95
Z6	19.5	80460	1.64	0.67	1.98
Z7	31	300645	2.39	0.52	1.78
Z8	11.5	12847	1.13	0.79	1.93
Z9	15	23140	1.40	0.86	2.32
Z10	14.5	10416	1.46	0.85	2.26
Z11	9.5	31958	0.82	0.71	1.60
Z12	12	32445	1.08	0.64	1.60
Z13	9.5	36354	0.83	0.69	1.59
Z14	15.5	51236	1.34	0.75	2.04
Z15	21.5	81514	1.82	0.68	2.07
Z16	18	37225	1.62	0.82	2.35
Z17	21	93125	1.75	0.60	1.77
Z18	25.5	91945	2.1455	0.7793	2.523
Z19	30	322472	2.2885	0.5839	1.986
Z20	25	176526	2.001	0.57625	1.835

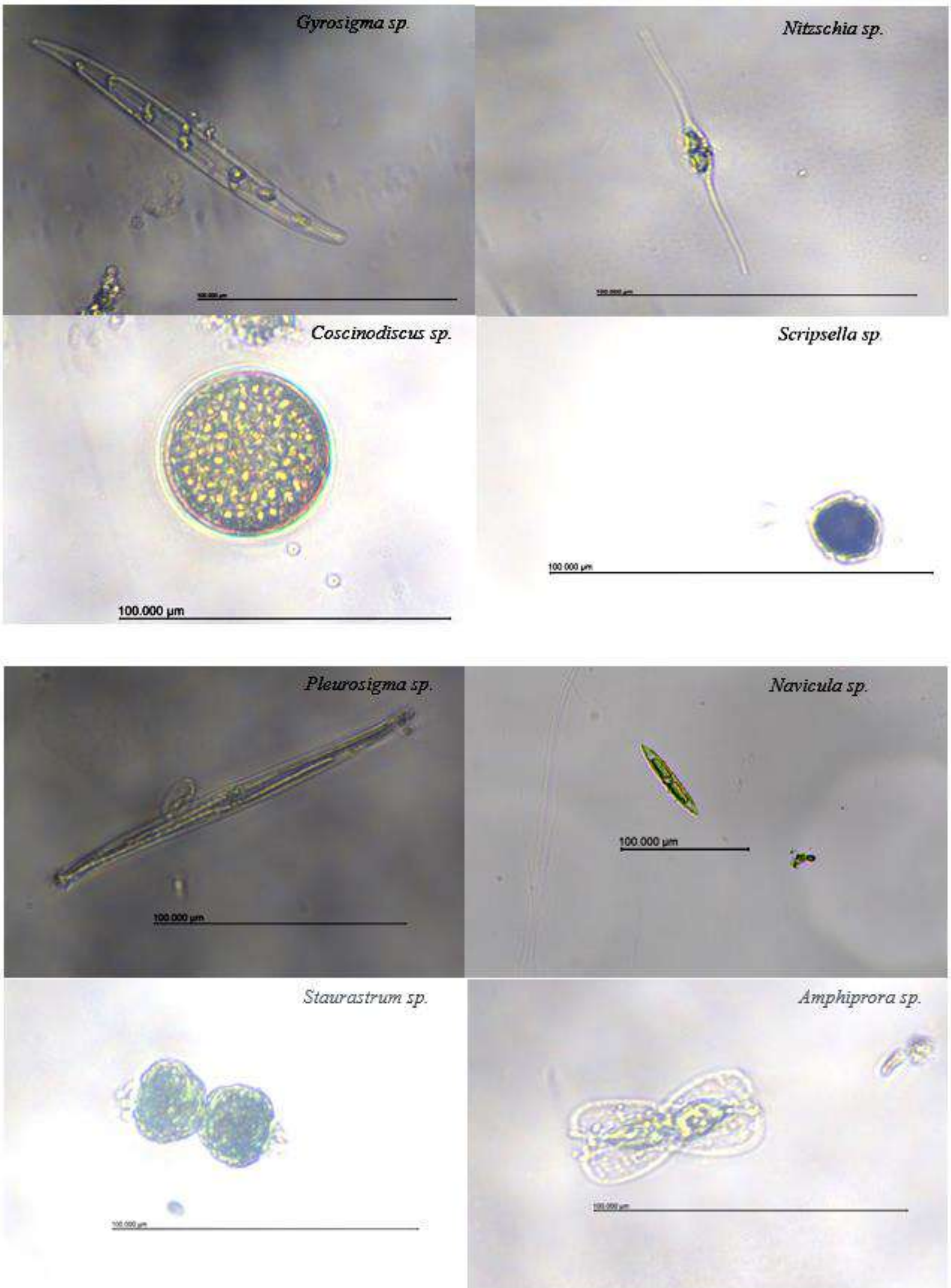


Plate 3.1: Representative species of Phytoplankton

3.3.2 Zooplankton

Zooplankton, the animal component of the planktonic community, is heterotrophic animals, unlike phytoplankton. They function as prey for economically important fish, grazers of primary production, and drivers of carbon and nutrient cycles (Xiong et al., 2019). In an estuary, environmental factors and human activities affect the distribution and abundance of these organisms. Multiple studies have made a consistent and crucial realization that zooplankton taxa are rapid responders to many environmental stressors, such as hydrological changes and anthropogenic activity-induced water pollution (Hanazato, 2010). Hence, they act as an indicator to monitor aquatic ecosystems.

A total of 20 stations were sampled from near mouth to upstream region of the Zuari river using a 200 micron pore size Heron Trancter net (horizontal tow). The samples were processed to study the biomass, abundance and diversity of zooplankton from each station.

Biomass and numerical abundance of Mesozooplankton

Biomass estimation of the zooplankton samples from the Zuari estuary (mouth to upstream) trend is shown in Figure 3.12. Along Zuari estuary, the biomass was at its lowest values, sometimes below measurable levels in the upstream regions. In the midstream stations (Z4 – Z8) observed very high biomass (max. 130.65 ml 100 m^{-3}) in the relatively low saline conditions (19-24 psu) due to a ctenophore swarm. In correlation with the previous study (Purushothaman et. al, 2020), we observed that the ctenophore swarm was comparatively more prominent at stns Z4 and Z5 in the salinity between 23 and 24 psu. Likewise, numerically the midstream region of the Zuari estuary also showed a relatively lower abundance of mesozooplankton than the river mouth or upstream region (Figure 3.13). The highest abundance was observed at stn Z5 (23,44,799 ind 100 m^{-3}) and the lowest at Z19 station (12,902 ind 100 m^{-3}).

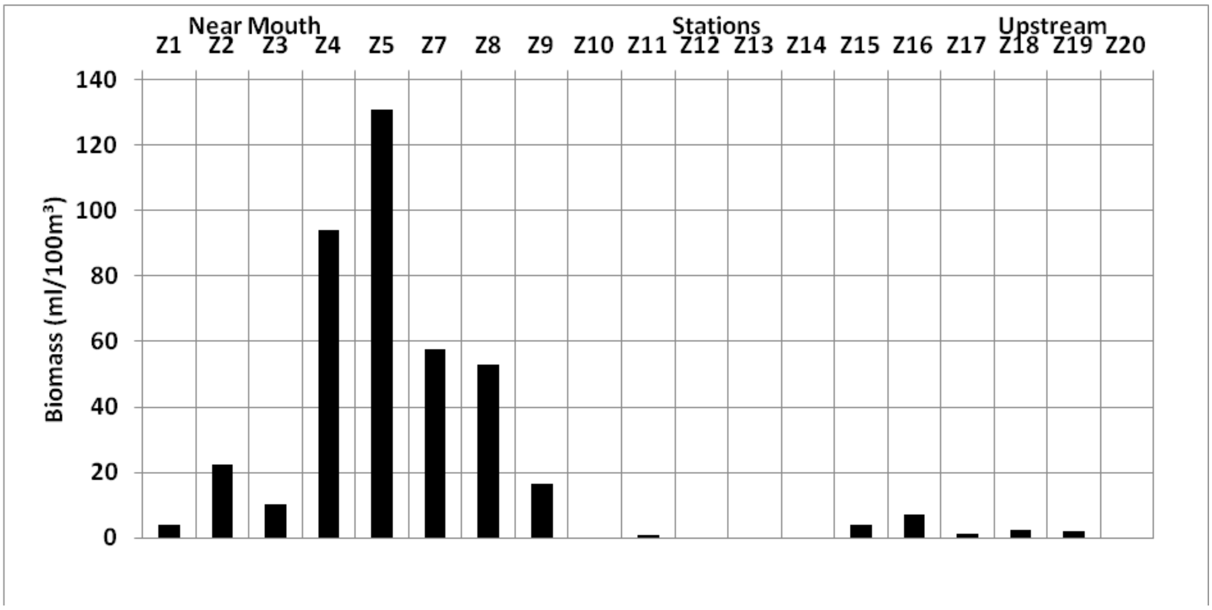


Figure 3.12: Biomass of mesozooplankton in the Zuari estuary

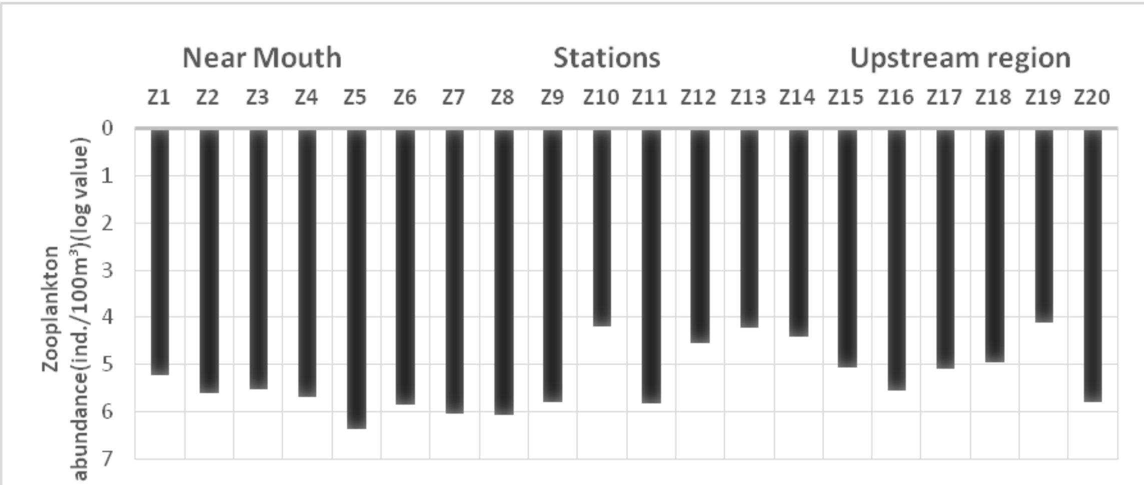


Figure 3.13: Abundance of mesozooplankton in the Zuari estuary

Distribution of various taxonomic groups of mesozooplankton

Mesozooplankton were classified into two major groups: copepods and non-copepods. Copepods were the dominant group all over the estuary, except at stn Z20. Copepod distribution varied from 17% (stn Z20) to 95% (stn Z9) (Figure 3.14). However, the community composition of copepods and non-copepods differs from the mouth to the upstream region.

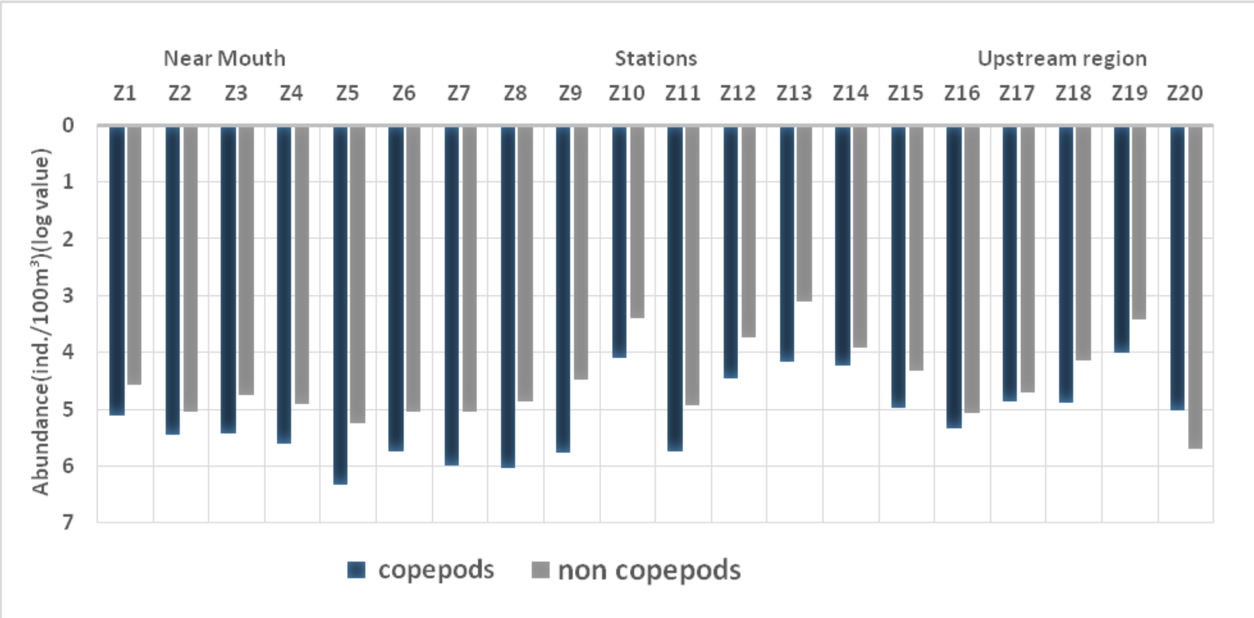


Figure 3.14: Distribution of copepods and non-copepods along the Zuari estuary

Abundance & distribution of non-copepod groups

A total of 25 non-copepod groups were identified from the Zuari estuary. The most abundant groups were decapod larvae, cladocerans, gastropods, chaetognaths, lucifer, hydrozoans, oekopleura, ctenophores, polychaetes and bivalves. Their total abundance was maximum at stn Z20 (5,03,892 ind. 100 m^{-3}) and minimum at Z13 (1,271.03 ind. 100 m^{-3}). In stn Z20, cladocerans alone contributed more than half of the total abundance of non-copepod organisms. Organisms such as echinoderm larvae and siphonophorans were present only at the mouth region, where the salinity ranged from 23-24 psu. While certain other organisms like chaetognatha, oekopleura, cypris, barnacle nauplius, lucifer, bryozoan larva, ctenophora and juveniles of isopods mainly were restricted to the river mouth to midstream regions. While, other planktonic forms like decapod larvae, fish larvae, gastropods, hydrozoans, polychaete larvae and bivalves were present all over the river. Moreover, cladocerans showed a staggered distribution due to their marine and riverine species composition. They were more abundant towards the estuary mouth and upstream stations. A single specimen of fish lice (*Argulus* sp.) was observed at station Z11. Upstream waters also showed the presence of a few water mites and stonefly larva.

Distribution of copepods

The copepods in the Zuari estuary belong to Calanoida, Cyclopoida, Harpacticoida, Poicelostomatoida, copepodite stages and nauplius. The Calanoida was the most dominant order all over the estuary (except station Z20) (Figure 3.15). The species such as *Centropages* *furcatus*, *Labidocera* sp. and *Temora turbinata* were present only near the mouth/downstream region. This may be due to their stenohaline nature. Additionally, *Tortanus barbatus* marked their presence towards midstream. Furthermore, *Acrocalanus gibber*, *Paracalanus* spp., *Pseudodiaptomus aurivilli*, *Acartia* sp., *Sinodiaptomus indicus* and *Oithona* spp. were observed all along the river. However, their abundance varied from mouth region to upstream. *Paracalanus* spp. was the most abundant copepod in the Zuari estuary, followed by *A. gibber*, *Acartia* spp., *Oithona* sp., *Pseudodiaptomus aurivilli* and *Synodiaptomus indicus*. *Ergasilus* sp., a parasitic copepod, was noticeable at certain midstream and upstream stations. Freshwater cyclopoid copepod *Diacyclops bicuspidatus* was seen in upstream regions in very few numbers. Harpacticoid copepod *Euterpina acutifrons* was present from the near mouth to the midstream. In contrast, *Longipedia weberi* was observed only at the midstream region and *Macrosetella grasilis* was found in midstream to upstream areas.

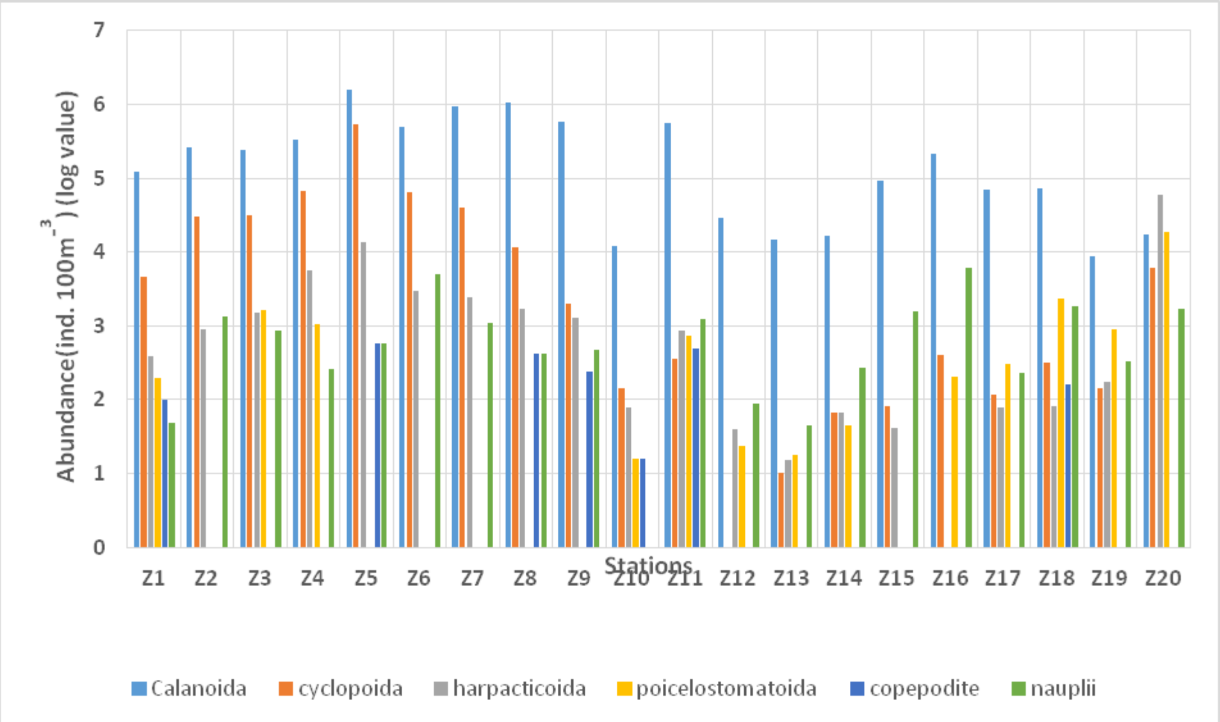


Figure 3.15: The abundance and spatial distribution of copepod orders in the Zuari estuary

Species Diversity

It is important to summarize the species diversity, species evenness, and richness to study a particular community to understand the ecosystem. Shannon indices are the most common diversity indices to characterize a community. From Figure 3.16, it is clear that species diversity (H') and the number of species (S) were maximum at the mouth region. The highest zooplankton diversity was at stn Z4 (2.15) and lowest at stn Z7 (1.02). Besides, species evenness (J') was maximum at stn Z14 (0.42) and minimum at stn Z1 (0.14). In addition, species richness (d) was maximum at stn Z7 (0.62) and minimum at Z3 (0.162).

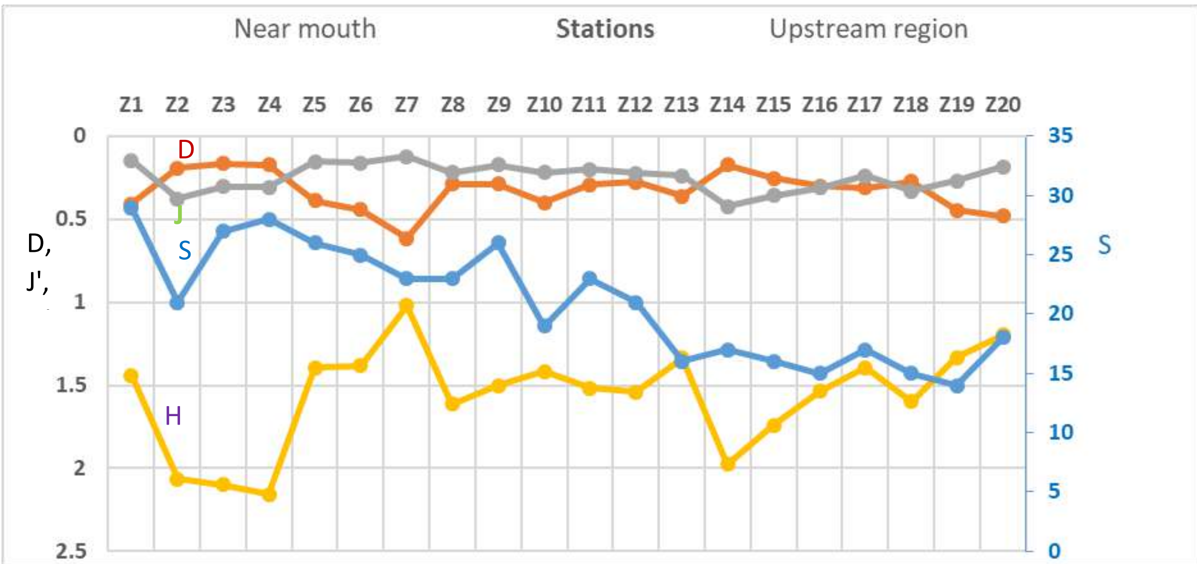


Figure 3.16: Number of species (S), species richness (d), evenness (J') and species diversity (H') of zooplankton in the Zuari estuary

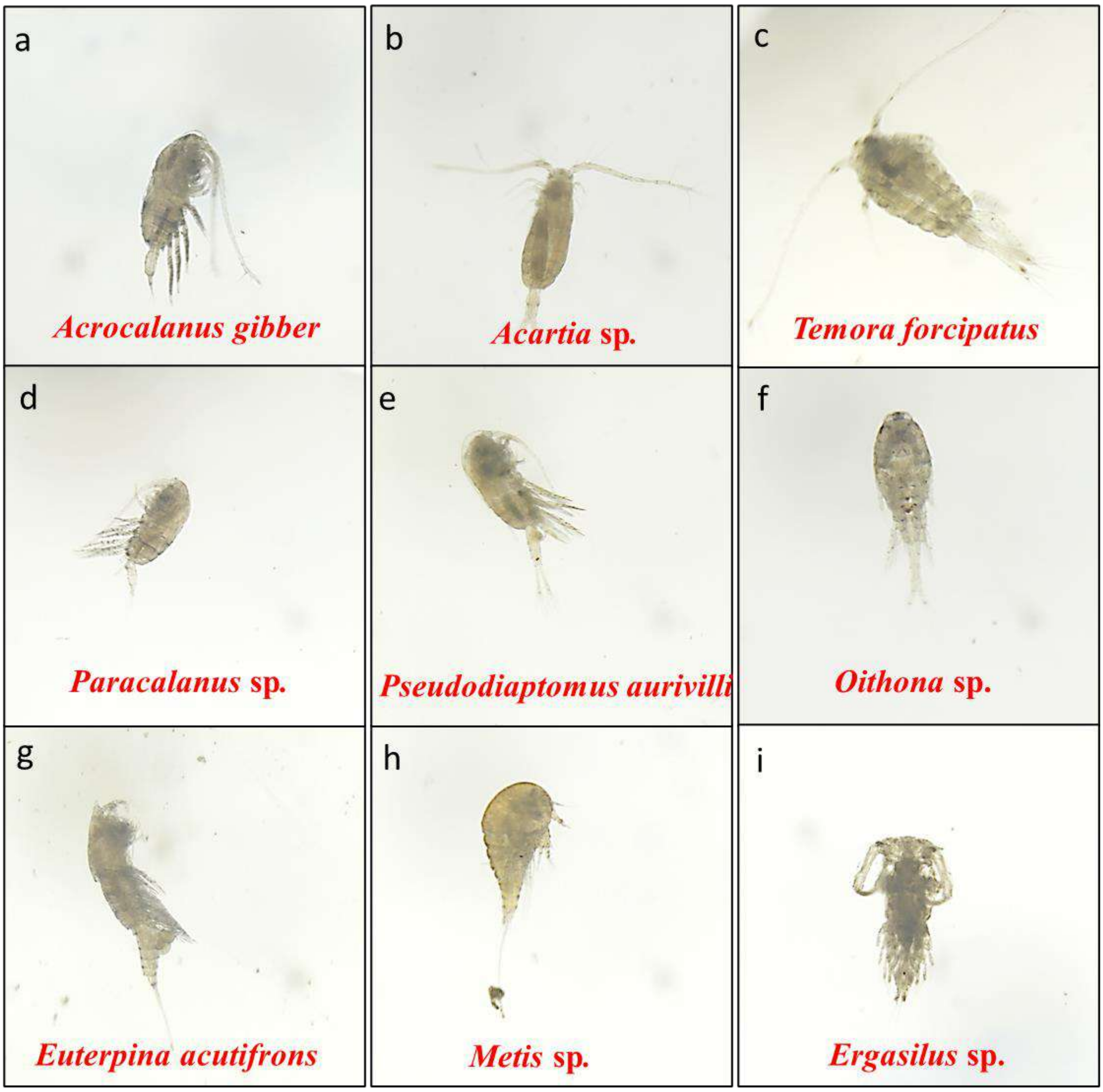


Plate 3.2: Representative Copepod zooplankton (a-i) : a-e: Calanoids, f: Cyclopoid, g-h: Harpacticoids, i: Poecilostomatoid

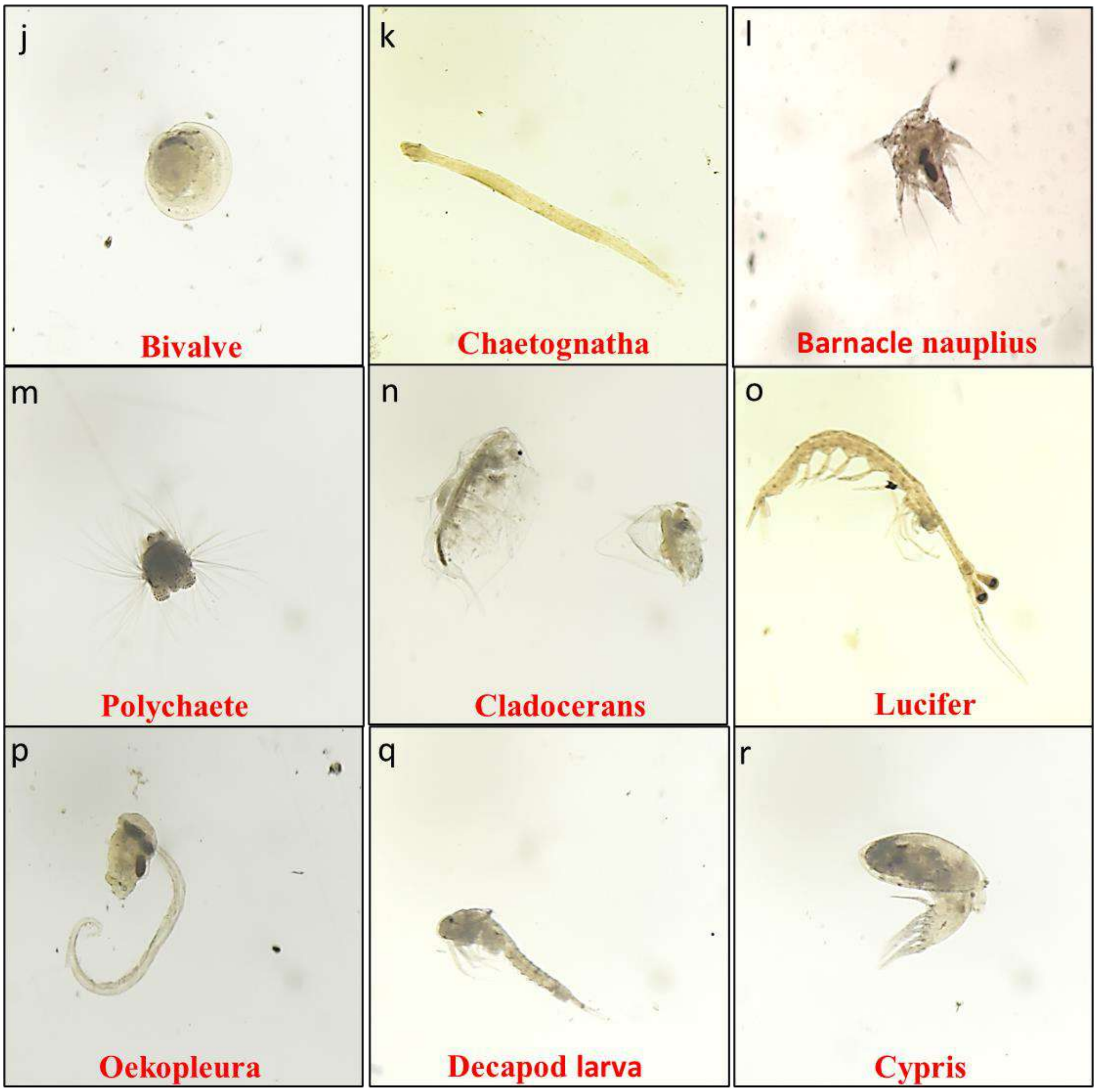


Plate 3.3: Representative species of non copepod groups of zooplankton

3.4 Sediment Characteristics

The sand includes >63 µm carbonate fraction. As expected, the stations in the middle of the channel had a very high sand fraction, as compared to the sediments at the adjacent margins of Zuari (Figure 3.17). The sand fraction decreased at stations upstream of Z11 in the Zuari.

The sediments towards the mouth of Zuari contained a relatively less organic carbon (Figure 3.18). The stations with higher sand fraction had corresponding lesser organic carbon in Zuari. As the margins had relatively finer sediment, the organic carbon was also higher on both the margins of the estuary and comparatively lesser in the central part. The calcium carbonate ($CaCO_3$) was estimated from the inorganic carbon. Except a few stations, $CaCO_3$ was insignificant (<2%) at a majority of the stations (Figure 3.19) in the Zuari estuary.

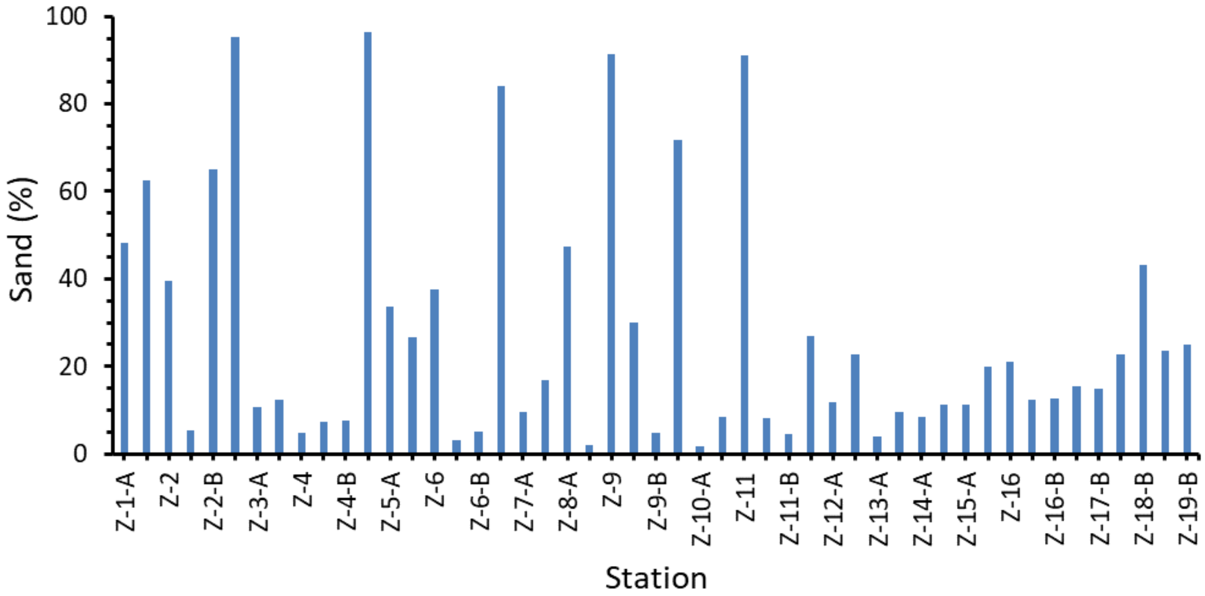


Figure 3.17: The relative abundance of sand in the surface sediments of Zuari estuary

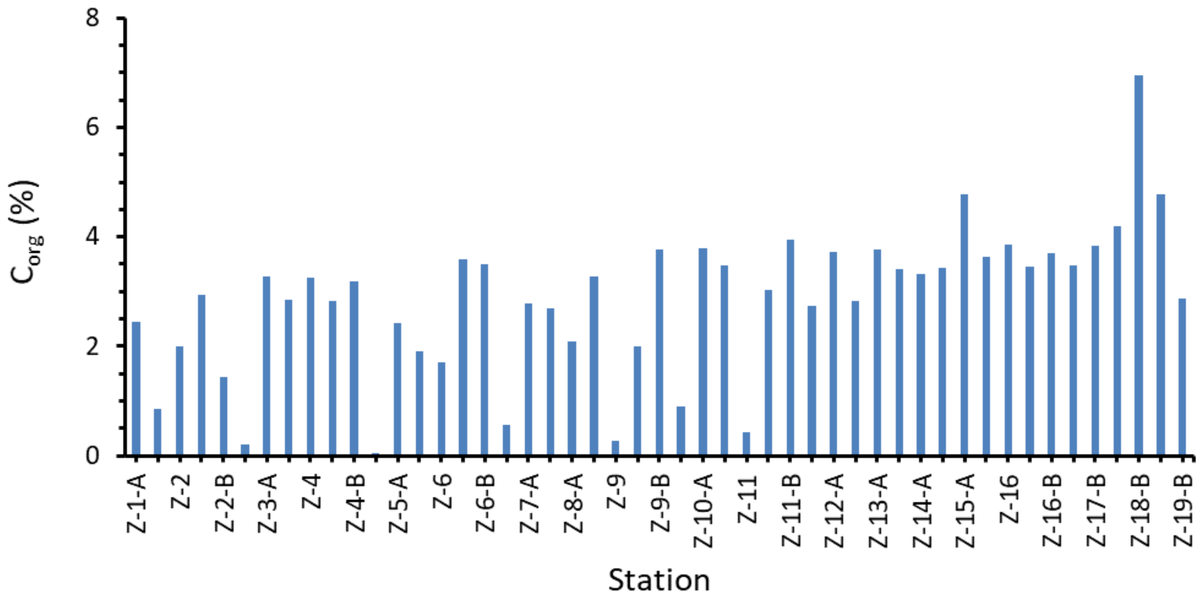


Figure 3.18: The organic carbon in the surface sediments of Zuari estuary

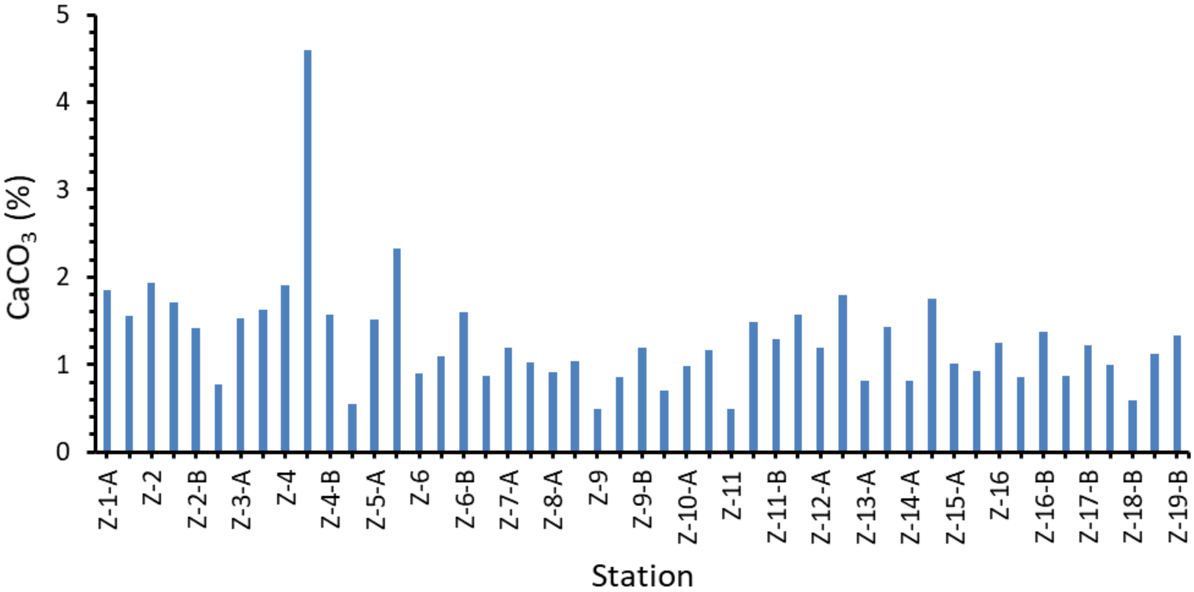


Figure 3.19: The calcium-carbonate percentage in the surface sediments of the Zuari estuary

Total suspended matter (TSM)

Except a few stations, the total suspended matter (TSM) was higher at the Zuari river mouth and decreased in the inner estuary (Figure 3.20). TSM in the Zuari varied from as high as 17.9 mg L^{-1} to as low as 0.6 mg L^{-1}. The higher TSM at the Zuari mouth is attributed to both the large trawler traffic and strong tidal influence leading to re-suspension of the materials.

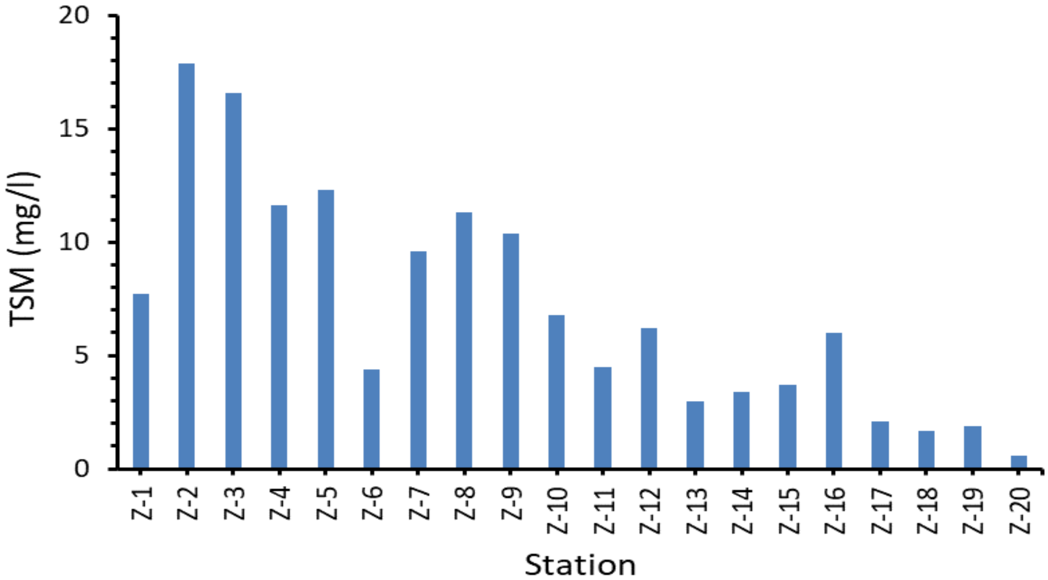


Figure 3.20: Total suspended matter at different stations of Zuari estuary

3.5 Meiobenthos

Central transect: A total of 10 meiofaunal taxa were identified from the central region of Zuari estuary. Nematoda was the most abundant group followed by Harpacticoida, Oligochaeta, Polychaeta, Turbellaria, Nemertea and Kinoryncha. Amphipoda and Naupli larvae were also present in few numbers (Table 3.3). The highest meiofaunal abundance (156 ind. $10cm^{-2}$) was recorded at Z10 station, while lowest abundance were observed at stations Z1, Z14, Z15, Z17, Z18 and Z19. Surprisingly Z20 showed no abundance (0 ind. $10cm^{-2}$) (Figure 3.21; Table 3.3). The percentage composition of meiofauna revealed that Nematoda was the most dominant meiofaunal group (64.8%). Other meiofaunal groups included Harpacticoida (10.7%), Oligochaeta (9.3%), Polychaeta (5.3%), Turbellaria (4.7%) and other meiofaunal groups (5.2%) in Zuari estuary (Figure 3.23).

Peripheral transect: In the peripheral region of the Zuari estuary 13 meiofaunal taxa were identified from a total of 40 stations. The highest meiofaunal abundance (788 ind. $10cm^{-2}$) was recorded at station at Z4A station and lowest abundance (0 ind. $10cm^{-2}$) at stations Z19A, Z19B, Z20A and Z20B in Zuari estuary (Table 3.4). The following meiofaunal groups were recorded from Zuari estuary: Nematoda, Harpacticoida, Oligochaeta, Turbellaria, Nemertea, Amphioda, Isopoda, Ostracoda, Naupli Larvae and Gastropoda larvae. The percentage comoposition of the meiofaunal community showed that Nematoda (67%) was the most dominant group followed by Harpacticoida (17%), Oligochaeta (5%), Polychaeta (4%), Naupli larva (2%), Kinoryncha (1%) and other meiofaunal groups (4%) (Figure 3.24).

Conclusion: Our observation of the meiobenthic group abundance revealed an increasing trend towards the periphery and less abundant towards the centre in most stations of the Zuari estuary. In the peripheral region, ZB Stations showed more abundance compared to ZA region except in Z4A region which showed the highest adundance in the Zuari estuary (788 ind. cm^{-2}). In the central region the higher abundance of meiofauna was recorded at stations Z9 (151 ind. cm^{-2}) and Z10 (156 ind. cm^{-2}), indicating higher abundance in the middle stream than the mouth and source of the river, whereas in periphery region the abundance was more towards the mouth region but the trend kept decreasing towards the upper region of the estuary.

Table 3.3: Total meiofauna abundance (ind. 10cm^{-2}) of the Zuari estuary central transect

Taxa	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11
Nematoda	0	19	1	3	38	30	13	5	106	89	40
Polychaeta	0	1	0	1	0	1	0	0	5	4	0
Harpacticoida	0	3	6	0	3	0	1	0	15	21	6
Naupli larvae	0	0	0	0	0	0	0	0	5	0	0
Amphipoda	0	0	0	0	0	0	0	0	0	1	0
Kinoryncha	0	0	0	0	1	3	0	0	0	1	0
Bivalvia	0	0	0	0	0	0	0	0	0	6	0
Oligochaeta	0	0	1	3	0	1	4	0	11	20	10
Nemertea	0	0	0	1	0	0	0	0	4	1	0
Turbellaria	0	1	0	0	1	1	0	0	5	11	3
Total	**0**	**23**	**9**	**8**	**43**	**37**	**18**	**5**	**151**	**156**	**59**

Table 3.3: Total meiofauna abundance (ind. 10cm^{-2}) of the Zuari estuary centarl transect (Continued)

Taxa	Z12	Z13	Z14	Z15	Z16	Z17	Z18	Z19	Z20	Total	%
Nematoda	23	24	0	0	5	0	0	0	0	395	64.8
Polychaeta	15	4	0	0	1	0	0	0	0	32	5.3
Harpacticoida	10	0	0	0	0	0	0	0	0	65	10.7
Naupli larvae	0	0	0	0	0	0	0	0	0	5	0.8
Amphipoda	1	0	0	0	0	0	0	0	0	3	0.4
Kinoryncha	1	0	0	0	0	0	0	0	0	6	1.0
Bivalvia	4	1	0	0	0	0	0	0	0	11	1.9
Oligochaeta	4	0	0	0	3	0	0	0	0	57	9.3
Nemertea	0	0	0	0	0	0	0	0	0	6	1.0
Turbellaria	5	1	0	0	0	0	0	0	0	29	4.7
Total	**63**	**30**	**0**	**0**	**9**	**0**	**0**	**0**	**0**	**610**	**100.0**

Table 3.4: Total meiofauna abundance (ind. $10cm^{-2}$) of the Zuari estuary peripheral transect

Table 3.4: Total meiofauna abundance (ind. $10cm^{-2}$) of the Zuari estuary peripheral transect (Continued)

Taxa	Z11 A	Z11 B	Z12 A	Z12 B	Z13 A	Z13 B	Z14 A	Z14 B	Z15 A	Z15 B	Z16 A	Z16 B	Z17 A	Z17 B	Z18 A	Z18 B	Z19 A	Z19 B	Z20 A	Z20 B	Total	%
Nematoda	33	29	18	24	3	3	9	1	10	5	20	4	4	13	11	19	0	0	0	0	2605	**67.4**
Polychaeta	10	4	0	15	1	10	2	5	6	3	21	0	0	3	0	0	0	0	0	0	172	**4.4**
Harpacticoida	20	28	4	21	0	0	31	4	38	25	53	10	10	15	0	0	0	0	0	0	663	**17.2**
Naupli larvae	0	1	0	3	0	0	1	0	5	10	13	5	5	5	0	0	0	0	0	0	70	**1.8**
Amphipoda	1	0	0	1	1	1	1	0	11	0	3	1	1	0	0	0	0	0	0	0	24	**0.6**
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0**
Ostracoda	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	38	**1.0**
Kinoryncha	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	47	**1.2**
Bivalvia	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	13	**0.3**
Gastropoda Larva	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	5	**0.1**
Oligochaeta	13	8	1	8	6	0	4	4	5	0	15	0	0	9	0	8	0	0	0	0	172	**4.5**
Nemertea	4	5	0	0	0	0	1	0	4	1	3	0	0	0	0	0	0	0	0	0	21	**0.5**
Turbellaria	3	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	34	**0.9**
Total	**84**	**74**	**23**	**73**	**11**	**14**	**50**	**14**	**81**	**49**	**131**	**20**	**20**	**44**	**11**	**26**	**0**	**0**	**0**	**0**	**3864**	**100**

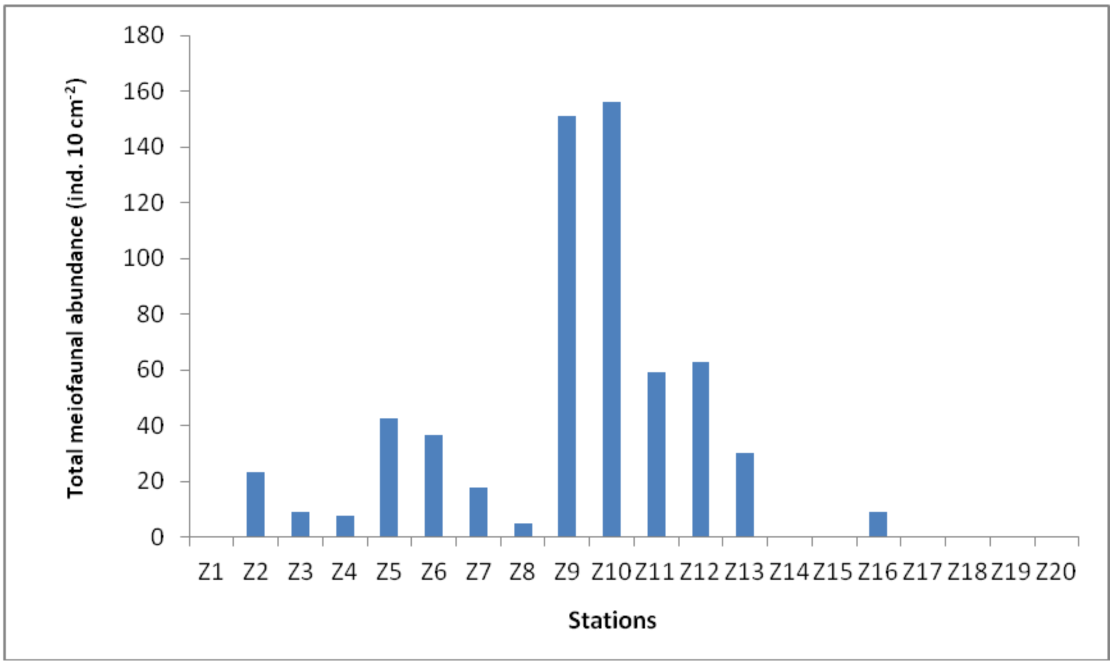


Figure 3.21: Station wise meiofaunal abundance (ind. 10 cm^{-2}) from Zuari estuary (central transect)

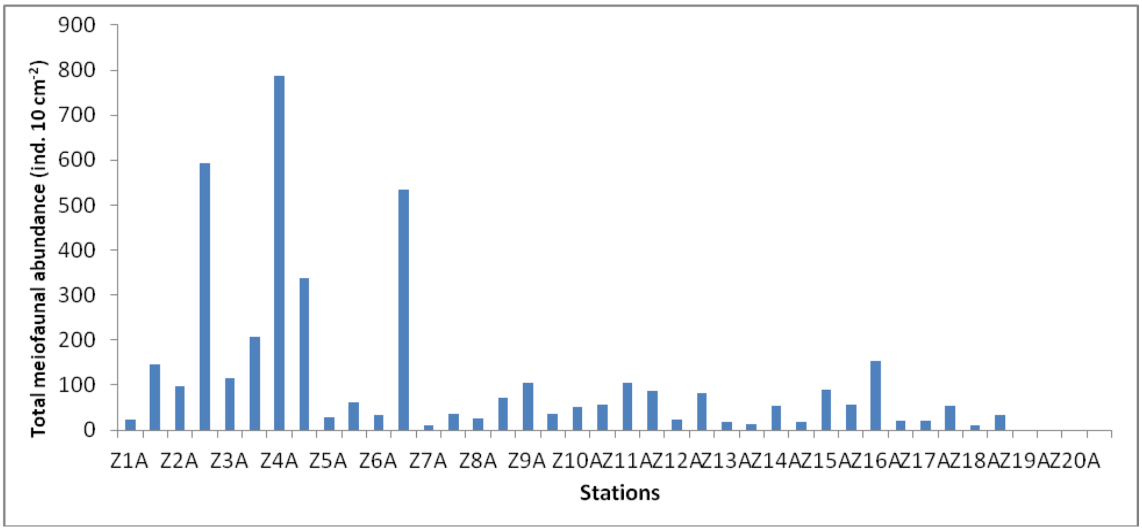


Figure 3.22: Station wise meiofaunal abundance (ind. 10 cm^{-2}) from Zuari estuary (peripheral transect)

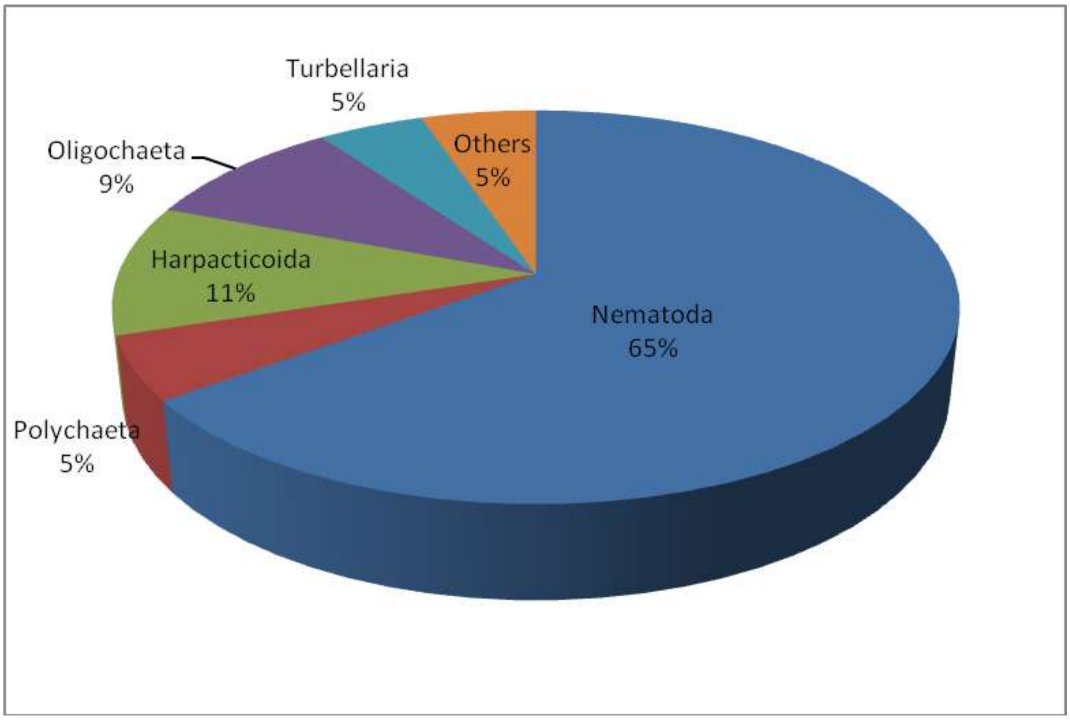


Figure 3.23: Percentage composition of meiofauna taxa from Zuari estuary (central transect)

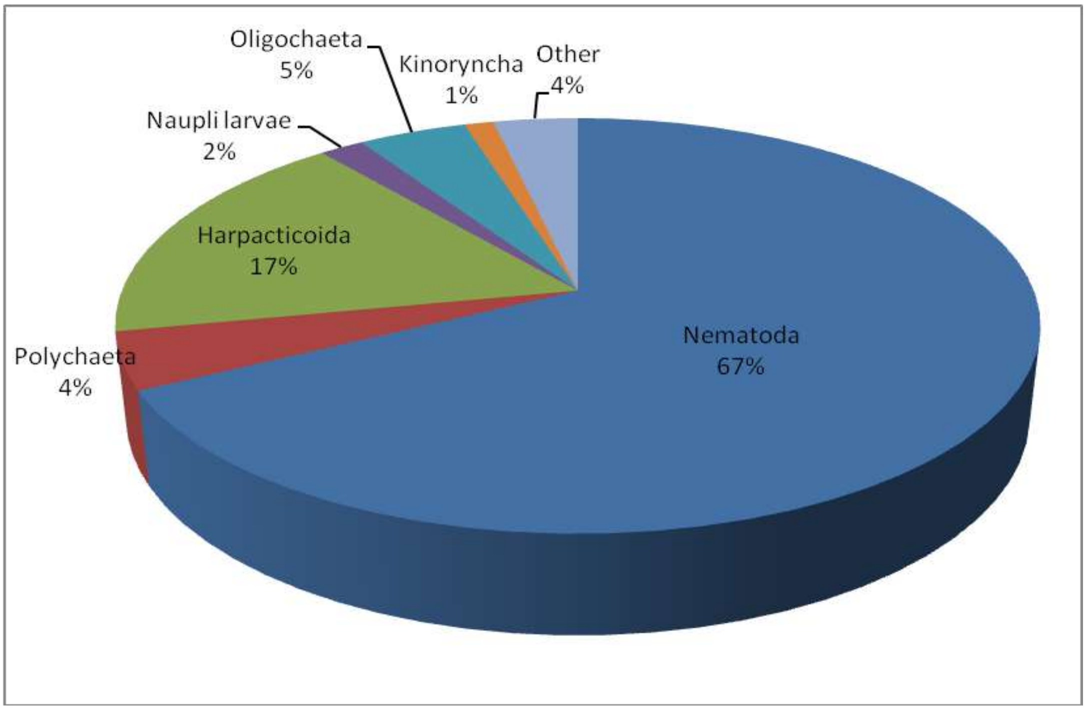


Figure 3.24: Percentage composition of meiofauna taxa from Zuari estuary (peripheral transect)

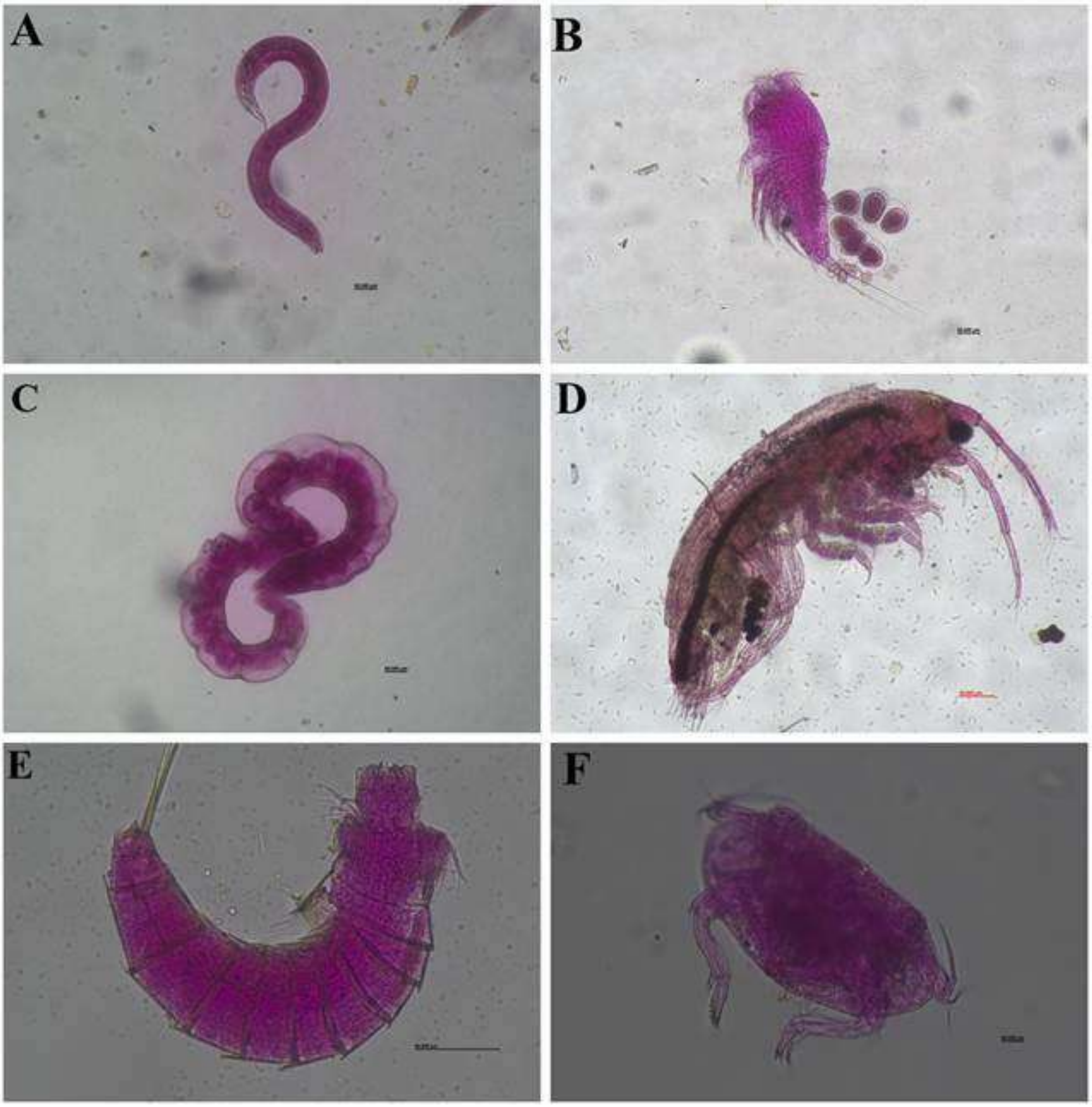


Plate 3.4: A-Nematode, B-Harpacticoid copepod, C-Oligochaete, D-Amphipod, E-Kinorynch, F-Naupli Larvae

3.6 Foraminifera Abundance

Both the living and dead benthic foraminifera were picked from the sand fraction. A minimum of 300 specimens were picked, wherever available. The abundance was high at stations close to the mouth of the Zuari (Figure 3.25). As expected, the abundance was low in the middle of the channel, as compared to the nearby margins. The abundance decreased upstream. Interestingly, the highest foraminifera abundance was found at station Z-5. The abundance, however, decreased significantly at stations upstream of Z-5. The living benthic foraminifera abundance was lower than that of the dead foraminifera at almost all the stations, suggesting accumulation of dead shells over a long duration. The higher foraminifera abundance towards the mouth of Zuari is attributed to the high salinity.

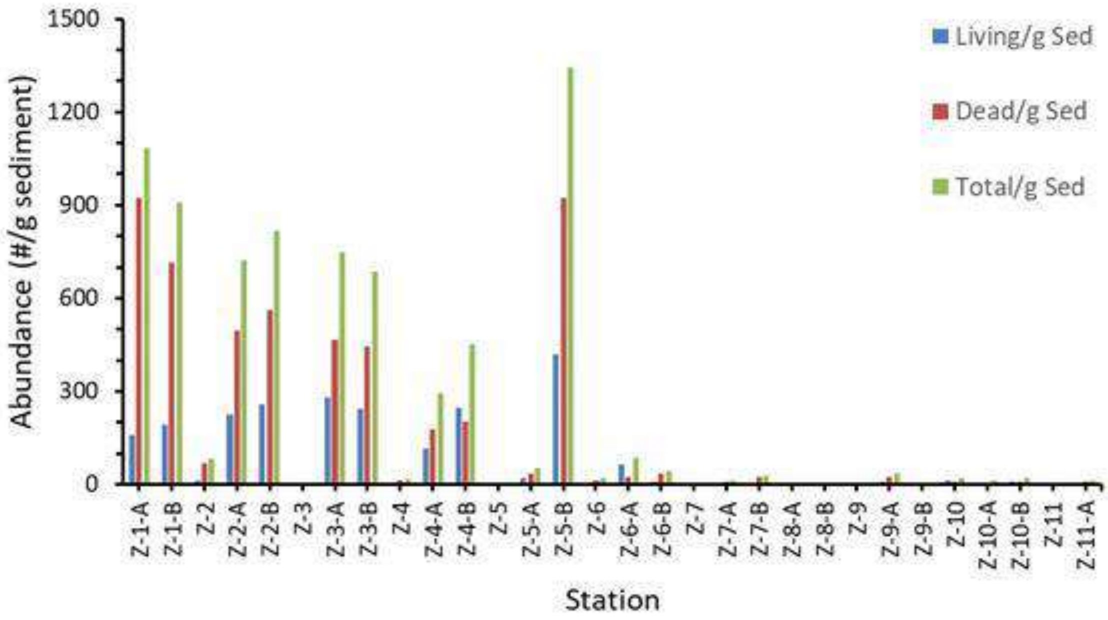


Figure 3.25: The absolute abundance of living and dead benthic foraminifera at different stations of the Zuari estuary. # denotes number of individuals

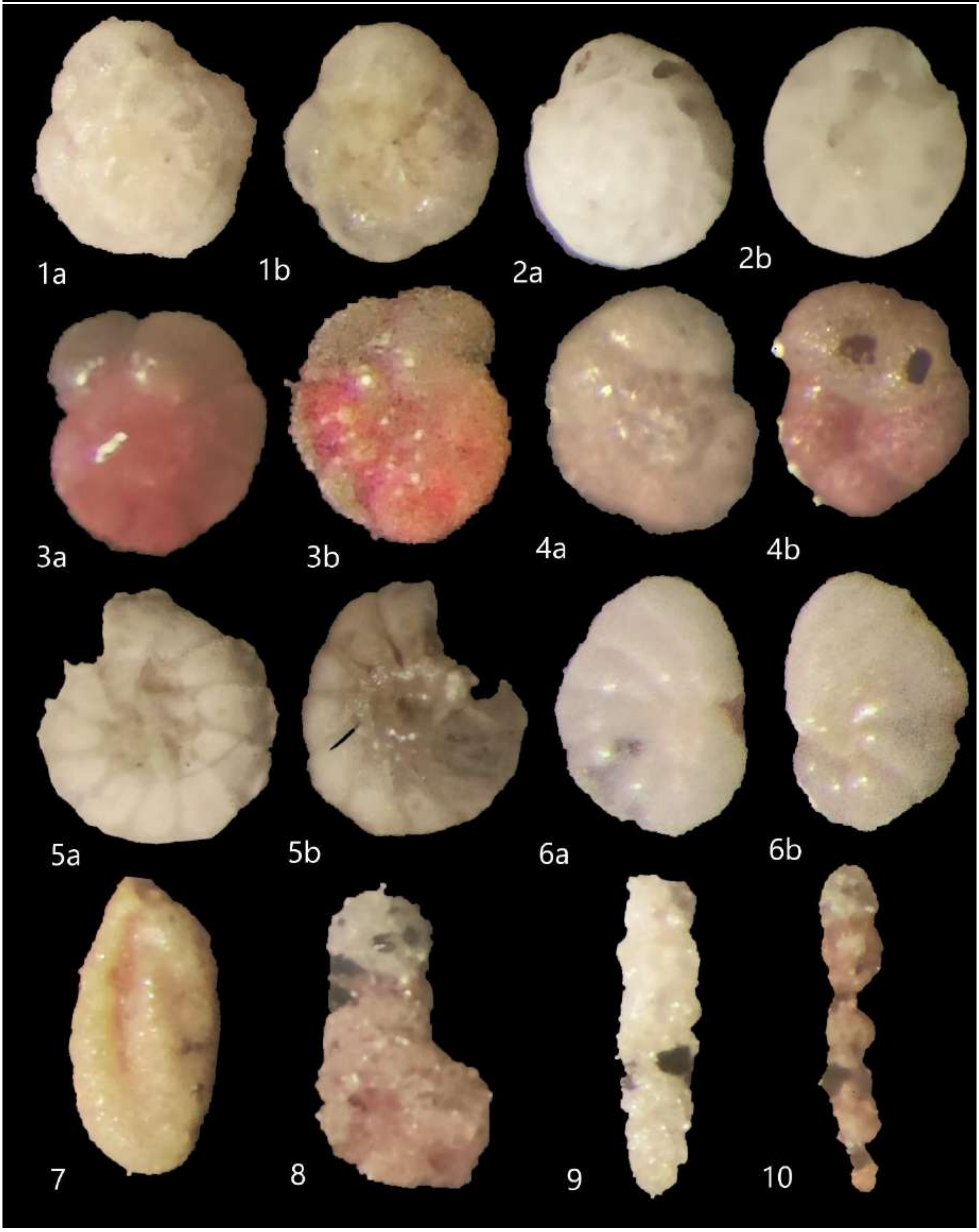


Plate 3.5: Abundant species of benthic foraminifera from different stations of Zuari. (Genus level identification) 1 to 3-*Ammonia*, 4-*Trochamina*, 5-*Rotalidium*, 6-*Nonion*, 7-*Miliolid*, 8-10-*Reophax*

3.7 Macrobenthos

Central Transect: Total 53 invertebrate taxa belonging to 7 phyla were identified from the central stations of Zuari estuary. Highest abundance of macrofauna was recorded at station Z10 (16040 ind. m^{-2}) followed by station Z1 (15042 ind. m^{-2}) whereas lowest abundance was recorded at station Z7 (170 ind. m^{-2}) (Figure 3.26) (Table 3.5). Among all the macrofauna, polychaetes were the most abundant taxa. High abundance of polychaetes was found at station Z10 (13338 ind. m^{-2}) followed by station Z1 (5014 ind. m^{-2}) and lowest abundance was found at staion Z7 (146 ind. m^{-2}). In Polychaeta, *Mediomastus capensis* was highly abundant species at station Z10 (6937 ind. m^{-2}) followed by Z12 (2677 ind. m^{-2}). *Prionospio cirrifera* was second abundant species found at station Z10 (5574 ind. m^{-2}) followed by station Z11 (2020 ind. m^{-2}). *Scololepsis* sp. found only at station Z7 (24 ind. m^{-2}). Macrofauna was absent at station Z8B, Z19A, Z20A and Z20B.

The macrofaunal composition (%) showed Polychaeta was highly abundant (66%) followed by Crustacean (19%), Ophiuroidae (7%) and remaining 22% of the fauna including Bryozoans, Nemertea, Platyhelminthes, Bivalvia, Oligochaeta and Barnacles (Figure 3.28). Among polychaeta, *Mediomastus capensis* (41%) showed highest composition followed by *Prionospio cirrifera* (32%), *Cossura* sp. (5%) and remaining 22% polychaeta species include *Glycera alba*, *Nephtys inermis*, *Sigmabra* sp. etc. were found less in abundance at the central station of Zuari estuary (Figure 3.29)

Peripheral Transect: Total 38 invertebrate taxa belonging to 6 phyla were recorded from peripheral stations of Zuari Estuary. Highest abundance of macrofauna was recorded at station Z15A (7264 ind. m^{-2}) followed by station Z14A (6912 ind. m^{-2}) and Z9B (6158 ind. m^{-2}) whereas lowest abundance was recorded at station Z18B (219 ind. m^{-2}) (Figure 3.27) (Table 3.6). Among all macrofaunal groups, polychaeta was the most dominant group in all the stations. Highest abundance of *Mediomastus capensis* recorded at station Z9B (4698 ind. m^{-2}) followed by station Z14A (3696 ind. m^{-2}) and the lowest abundance was recorded at station Z4B (24 ind. m^{-2}). *Prionospio cirrifera* was the second dominant species with (3189 ind. m^{-2}) at station Z16A followed by station Z14A (2992 ind. m^{-2}) and less abunadance found at station Z3B, Z6A, Z6B, Z7A and Z16B (24 ind. m^{-2}). *Paraprionospio* sp. found at only one station Z2A (24 ind. m^{-2}). Other taxa include Nematode, Nemertea, Oligochaeta, Chironomidae larvae, Gastropod larvae and Platyhelminthes which were found in less abundance (Table 3.6).

The macrofaunal composition showed polychaeta (79%), Oligochaeta (9%), Crustacea (8%) and other (4%) fauna includes Bryozoans, Nemertea, Chironomidae larvae etc. (Figure 3.30). Among polychaeta, *Mediomastus capensis* showed high composition (45%) followed by *Priosonspio cirrifera* (36%) as the second dominant composition followed by *Cossura* sp. (6%) and remaining (13%) polychaete species include *Dendroneries* sp., *Lumbrinieries* sp., *Orbinia* sp. etc. (Figure 3.31).

Biomass: Macrofaunal biomass (wet weight) from central station of Zuari Estuary varies from 0.82 to 279.91 g $m^{-2.}$ Highest diversity of macrofauna was recorded at station Z1 (279.91 g m^{-2}) which was contributed by polychaetes and ophiuroides and lowest was recorded at station Z6 (0.82 g m^{-2}) respectively due to low abundance (Figure 3.32). Peripheral stations of macrofaunal biomass of Zuari estuary vary from 0.29 to 37.32 g m^{-2}. Highest diversity in the peripheral region was recorded at station Z9B (37.32 g m^{-2}) due to high abundance of polychaetes and lowest diversity was recorded at station Z1A (0.29) due to low abundance (Figure 3.33).

Conclusion: Based on the present data set, macrofaunal abundance was found to be higher at peripheral region of the Zuari estuary as compared to upper stream area. The present analysis also found that the peripheral region of Zuari estuary was rich in macrofaunal diversity, while the abundance decreased gradually towards the upper stream area. The central stations of the estuary found less diversity due to the continuous dredging in the estuary. The observed benthic polychaetes and crustacean which constitute a major food source for fishes and avifauna.

Table 3.5: Total abundance (ind. m^{-2}) of macrofauna from Zuari Estuary (Central transect)

Taxa	Z 1	Z 2	Z 3	Z 4	Z 5	Z 6	Z 7	Z 8	Z 9	Z 10	Z 11	Z 12	Z 13	Z 14	Z 15	Z 16	Z 17	Z 18	Z 19	Z 20	Total	%
Bryozoan	122	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	146	0.27
Nematoda	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.09
Mediomastus capensis	97	2531	219	146	0	73	0	0	755	6937	1241	2677	0	0	0	292	0	0	0	0	14969	27.49
Neomediomastus sp.	0	0	0	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	0	0	49	0.09
Prionospio cirrifera	195	268	73	0	0	0	0	0	876	5574	2020	1923	0	0	0	609	0	0	0	0	11537	21.19
Prionospio pinnata	0	0	0	49	0	0	0	0	0	438	0	0	0	0	0	0	0	0	0	0	487	0.89
Polydora sp.	24	0	0	0	0	0	0	0	0	0	97	0	0	0	0	0	0	0	0	0	122	0.22
Scololepsis sp.	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0.04
Paraprionospio sp.	0	170	49	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	316	0.58
Cossura sp.	0	365	0	1485	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1850	3.40
Glycera alba	170	122	49	49	0	49	49	0	49	24	49	0	0	0	0	0	0	0	0	0	609	1.12
Orbinia sp.	0	0	0	146	0	0	73	0	0	0	0	0	0	0	0	24	0	0	0	0	243	0.45
Onuphis sp.	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.09
Nephtys inermis	0	0	0	0	0	0	0	0	0	0	122	0	0	0	0	0	0	0	0	0	122	0.22
Sigambra sp.	0	24	49	195	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	292	0.54
Namalycastis sp.	0	24	0	24	0	49	0	0	0	0	49	0	0	0	0	0	0	0	0	0	146	0.27
Dendroneries sp.	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	268	0	0	0	0	292	0.54
Neanthes sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00

Neries sp.	1704	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1704	3.13
Lumbrineries sp.	0	0	0	0	0	0	0	0	0	97	0	0	0	0	0	0	0	0	0	0	97	0.18
Pectinaria sp.	755	0	0	0	0	0	0	0	24	243	49	0	0	0	0	0	0	0	0	0	1071	1.97
Melinna sp.	170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	170	0.31
Amphictene sp.	1047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1047	1.92
Syllis sp.	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0.04
Autolytus	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.09
Phyllodocae sp.	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	0.13
Eteone sp.	195	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	195	0.36
Mystides sp.	170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	170	0.31
Maldane sp.	49	0	0	24	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97	0.18
Paraonis sp.	24	219	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	243	0.45
Lepidonotus sp.	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.09
Lionia sp.	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0.04
Trochochaetus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Poecilochaetus sp.	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.09
Spirorbis sp.	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97	0.18
Serpula sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Sternaspis sp.	0	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.09
Sabella sp.	0	0	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.09
Amphipoda	3383	0	0	0	0	0	24	0	0	1606	243	97	0	0	0	1850	0	0	0	0	7205	13.23
Isopoda	1899	0	0	0	0	0	0	0	0	195	0	0	0	0	0	219	0	0	0	0	2312	4.25

Hermit crab	24	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.09
Decapoda	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	24	0.04
Shrimp	24	0	24	49	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	0	146	0.27
Bivalvia	438	0	0	49	0	0	0	0	0	438	487	0	0	0	0	0	0	0	0	0	1412	2.59
Gastropod larvae	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	24	0.04
Platyheminthes	0	0	0	0	0	0	0	0	0	268	73	49	0	0	0	24	0	0	0	0	414	0.76
Nemertea	146	49	170	97	0	49	0	0	0	24	0	0	0	0	0	0	0	0	0	0	535	0.98
Oligochaeta	0	0	146	1022	0	316	0	0	0	73	0	0	0	0	0	0	0	0	0	0	1558	2.86
Limpet	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97	0.18
Barnacle	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0.04
Ophiuroidae	3821	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3821	7.02
Phoronida	0	0	0	0	0	0	0	0	73	24	0	97	0	0	0	0	0	0	0	0	195	0.36
Pycnogonia	0	0	0	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	0.13
Abundance (ind. m^{-2})	**15042**	**3821**	**852**	**3505**	**0**	**584**	**170**	**0**	**1777**	**16040**	**4479**	**4892**	**0**	**0**	**0**	**3286**	**0**	**0**	**0**	**0**	**54449**	**100.00**

Table 3.6: Total abundance (ind. m^{-2}) of macrofauna from Zuari estuary (peripheral transect)

Taxa	Z 1A	Z 1B	Z 2A	Z 2B	Z 3A	Z 3B	Z 4A	Z 4B	Z 5A	Z 5B	Z 6A	Z 6B	Z 7A	Z 7B	Z 8A	Z 8B	Z 9A	Z 9B	Z 10 A	Z 10 B	Z 11 A	Z 11 B	Z 12 A	Z 12 B	Z 13 A	Z 13 B
Bryozoan	0	0	0	0	0	219	243	0	73	316	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	48
Nematoda	0	0	0	0	0	0	0	0	0	0	73	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mediomastus capensis	97	730	292	49	73	122	243	24	0	97	1339	414	170	998	1144	0	316	4698	2256	848	560	1056	1184	832	448	2672
Neomediomastus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	0
Prionospio cirrifera	0	706	779	682	219	24	1412	49	0	122	24	24	24	0	657	0	365	657	2608	1360	192	1200	928	1264	672	1808
Prionospio pinnata	365	0	24	0	73	195	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scololepsis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	24	49	0	0	0	0	0	0	0	0	0	0	0
Paraprionospio sp.	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cossura sp.	73	292	1558	49	2799	49	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glycera alba	24	268	122	146	146	24	97	24	24	97	0	0	49	0	49	0	0	243	0	0	0	32	16	112	16	0
Orbinia sp.	0	0	0	0	0	0	0	219	0	0	49	24	0	0	24	0	0	0	16	16	0	0	0	0	0	32
Onuphis sp.	0	0	0	0	0	0	0	0	0	633	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nephtys inermis	0	0	73	24	49	219	195	511	0	49	219	73	268	170	146	0	24	122	32	16	0	16	0	0	0	0
Sigambra sp.	24	24	219	0	170	49	97	0	0	122	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Namalycastis sp.	0	24	0	0	24	0	24	24	0	24	0	0	0	24	0	0	24	24	0	32	0	32	32	0	0	0

Dendroneries sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0
Neanthes sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neries sp.	0	0	0	0	0	0	0	24	0	0	0	49	0	0	0	0	0	24	0	0	0	0	0	0	0	0
Lumbrineries sp.	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	170	49	16	0	112	0	0	0	0	16
Pectineria sp.	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	73	0	0	0	0	0	0	0	0	0
Cirratulus sp.	0	49	0	0	49	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0
Phyllodocae sp.	0	0	0	0	0	0	0	0	0	0	0	24	0	0	24	0	0	0	0	0	0	0	0	0	0	0
Trochochaetus sp.	0	0	0	0	0	0	0	0	0	0	146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sternaspis sp.	24	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sabella sp.	0	0	0	0	0	0	0	0	0	0	0	0	73	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	24	0	0	49	0	0	0	0	0	0	0	0	24	0	0	0	122	73	128	16	0	0	32	64	64	272
Isopoda	0	0	0	0	0	0	49	0	0	0	24	0	24	0	24	0	0	24	16	0	64	0	0	0	32	32
Decapoda	0	0	0	0	49	24	195	0	0	0	49	49	0	0	49	0	0	73	0	32	32	0	0	0	0	0
Shrimp	73	0	49	0	73	146	24	0	97	24	0	0	0	170	0	0	97	24	0	0	0	0	0	32	0	0
Bivalvia	0	0	0	24	49	73	97	24	49	0	24	0	24	0	0	0	24	24	0	0	32	0	0	0	0	16
Gastropod larvae	0	0	0	0	0	49	24	0	0	0	0	0	0	146	0	0	0	0	0	0	0	0	0	0	0	0
Platyheminthes	0	0	24	0	0	24	0	0	0	0	0	24	0	49	0	0	0	0	32	48	0	16	0	32	0	48
Nemertea	0	97	97	146	73	0	0	0	0	73	0	0	0	0	73	0	0	73	0	0	0	0	0	0	0	0
Chironomidae larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	43	53	11	0	41	21	94	0	0	60	97	0	0	15	82	0	0	0	0	0	0	0	0	80	0	96

	8	5	20		4	9	9			9	4			58	8											
Fish juvenile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	0	0
Phoronida	0	0	49	0	0	0	0	0	0	49	97	0	0	0	0	0	24	0	0	0	0	0	0	64	0	0
Pycnogonia	0	0	73	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Abundance (ind. m^{-2})	**1144**	**2726**	**4503**	**1193**	**4260**	**1460**	**3724**	**925**	**243**	**2239**	**3018**	**755**	**682**	**3164**	**3067**	**0**	**1314**	**6158**	**5104**	**2368**	**992**	**2352**	**2192**	**2480**	**1232**	**5040**

Table 3.6: continued																
Taxa	**Z 14A**	**Z 14B**	**Z 15A**	**Z 15B**	**Z 16A**	**Z 16B**	**Z 17A**	**Z 17B**	**Z 18A**	**Z 18B**	**Z 19A**	**Z 19B**	**Z 20A**	**Z 20B**	**Total**	**%**
Bryozoan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	924	0.97
Nematoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97	0.10
Mediomastus capensis	3696	2768	2544	1568	2093	49	0	365	0	0	0	0	0	0	33746	35.56
Neomediomastus sp.	0	0	0	0	0	0	0	0	49	0	0	0	0	0	97	0.10
Prionospio cirrifera	2992	1712	2144	368	3189	24	97	803	0	0	0	0	0	0	27106	28.56
Prionospio pinnata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	682	0.72
Scololepsis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	0.08
Paraprionospio sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0.03
Cossura sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4892	5.16
Glycera alba	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1490	1.57
Orbinia sp.	0	0	0	0	24	0	0	0	0	0	0	0	0	0	405	0.43
Onuphis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	633	0.67
Nephtys inermis	16	0	0	0	0	0	0	0	0	0	0	0	0	0	2222	2.34
Sigambra sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	730	0.77
Namalycastis sp.	32	16	64	0	0	49	49	24	24	0	0	195	0	0	743	0.78
Dendroneries sp.	0	80	256	16	292	268	49	146	0	49	0	0	0	0	1180	1.24
Neanthes sp.	0	0	0	0	0	0	0	0	97	24	0	0	0	0	122	0.13
Neries sp.	0	16	0	0	49	0	0	0	0	0	0	0	0	0	162	0.17
Lumbrineries sp.	0	48	0	0	0	0	0	0	0	146	0	0	0	0	581	0.61
Pectineria sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97	0.10
Cirratulus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	122	0.13
Phyllodocae sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.05
Trochochaetus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	146	0.15
Sternaspis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.05
Sabella sp.	0	16	0	0	0	0	0	0	0	0	0	0	0	0	89	0.09

Amphipoda	48	80	1952	0	389	122	24	1363	195	0	0	0	0	0	5041	5.31
Isopoda	80	16	0	0	49	24	0	24	0	0	0	0	0	0	483	0.51
Decapoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	551	0.58
Shrimp	0	0	16	0	0	0	0	49	0	0	0	0	0	0	876	0.92
Bivalvia	0	32	48	16	49	0	97	0	24	0	0	0	0	0	728	0.77
Gastropod larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	219	0.23
Platyheminthes	16	0	112	16	24	49	49	49	24	0	0	0	0	0	636	0.67
Nemertea	0	0	16	0	0	0	0	0	0	0	0	0	0	0	649	0.68
Chironomidae larvae	16	16	48	16	49	0	49	24	24	0	0	0	0	0	242	0.26
Oligochaeta	16	64	64	0	0	292	0	0	146	0	0	0	0	0	8401	8.85
Fish juvenile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0.05
Phoronida	0	16	0	0	0	0	49	0	49	0	0	73	0	0	469	0.49
Pycnogonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	97	0.10
Abundance (ind. m^{-2})	**6912**	**4880**	**7264**	**2000**	**6207**	**876**	**462**	**2848**	**633**	**219**	**0**	**268**	**0**	**0**	**94904**	100.00

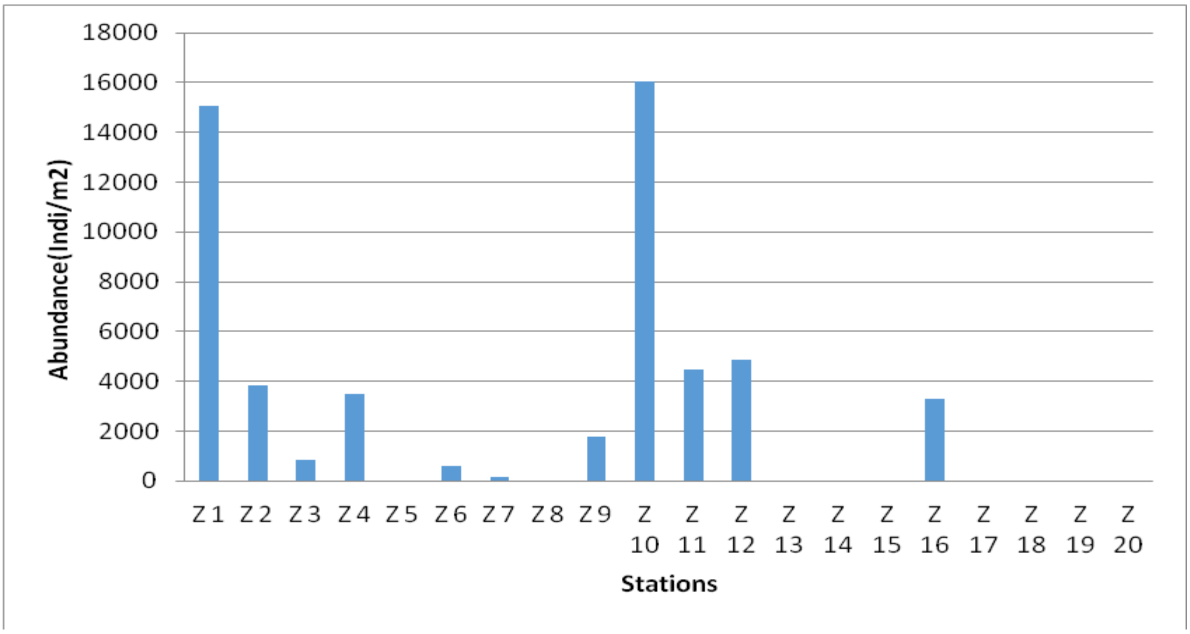


Figure 3.26: Station wise macrofaunal abundance (ind. m^{-2}) of Zuari estuary (central transect)

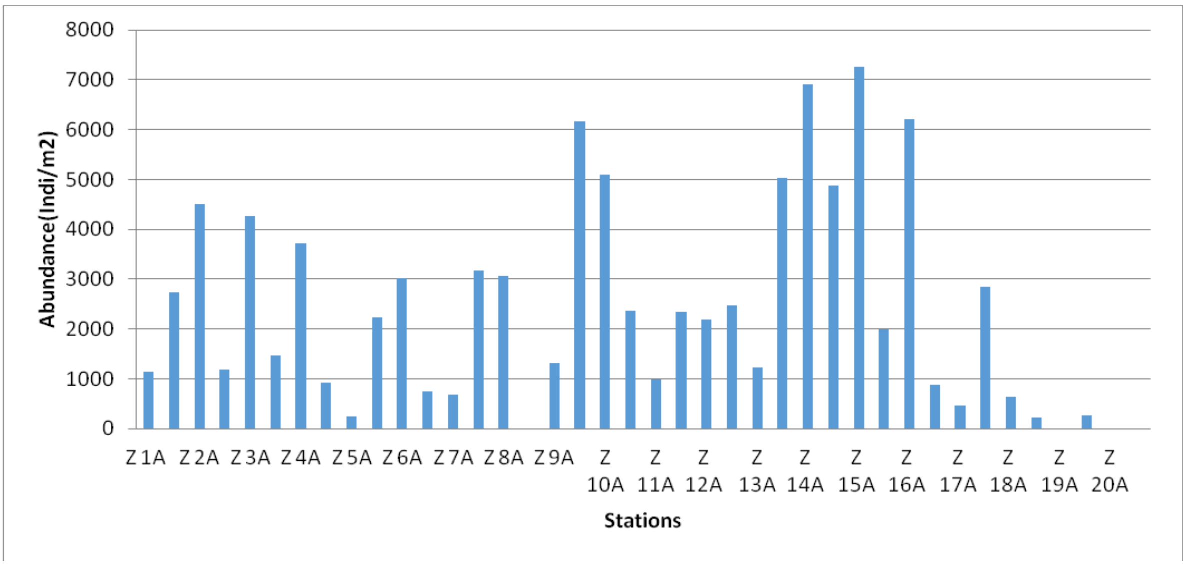


Figure 3.27: Station wise macrofaunal abundance (ind. m^{-2}) of Zuari estuary (peripheral transect)

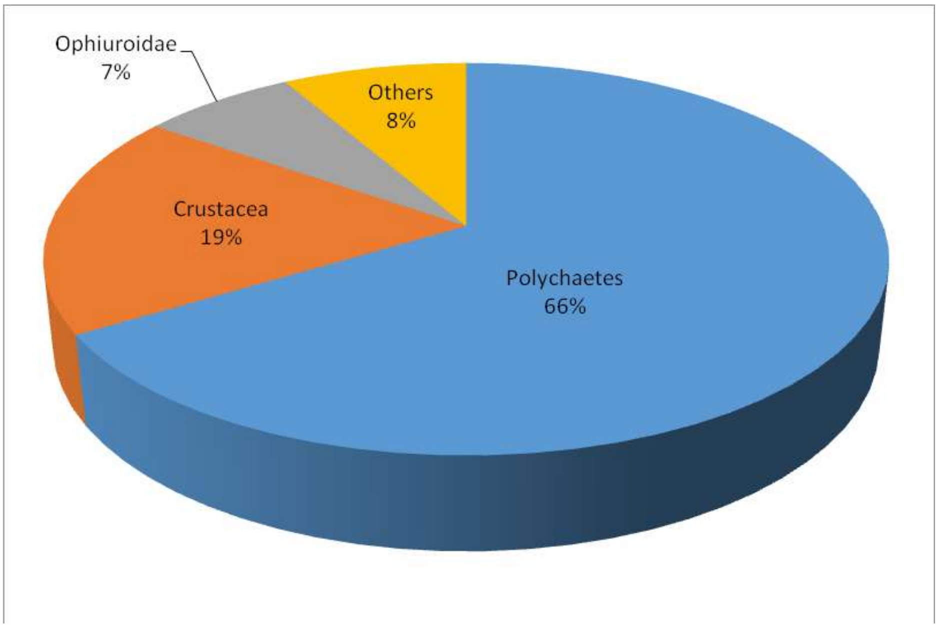


Figure 3.28: Percent (%) composition of macrofaunal abundance of Zuari estuary (Central transect)

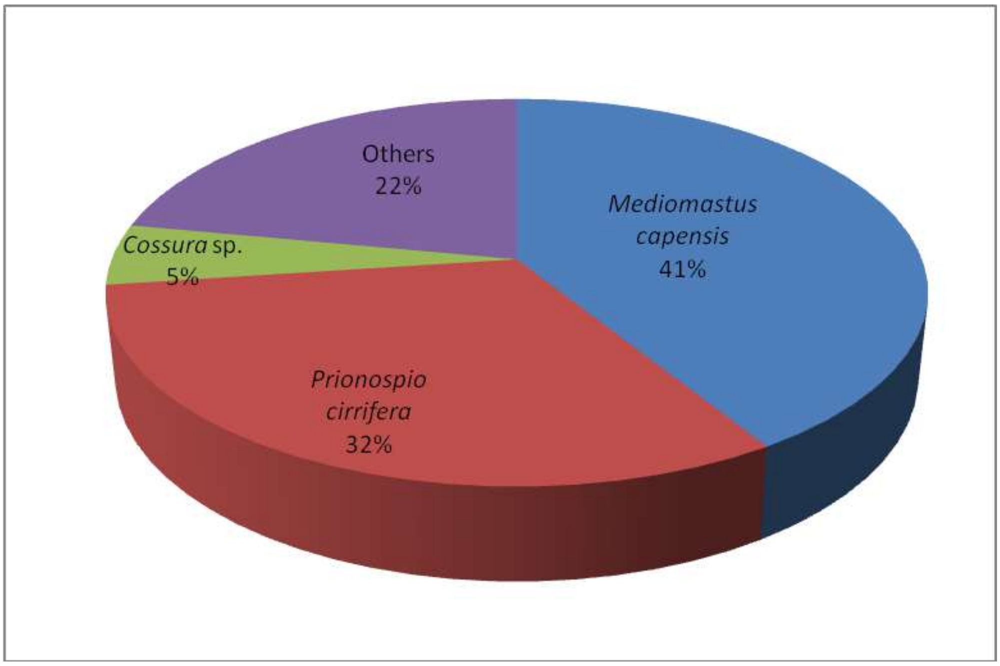


Figure 3.29: Percent (%) composition of polychaetes of Zuari estuary (central transect)

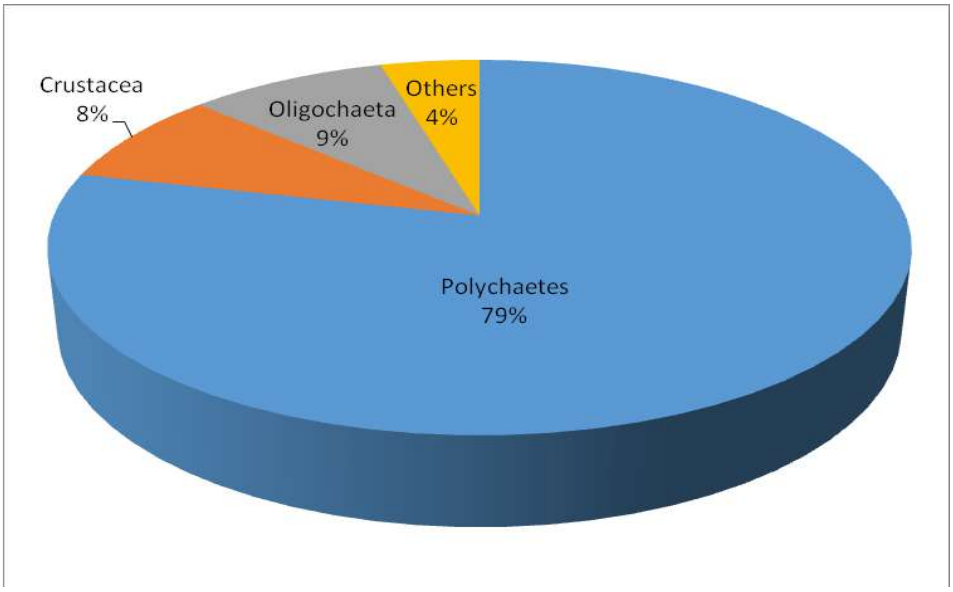


Figure 3.30: Percent (%) composition of macrofauna abundance of Zuari estuary (peripheral transect)

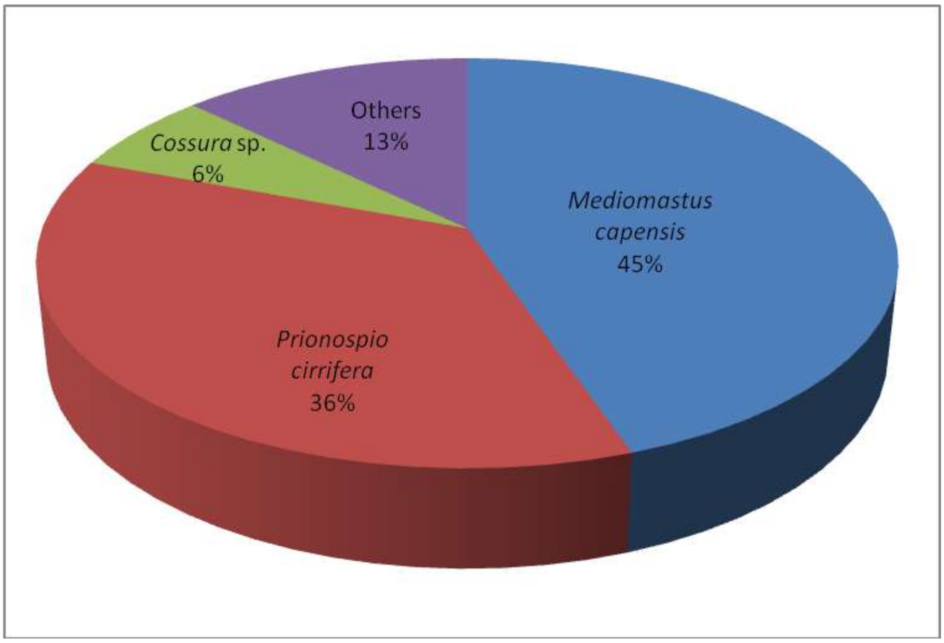


Figure 3.31: Percent (%) composition of polychaetes of Zuari estuary (peripheral transect)

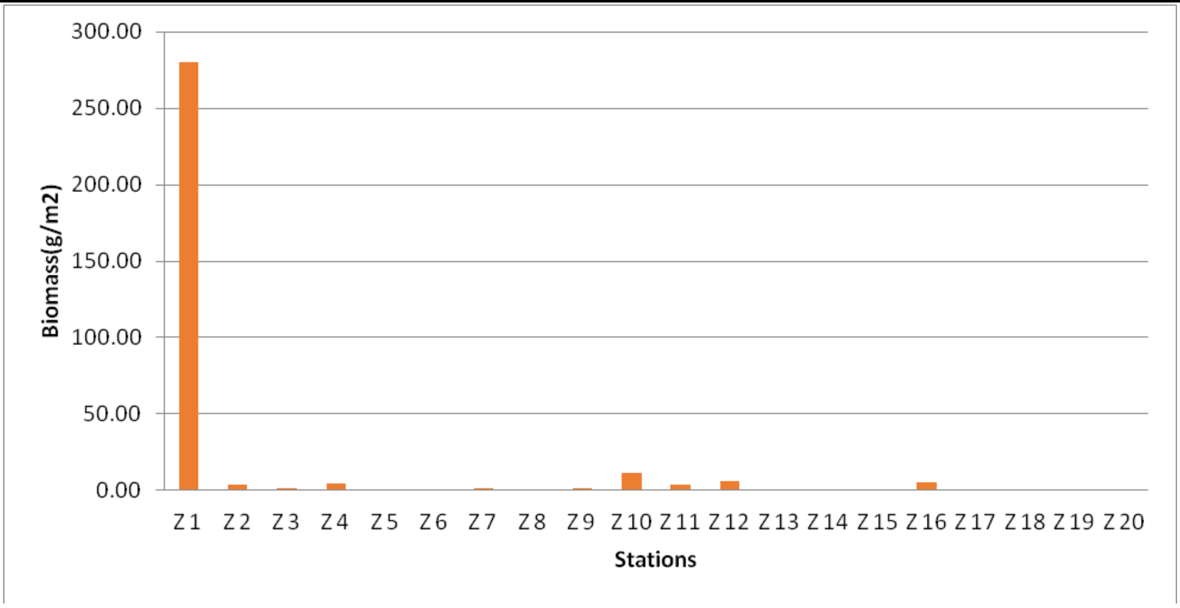


Figure 3.32: Station wise Biomass (g m^{-2}) of Zuari estuary (central transect)

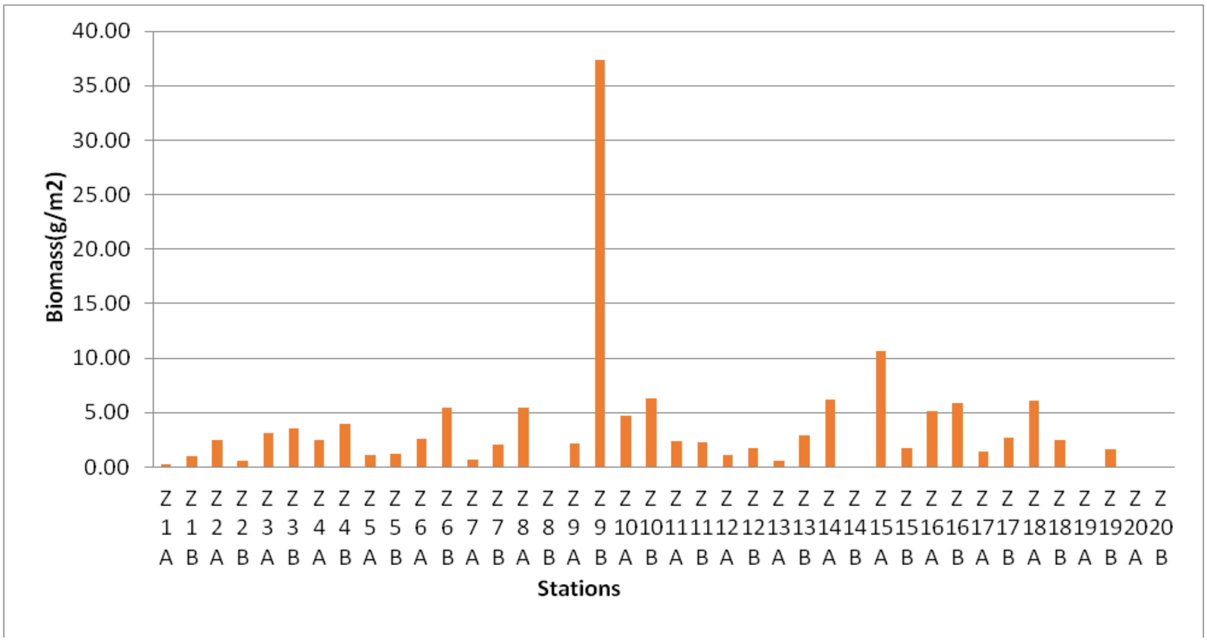


Figure 3.33: Station wise Biomasss (g m^{-2}) of Zuari estuary (peripheral transect)

Benthic Polychaete: Amphipoda (BPA) Ratio:

At the centre region of Zuari estuary, the BPA ratio ranged from 0.095 to 0.301. At station Z16 the BPA ratio showed good status and in station Z1 the BPA ratio showed moderate status whereas the remaining stations Z2, Z3, Z4, Z6, Z7, Z9, Z10, Z11 and Z12 the BPA ratio showed poor status (Table 3.7). Poor BPA ratios at the aforesaid stations indicated absence or low abundance of amphipods and high abundance of polychaetes. At the periphery region, the BPA ratio ranged from 0.26 to 0.30. All the stations showed poor status (Table 3.8). *Mediomastus capensis* of the family Capitellidae and *Prionospio cirrifera* of family Spionidae dominated in the Zuari estuary, which are the opportunistic polychaete species.

Table 3.7: Benthic Polychaete Amphipod (BPA) ratio of Zuari estuary (central transect)

Stations	Benthic Polychaete Amphipod ratio (BPA)
Z 1	0.154
Z 2	0.301
Z 3	0.301
Z 4	0.301
Z 6	0.301
Z 7	0.243
Z 8	0.000
Z 9	0.301
Z 10	0.257
Z 11	0.275
Z 12	0.292
Z 16	0.095

Table 3.8: Benthic Polychaete Amphipod (BPA) ratio of Zuari estuary (peripheral transect)

Stations	Benthic Polychaete Amphipod ratio (BPA)
ZE 1A	0.28
ZE 1B	0.30
ZE 2A	0.30
ZE 2B	0.28
ZE 3A	0.30
ZE 3B	0.30
ZE 4A	0.30

ZE 4B	0.30
ZE 5A	0.30
ZE 5B	0.30
ZE 6A	0.30
ZE 6B	0.30
ZE 7A	0.28
ZE 7B	0.30
ZE 8A	0.30
ZE 9A	0.26
ZE 9B	0.30
ZE 10 A	0.29
ZE 10 B	0.30
ZE 11A	0.30
ZE 11B	0.30
ZE 12A	0.29
ZE 12B	0.30
ZE 13A	0.30
ZE 13B	0.30
ZE 14 A	0.30
ZE 14 B ZE 15 A	0.30 0.30
ZE 16 A	0.30
ZE 16 B	0.30
ZE 17 A	0.30
ZE 17 B	0.30
ZE 18 A	0.30

The macrofaunal diversity was explained in terms of number of individuals or specimens (N), number of species (S), Margalef's species richness (d), Pielou's evenness (J') and Shannon index (H') and Simpson index (1-lambda') using square root scale at each station (Clarke & Gorley, 2001). In central region of Zuari estuary, the number of species was maximum at station Z1 (33) and lowest at station Z7 (5). The species richness (d) was maximum at station Z1 (d=3.3258) and minimum at station Z12 (d=0.5886). Evenness was recorded highest at station Z7 (J'=0.92) and lowest at station Z10 (J'=0.51). The Shannon index was highest at Z1 (H'=2.3034) and lowest at Z12 (H'=0.9). Simpson index was high at Z12. Z locations were situated at the central part of the river where sand mining is accomplished and that may be the reason for low macrofaunal diversity (Figure 3.34). In peripheral region, the number of species was maximum at station Z2A and Z19B (16) and minimum at station Z17B (2). The species richness (d) was highest at Z2A (d= 2.0539) and lowest at Z17A (d= 0.3711). Evenness was recorded highest at Z15B (J'=0.9598) and lowest at Z14A (J'=0.36). The Shannon index was highest at Z2A (H'=2.4352) and lowest at Z17B (H'=0.58). Simpson index was high at Z2A. As the ZA and ZB mangroves situated adjacent to the estuary, the diversity was high in the peripheral area (Figure 3.35).

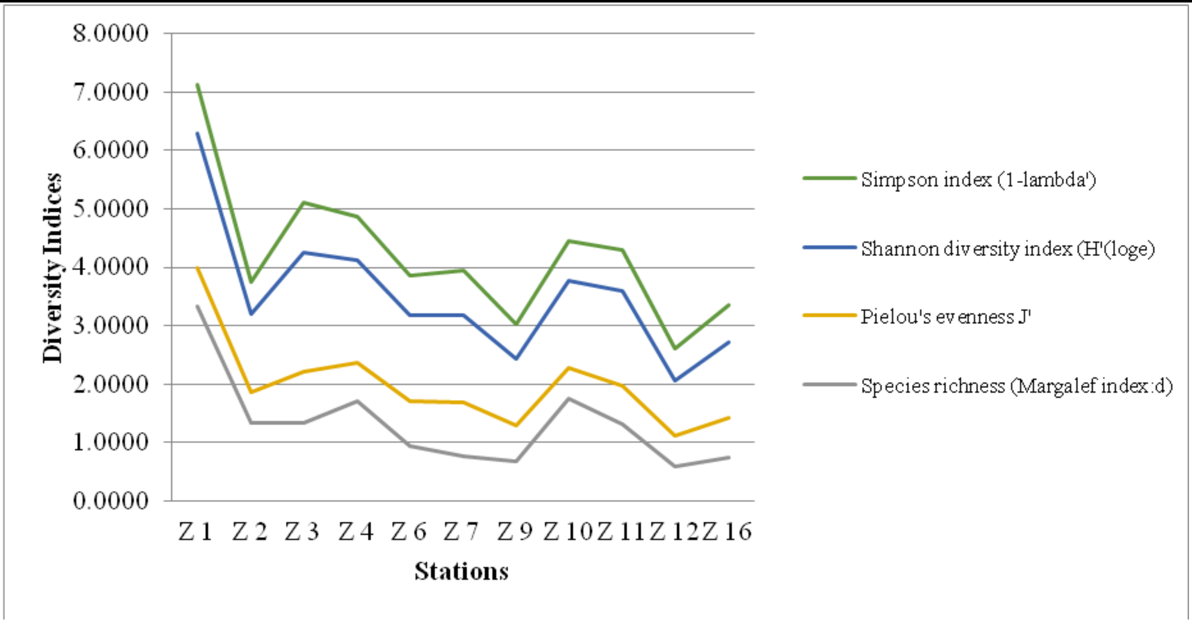


Figure 3.34: Station wise diversity indices of Zuari estuary (central transect)

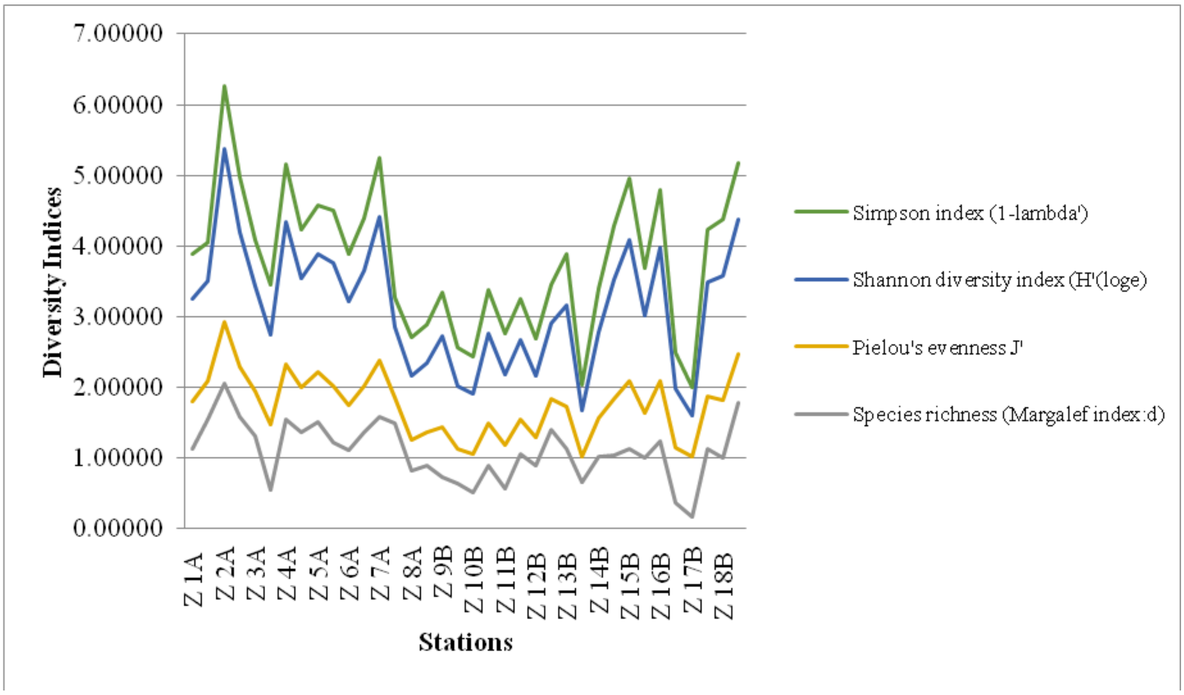


Figure 3.35: Station wise diversity indices of Zuari estuary (peripheral transect)

Biotic indices

Ecological quality status assessment carried out by AMBI analysis based on the benthic polychaete diversity and abundance. This index assigned most of the sampling sites as moderately disturbed to slightly disturbed. Stations such as Z1, Z4B, Z5B, Z7, Z7A and Z18B of Zuari estuary were slightly disturbed and Z19B is extremely disturbed based on the MBI results (Figure 3.36). According to M-

AMBI, most of the sampled sites were assigned to poor ecological quality status. Stations Z3B, Z4B and Z5B were in good status, Z1A, Z1B, Z2 and Z2A showed moderate status, while stations Z5A and Z19B showed poor status. Among all stations, Z1 showed high ecological status. Stations towards the mouth of the estuary showed good to moderate status whereas the stations towards the upper stream areas showed poor status (Figure 3.37).

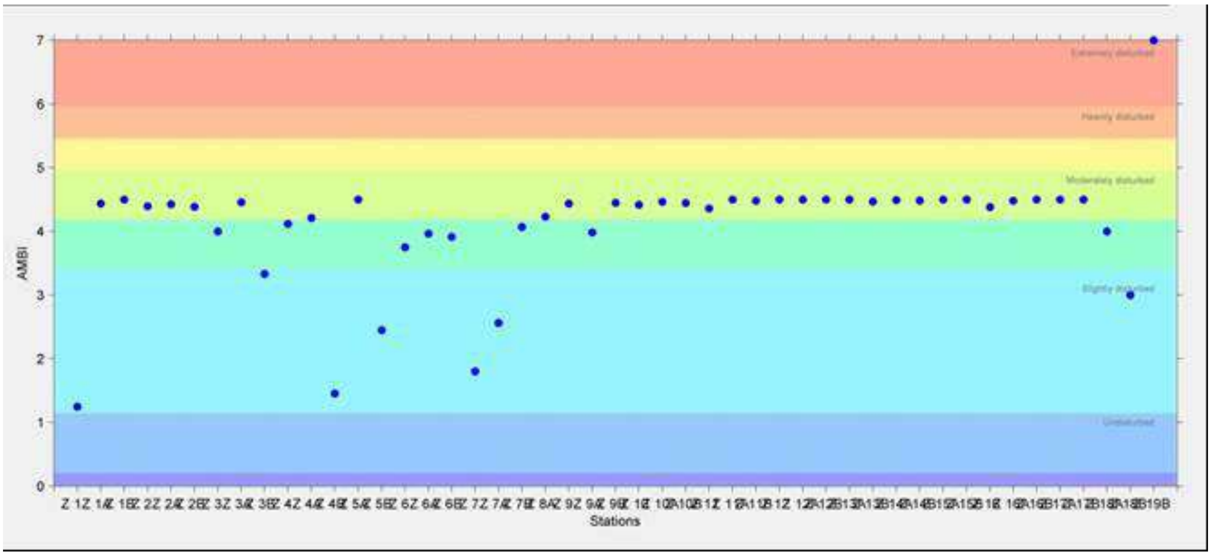


Figure 3.36: Ecological quality status assessment through AMBI index from Zuari estuary

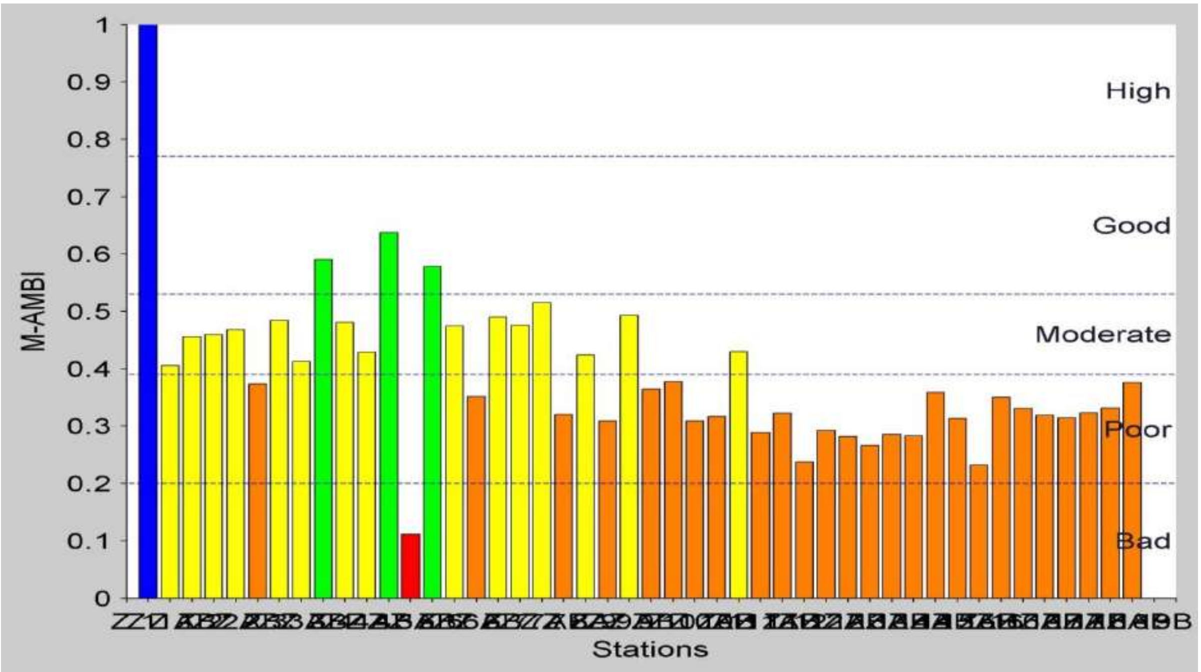


Figure 3.37: Ecological quality status assessment through M-AMBI index from Zuari estuary

Bentix produced a poor status in most of the stations mainly in upper stream of the Zuari estuary, except station Z4A, Z4B, Z5B, Z7A, Z7B, Z8A, Z9A, Z10A, Z10B and Z14A showed high ecological status and some stations displayed moderate ecological status. Stations of upper stream areas showed poor ecological quality status due to the diversity and abundance in benthic fauna present in all the stations. Tolerant species were more dominant in all the sampling stations (Figure 3.38).

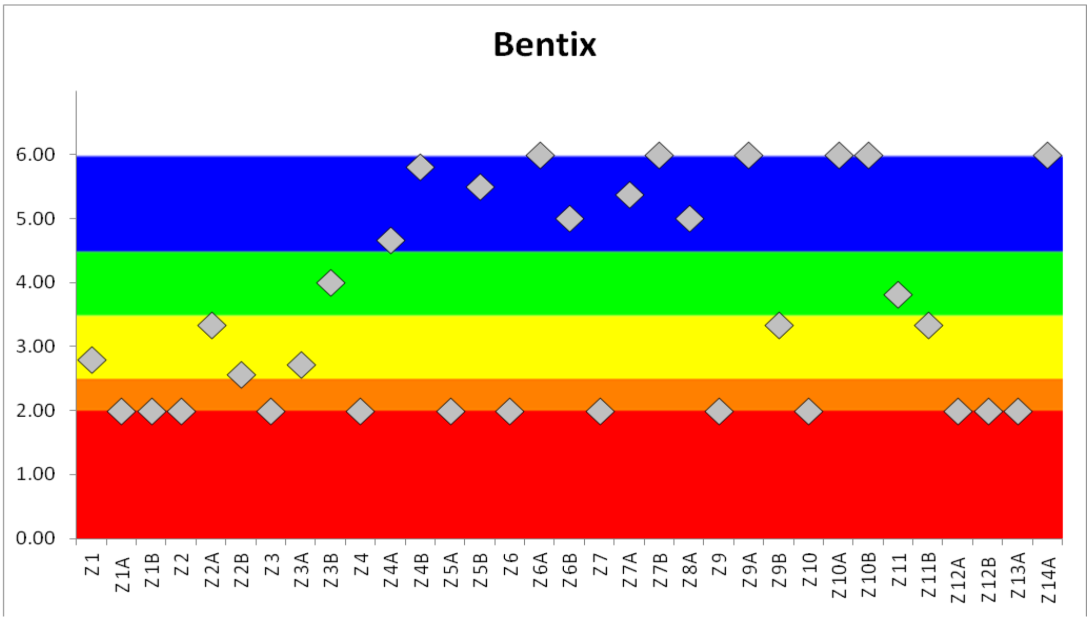


Figure 3.38: Ecological quality status assessment through BENTIX index from Zuari estuary

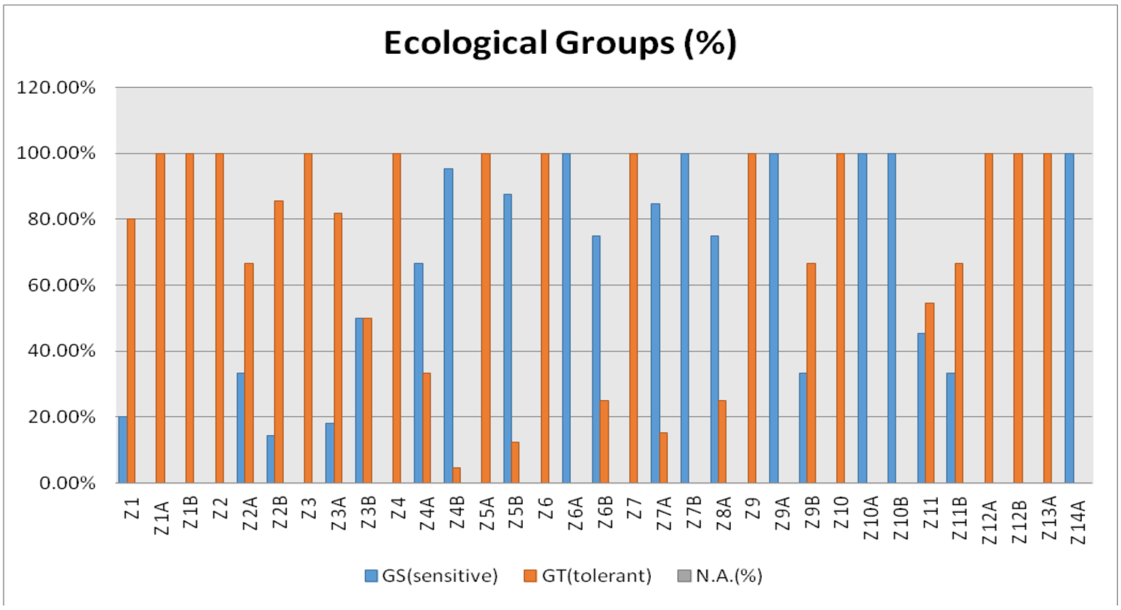


Figure 3.39: Distribution of macrobenthic-Polychaeta based on the ecological sensitivity group assessed through BENTIX index from Zuari estuary

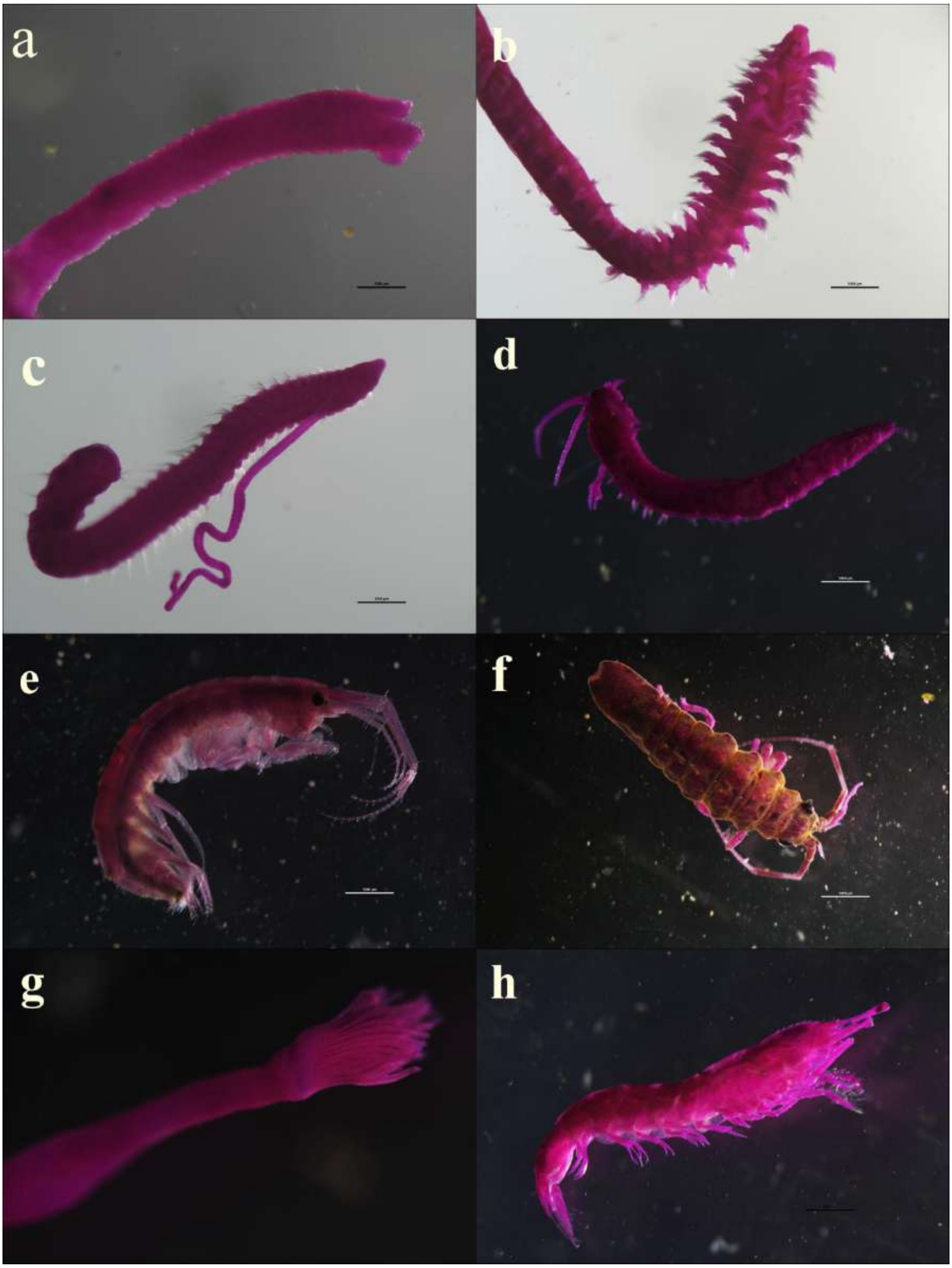


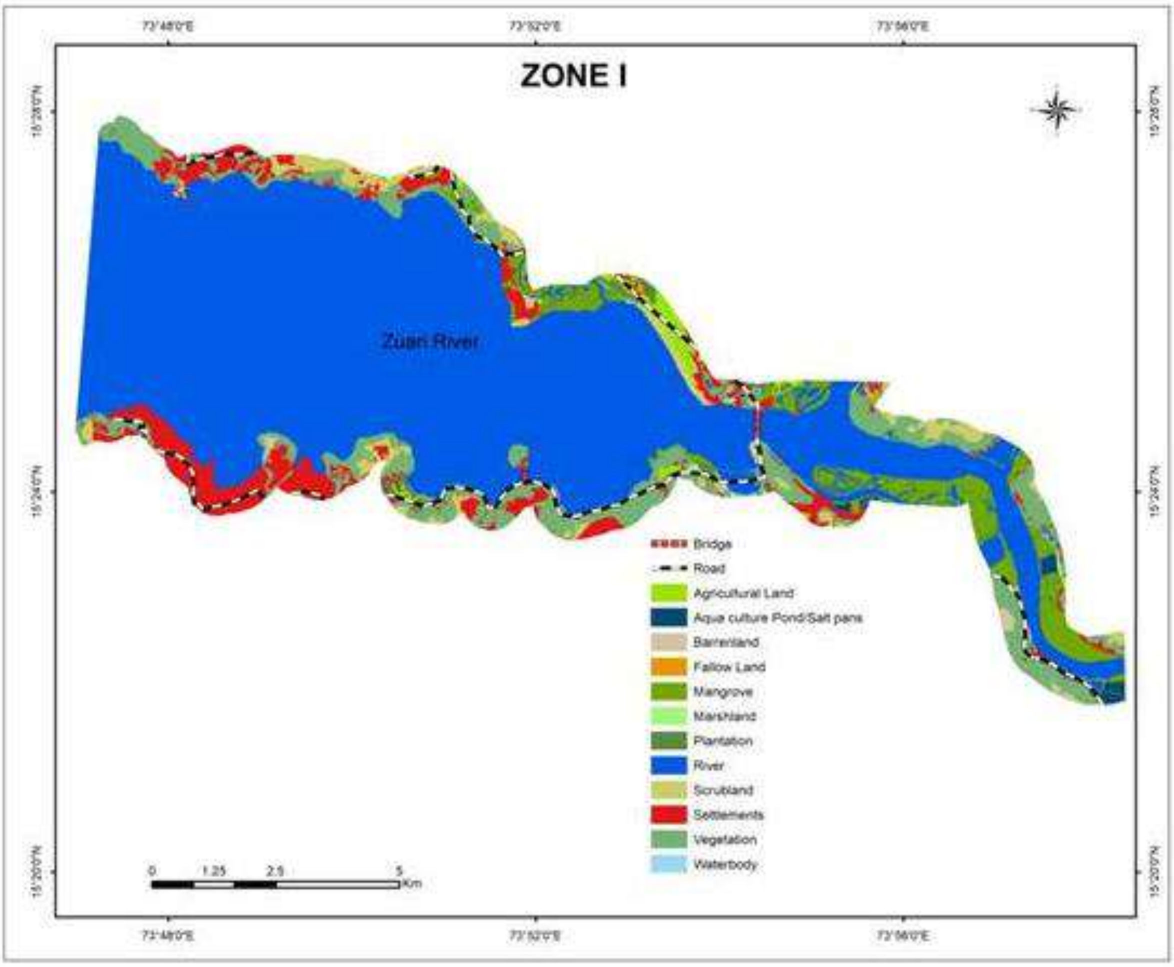
Plate 3.6: a. *Mediomastus capensis*; b. *Prionospio* sp.; c. *Cossura* sp.; d. *Onuphis* sp.; e. Amphipoda; f. Isopoda; g. Phoronida; h. Shrimp

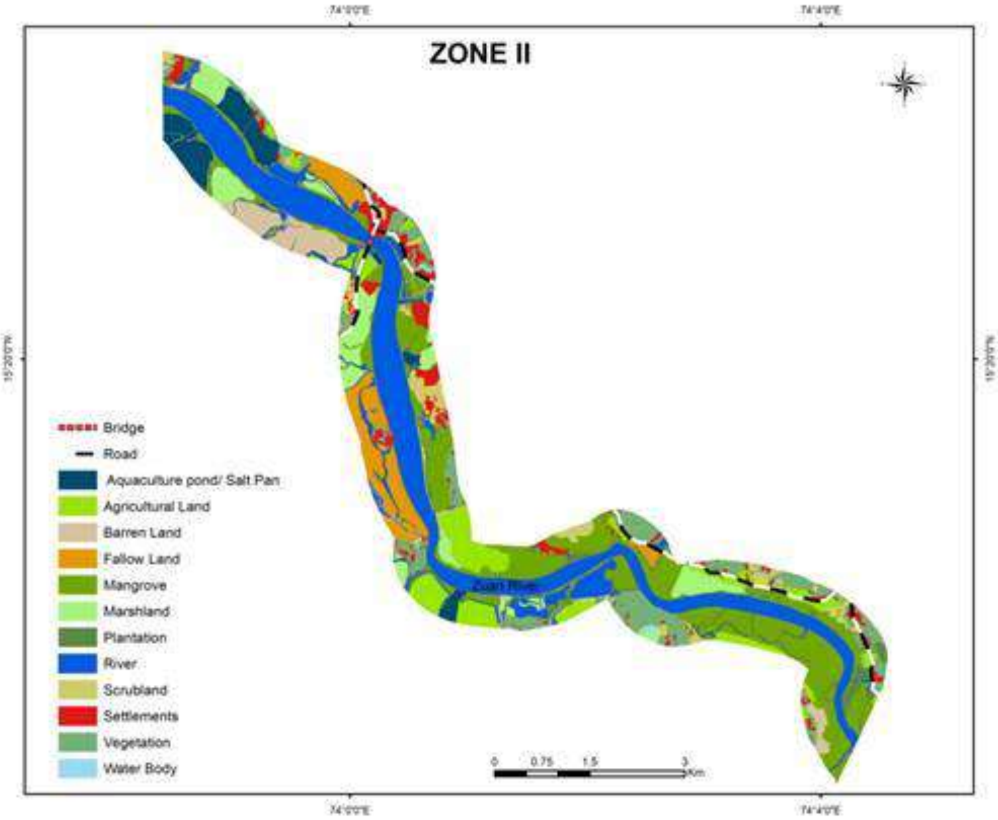
3.8 Land Use Land Cover (LULC)

LISS IV data was used for the purpose of classification of Land use Land Cover for the study area. The LISS-4 (Linear Imaging Self-Scanning Sensor-4) multispectral high-resolution camera is the prime instrument of Resourcesat satellite series, with a spatial resolution of 5.8 m and a swath of 70 km.

The study area comprised of the sub scene (A) of path and row 96 and 62 respectively of the LISS IV data. The Red (Band 2, 0.62-0.68), Green (Band 3, 0.52-0.59) and Infrared Red (Band 4, 0.77-0.86) bands were used to prepare the false colour composite for the area.

The land use and land cover for an area of 500 meters around the Zuari estuary was extracted from the imagery with the help of object-oriented classification of the data where a group of pixels were identified as features with the help of factors such as Shape, Texture, Tone, and spatial relation between the surrounding pixels. All the LULC maps of Zuari estuary was prepared by using ArcGIS.





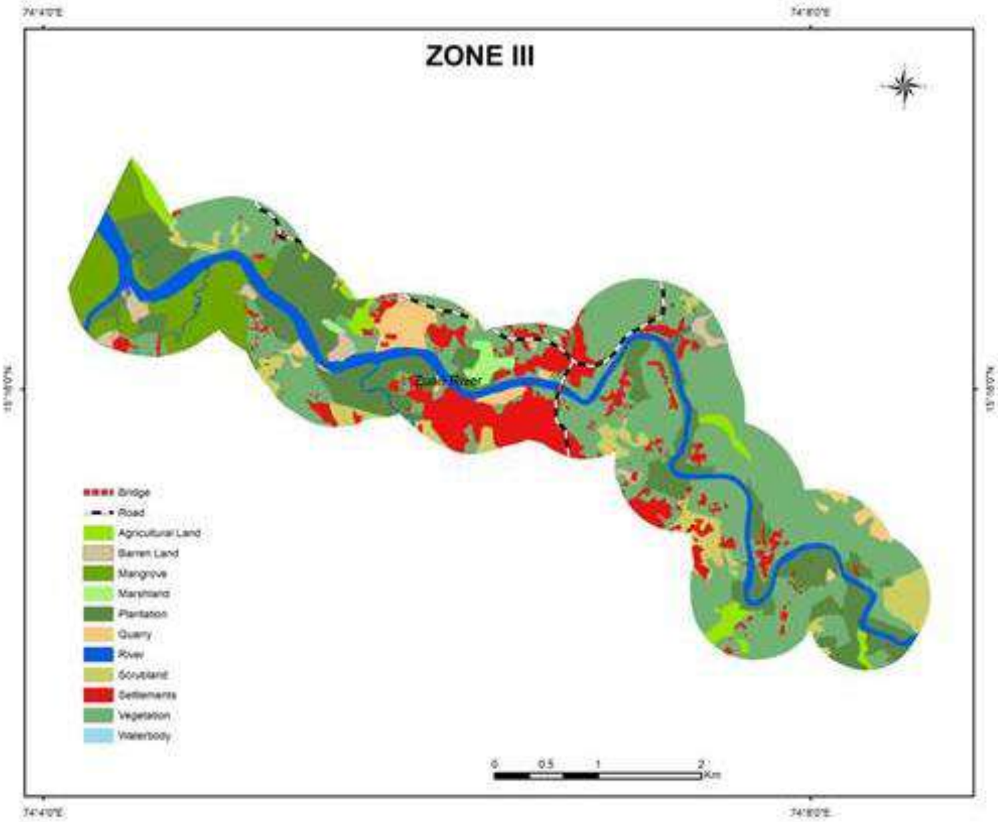


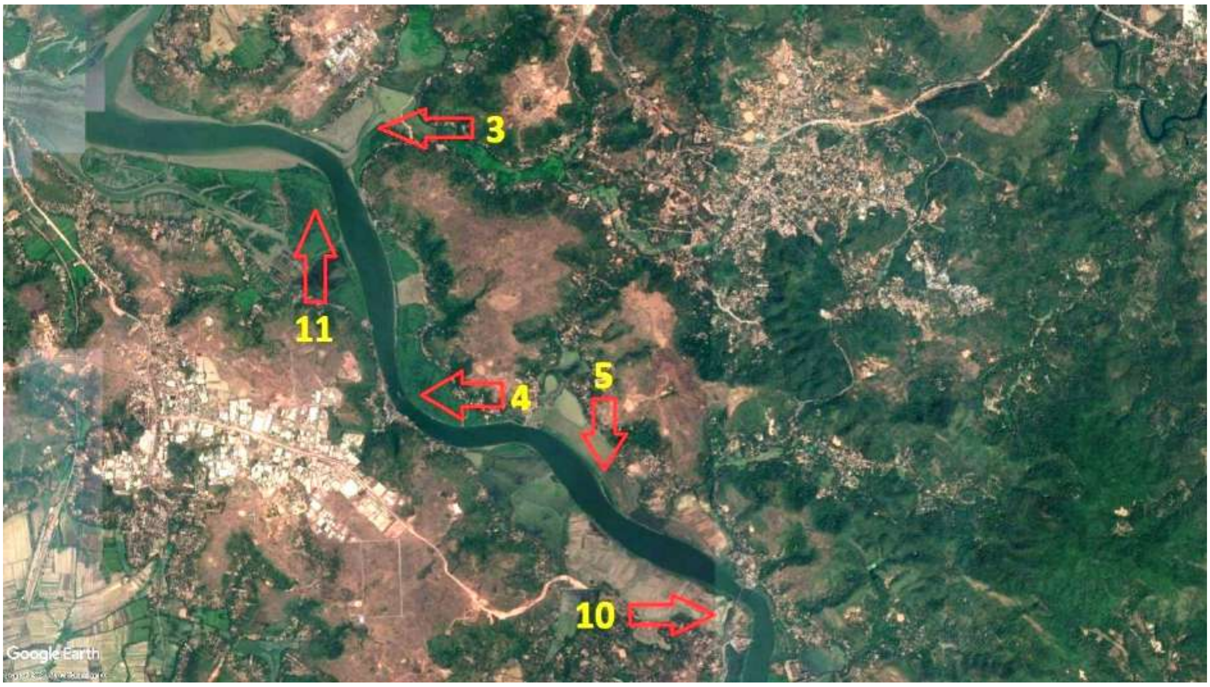
Figure 3.40: LULC of Zuari estuary (divided into three zones), image used LISS-IV

Land Use pattern

In the present study of Zuari estuary Land Use Land Change (LULC) cover was observed and obtained by mapping the project area by comparing present scenario with year 2010. Several areas were noted and maps were prepared accordingly along the entire stretch of Zuari estuary. A total of 13 regions of Zuari estuary were identified and depicted based on land use change. For all the regions two maps were created, representing current scenario and the other depicting 2010 scenario. These maps have been numbered as 1-13.

The First region i.e. (1) and the last region of Zuari i.e. (13) lies near the mouth area of the estuary, from the year 2010 to present time has shown a drastic major change. Image 1 showed mangrove cover in 2010 while in 2021 the image has shown the use of that land is used for the construction of Zuari suspension bridge and workshop needed to fabricate materials for the bridge. Mangrove cover has increased in some regions in 2021 which were not present in 2010 as seen in images (1, 2, 3, 6, 11, and 12). Image 10 shows a decrease in mangrove cover these mangroves were cleared for structures such as buildings, bridges and roads in images (1, 4 and 12). Mangroves were not present in images 7 and 8 as these are upstream and have no salinity, these areas have coconut plantations image 7 shows no drastic changes in 10 years while in image 8 it is seen that large areas have been deforested and land is cleared for agriculture purpose. Images (5, 6, 10, and 12) denoted use of land for construction of aquaculture purpose, where aquaculture ponds are clearly visible. Images 6 and 10 showed agriculture land and aquaculture pond were in use in 2010 but were in disuse in 2021. The reason is salt water intrusions and increase in mangrove cover which has grown in thicket. The areas once utilised for paddy field cultivation has now turned barren/fallow probably due to single saline water surge or recurrent high tide water bringing in salinity. The intrusion of saline water could be due to lack of maintenance of already existing bunds/embankments, breach in embankments, erosion of mudflats or shift in mangrove area to the landward side as well as excavation of sand which in turn increases the water depths and the water breaches the embankments making it saline. There is no major change in the river except near the mouth of Zuari where changes are noticeable.


1
2
13
12
Google Earth


3
11
4
5
10
Google Earth

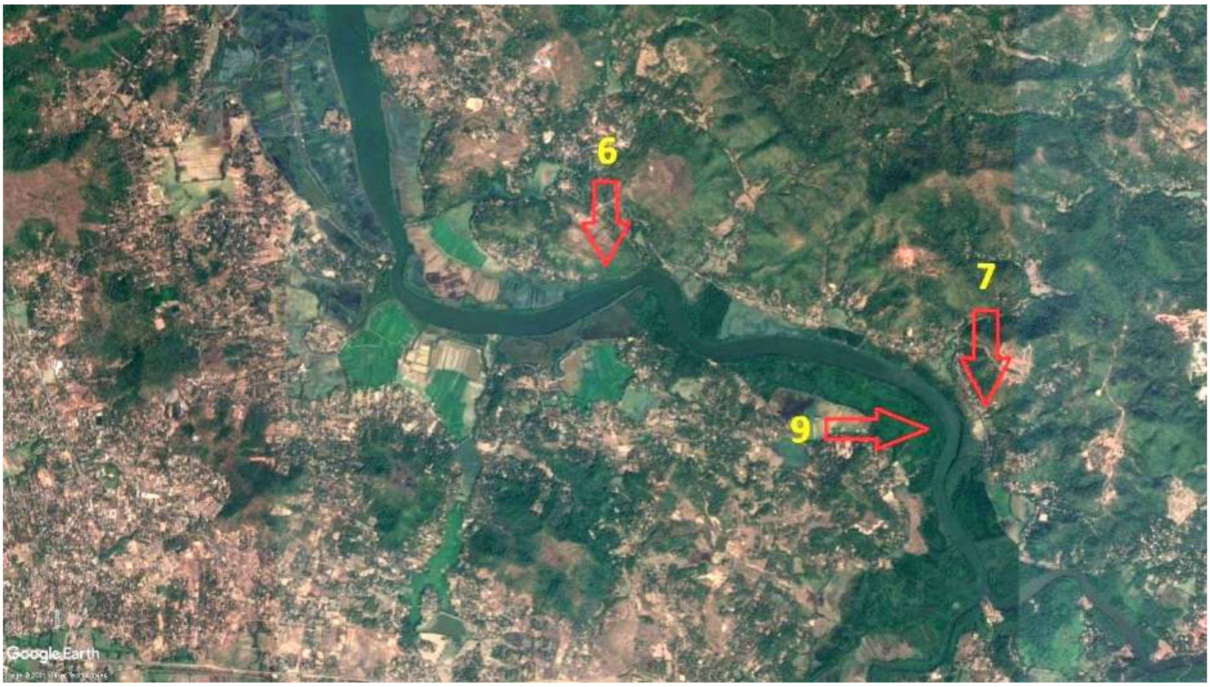


Figure 3.41: Sections of the Zuari rivers depicting areas highlighted in the subsequent figures for land use changes

2010	2021
 1a	 1b
 2a	 2b
 3a	 3b
 4a	 4b

 5a	 5b
 6a	 6b
 7a	 7b
 8a	 8b

 9a	 9b
 10a	 10b
 11a	 11b
 12a	 12b

 13a	 13b
 14a	 14b
 15a	 15b
 16a	 16b

17a

17b

18a

18b

Figure 3.42: Areas depicting Land Use Land Cover along the Zuari estuary in 2010 and 2021.

3.9 Fishery

As Goa is a coastal region fishery is one of the important economic activities in the state. The continental shelf of goa is about ten million hectare and actively fished area of the state is 20,000 sq.km; estimated annual yield for pelagic fishery is 77,660 tons and demersal fishery is 1,12,600 tons. A majority of the communities in Goa is dependent upon fishing as a source of livelihood in both coastal as well as inland areas. Fishing activity is carried out through fibre reinforced plastic (FRP) outboard engine boats, trawlers and small size traditional dugout canoes. Fishery data was collected from observations during sampling and through secondary data from fisherman and local communities. Cortalim jetty is the major fish landing center in the Zuari estuary, commercially important fish varieties such as sardines, mackerels, mullets, catfish , sharks, seerfish, cuttlefish, prawns, crabs and other shellfishes are found in Zuari and surrounding coastal waters (Table 3.9) Fishery data constitutes marine, brackish and fresh water fish species, the methods and gears involved in fish catching are cast-nets, gill nets, stake nets, hook and line, shore seine (Rapon), purse seine, trawling and free diving for the collection of clams oysters and green mussels.

Table 3.9: Fish diversity from Zuari estuary				
Families	**Species**	**Common name**	**Vernacular name**	**Habitat class**
Upper Estuary				
Cyprinidae	*Dawkinsia filamentosa*	Blackspot barb	-	Demersal
Cyprinidae	*Devario malabaricus*	Malabar danio	-	Demersal
Cyprinidae	*Pethia setnai*	Pethia	-	Demersal
Cyprinidae	*Rasbora daniconius*	Slender rasbora	-	Demersal
Cyprinidae	*Garra mullya*	Sucker fish	-	Demersal
Cyprinidae	*Systomus sarana*	Olive barb	-	Demersal
Cyprinidae	*Puntius mahecola*	Mahecola barb	-	Demersal
Cyprinidae	*Cabdio morar*	Morari	-	Demersal
Tetraodontidae	*Chelonodonpatoca*	milkspotted puffer	Bebo	Pelagic
Cobitidae	*Lepidocephalichthys thermalis*	Common spiny loach	-	Demersal
Middle Estuary				
Gobiidae	*Glossogobius giuris*	Tank goby	Khorsani	Demersal
Aplocheilidae	*Aplocheilus lineatus*	Striped panchax	-	Demersal
Mugilidae	*Mugil cephalus*	Flathead grey mullet	Shevtto	Demersal
Tetraodontidae	*Dichotomyctere nigroviridis*	Spotted green pufferfish	Bebo	Demersal
Lower Estuary				
Oxudercidae	*Boleophthalmus sp.*	Mudskipper	Kheldho	Demersal
Mugilidae	*Mugil cephalus*	Flathead grey mullet	Shevtto	Demersal
Gobiidae	*Glossogobius giuris*	Tank goby	Khorsani	Demersal
Gobiidae	*Acentrogobius nebulosus*	Shadow goby		Demersal
Sciaenidae	*Johnieops belangerii*	Croaker	Dhodiyare	Demersal
Sciaenidae	*Johnius borneensis*	Croaker	Dhodiyare	Demersal
Sciaenidae	*Johnius carouna*	Caroun croaker	Dhodiyare	Demersal
Sciaenidae	*Johnius dussumieri*	Croaker	Dhodiyare	Demersal
Sciaenidae	*Johnius macrorhynus*	Croaker	Dhodiyare	Demersal
Sciaenidae	*Otolithes ruber*	Tiger toothed croaker	Dhodiyare	Demersal
Sciaenidae	*Otolithes argenteus*	Croaker	Dhodiyare	Demersal
Lactariidae	*Lactarius lactarius*	False trevally	Saundallo	Pelagic
Clupeidae	*Sardinella longiceps*	Indian oil sardine	Tarle	Pelagic

Clupeidae	*Sardinella fimbriata*	Fringscale sardine	Pedi	Pelagic
Leiognathidae	*Secutor insidiator*	Pugnose pony fish	Kapi	Demersal
Leiognathidae	*Secutor ruconius*	Deep pugnose pony fish	Kapi	Demersal
Leiognathidae	*Leiognathus brevirostris*	Silver bellies	Kapi	Demersal
Leiognathidae	*Leiognathus blochii*	Silver bellies	Kapi	Demersal
Leiognathidae	*Leiognathus bindus*	Silver bellies	Kapi	Demersal
Leiognathidae	*Leiognathus splendens*	Silver bellies	Kapi	Demersal
Leiognathidae	*Leiognathus daura*	Silver bellies	Kapi	Demersal
Carangidae	*Alepes kleinii*	Razorbellyscad	-	Pelagic
Carangidae	*Parastromateus niger*	Black pomfret	Paplet	Pelagic
Carangidae	*Carangoides ferdau*	Blue trevally	Konkor	Pelagic
Chanidae	*Chanos chanos*	Milkfish	Gholsi	Pelagic
Carcharhinidae	*Carchachrinus sp.*		Vattu	Pelagic
Stromatidae	*Pampus chinensis*	Chinese pomfret	Paplet	Pelagic
Stromatidae	*Pampus argenteus*	Silver pomfret	Paplet	Pelagic
Stromatidae	*Rastrelliger karagurata*	Indian mackerel	Bangdo	Pelagic
Polynemidae	*Leptomelanosoma indicum*	Indian threadfin	Rawas	Demersal
Engraulidae	*Stolophorus indicus*	Indian anchovy	Dindvus	Pelagic
Engraulidae	*Thryssa malabarica*	Malabar thryssa	Khavali	Pelagic
Congridae	*Bathy congrusnasicus*	Eel	Vam	Demersal
Chirocentridae	*Chirocentrus dorab*	Wolf herring	Karli	Pelagic
Pristigasteridae	*Opisthopterus tardoore*	Tardoore	Kateri	Pelagic
Platycephalidae	*Eurycephalus carbunculus*	Papilose flathead	-	Demersal
Ambassidae	*Ambassis gymnocephalus*	Bald glassy	Burantte	Pelagic
Ambassidae	*Ambassis urotaenia*	Banded-tail glassy perchlet	Burantte	Pelagic
Nemipteridae	*Nemipterus japonicas*	Japanese threadfin bream	Rano	Demersal
Lutjanidae	*Lutjanus campechanus*	Red snapper	Tamoshi	Pelagic
Serranidae		Grouper	Palu	Pelagic
Cichlidae	*Etroplus suratensis*	Pearl spot	Kalunder	Benthopelagic

Terapontidae	*Terapon jarbua*	Crescent grunter	Korkoro	Pelagic
Terapontidae	*Terapon puta*	spiny-checked grunter	Korkoro	Pelagic
Gerridae	*Gerres filamentosus*	Silver biddy	Shetuk	Demersal
Gerridae	*Gerres limbatus*	Silver biddy	Shetuk	Demersal
Gerridae	*Gerres oyena*	Silver biddy	Shetuk	Demersal
Latidae	*Lates calcarifer*	Giant sea perch	Chonak	Demersal
Megalopidae	*Megalops cyprinoides*	Indo-Pacific tarpon	Ker	Pelagic
Muraenesocidae	*Muraenesox bagio*	Common pike conger	Toem-Baiem	Demersal
Muraenesocidae	*Congresox talabonoides*	Indian pike conger	Divodd Baiem	Demersal
Sillaginidae	*Sillago sihama*	Silver whiting	Mudoshi	Demersal
Polynemidae	*Polydactylusplebeius*	Stripped threadfin	Ravas	Pelagic
Scombridae	*Scomberomorus commerson*	seerfish	Visvonn	Pelagic
Scombridae	*Scomberomorus guttatus*	seerfish	Visvonn	Pelagic
Sparidae	*Chyrsophrys datnia*		Palu	
Sphyraenidae	*Sphyraena jello*	Pickhandle barracuda	Tonki	Pelagic
Triacanthidae	*Tricanthus biaculeatus*	Short-nosed tripodfish	Chamat	Demersal
Scatophagidae	*Scatophagus argus*	Spotted scat	Bannsire	Pelagic
Ariidae	*Arius jella*	Blackfin sea catfish	Sangot	Demersal
Ariidae	*Arius arius*	threadfin sea catfish	Sangot	Demersal
Ariidae	*Arius caelatus*	Spotted catfish	Sangot	Demersal
Ariidae	*Arius platystomus*	Flatmouth sea catfish	Sangot	Demersal
Ariidae	*Arius tenuispinis*	Thinspine sea catfish	Sangot	Demersal
Ariidae	*Arius thalassinus*	Giant catfish	Sangot	Demersal
Ariidae	*Arius venosus*	Veined catfish	Sangot	Demersal
Dasyatidae	*Himantura uarnak*	Reticulate whipray	Vagollim	Demersal
Dasyatidae	*Himantura imbricata*	Scaly whipray	Xevnne Vagollim	Demersal

Trichiuridae	*Lepturacanthus savala*	Ribbon fish	Baye	Pelagic
Trichiuridae	*Trichiurus lepturus*	Ribbon fish	Baye	Pelagic
Solidae	*Synapturaalbo maculata*	Kaup's sole fish	Lepo	Demersal
Pleuronectidae		Flounder	Lepo	Demersal
Cynoglossidae	*Cynoglossus arel*	Sole fish	Lepo	Demersal
Cynoglossidae	*C. macrostomus*	Malabar tongue sole	Lepo	Demersal
Penaeidae	*Penaeus monodon*	Tiger shrimp	Vaghi	Demersal
Penaeidae	*Fenneropenaeus merguensis*	Banana prawn	Safed sungata	Demersal
Penaeidae	*Metapenaeus affinis*	Jinga shrimp	Sungat	Demersal
Penaeidae	*Metapenaeus dobsonii*	Kadal shrimp	Sungat	Demersal
Penaeidae	*Meapeaneus monoceros*	Speckled shrimp	Sungat	Demersal
Penaeidae	*Parapenaeopsis hardwickii*	Spear shrimp	Kandianim	Demersal
Palaemonidae	*Palaemon stylifera*	-	Poting	Demersal
Sergestidae	*Acetes spp*	-	Galmo	Demersal
Portunidae	*Scylla serrata*	Mud crab	Kulli	Demersal
Portunidae	*Scylla olivacea*	Mud crab	Kulli	Demersal
Portunidae	*Charybdis lucifera*	-	Kulli	Demersal
Portunidae	*Charybdis (Charybdis) natator*	-	Kulli	Demersal
Portunidae	*Portunuss anguinolentus*	Three spot swimming crab	Tin doyanchi kurli	Demersal
Portunidae	*Portunus pelagicus*	Blue swimming crab	Padyachi kurli	Demersal
Portunidae	*Charybdis feriatus*	Crucifix crab	Khrusachi kurli	Demersal
Calappidae	*Matuta lunaris*	Moon crab	Bhamburte	Demersal
Dotillidae	*Dotilla myctiroides*	Sand bubbler crab	-	Demersal

Ocypodidae	*Uca sp.*	Fiddler crab	-	Demersal
Ocypodidae	*Gelasimus vocans*	Fiddler crab	-	Demersal
Oziidae	*Epixanthus frontalis*	-	-	Demersal
Pilumnidae	*Heteropanope glabra*	-	-	Demersal
Grapsidae	*Sesarma sp.*	Marsh crab	-	Demersal
Grapsidae	*Metopograpsus frontalis*		-	Demersal
Lithodidae	*Calappalophos*	Box crab	-	Demersal
Squillidae	*Oratosquilla aquinquedentata*	Mantis shrimp	Luchi	Demersal
Diogenidae	*Pagurus sp*	Hermit crab	-	Demersal
Xanthidae	*Leptodius exaratus*	-	-	Demersal
Loliginidae	*Uroteuthis duvauceli*	Indian squid	Manki	Demersal
Sepiidae	*Sepia* sp.	Cuttle fish	Bebo	Demersal
Cyrenidae	*Villoritacyprinoides*	Black clams	Khube	Benthic
Cyrenidae	*Polymesoda erosa*	Mud clam	Khube	Benthic
Mactridae	*Mactra sp.*	-	-	Benthic
Veneridae	*Meretrix meretrix*	Asiatic hard clam	Tissryo	Benthic
Veneridae	*Meretrix casta*	Backwater hard clam	Tissryo	Benthic
Veneridae	*Timoclea scabra*	-	-	Benthic
Veneridae	*Gafrarium pectinatum*	-	-	Benthic
Ostreidae	*Paphia malabarica*	Venus clams	Khube	Benthic
Ostreidae	*Paphia textilis*	Venus clams	Khube	Benthic
Ostreidae	*Crassostrea madrasensis*	Oyster	Kalva	Benthic
Ostreidae	*Crassostrea gigas*	Oyster	Kalva	Benthic
Ostreidae	*Crassostrea gryphoides*	Oyster	Kalva	Benthic
Ostreidae	*Saccostrea cuccullata*	Oyster	Kalva	Benthic
Mytilidae	*Perna viridis*	Asian green mussel	Shenanyo	Benthic
Mytilidae	*Modiolus sp.*	-	Shenanyo	Benthic
Tellinidae	*Tellina sp.*	-	-	Benthic
Littorinidae	*Littorina scabra*	-	-	Benthic
Littorinidae	*Littorina intermedia*	-	-	Benthic

Melongenidae	*Hemifususpugilinus*	Sea snail	-	Benthic
Turritellidae	*Turritella acutangula*	Screw shell	Congali	Benthic
Rostellariidae	*Tibia curta*	Indian tibia	Congali	Benthic
Cerithiidae	*Cerithium echinatum*	-	-	Benthic
Burside	*Bufonaria rana*	Frog shell	-	Benthic
Muricidae	*Murex aduncospinosus*	Spine murex	-	Benthic
Naticidae	*Natica picta*	Moon snail		Benthic
Naticidae	*Notocochlis tigrina*	Moon snail		Benthic
Babyloniidae	*Babylonia spirata*	Whelks	-	Benthic
Conidae	*Conus* sp.	Cone shell	-	Benthic
Potamididae	*Pirenella cingulata*	Horn snail	-	Benthic
Potamididae	*Telescopium telescopium*	Horn snail	-	Benthic
Trochidae	*Umbonium vestiarium*	Button tops	-	Benthic
Astropectinidae	*Astropectenindicus*	Star fish	-	Benthic
Rhzostomatidae	*Rhopilema* spp.	Jelly fish	Zar	Pelagic

3.10 Reptiles & Mammals

Zuari estuary supports a variety of reptiles and mammals such crocodiles, snakes, turtles, otters and dolphins. The estuarine crocodile *Crocodylus palustris* is found along the banks of Zuari. The Indian Ocean humpback dolphin and the finless porpoise are found in the coastal waters off Zuari. Sea snake such as *Enhydrina schistosa and Hydrophis curtus* are also found commonly in the estuary. Mammals are mainly represented by otters, jackals and Indian flying fox. These mammals visit mangroves for shelter, breeding or feeding on molluscs, crabs, fishes and other crustaceans (Table 3.10). The animals that belong to the Schedule I species are the highly protected species and falls in the priority list. Hunting of scheduled species is strictly prohibited and animal trading, trophies and buying and possession of wild animals is illegal (Wildlife Protection Act, 1972).

Table 3.10: List of Reptiles and Mammals around Zuari estuary				
Sr. no.	**Common name**	**Scientific name**	**IUCN status**	**Wildlife Protection Act (1972)**
1	Indian flapshell turtle	*Lissemyspunctate punctata*	Least concern	Schedule I
2	Mugger crocodile	*Crocodylus palustris*	Vulnerable	Schedule I
3	Indian rock python	*Python molurus*	Near threatened	Schedule I
4	Beaked sea snake	*Enhydrina schistosa*	Least concern	Schedule IV
5	Short sea snake	*Hydrophis curtus*	Least concern	Schedule IV
6	Finless porpoise	*Neophocaena phocaenoides*	Vulnerable	Schedule I
7	Indian Ocean humpback dolphin	*Sousa plumbea*	Endangered	Schedule I
8	Smooth-coated Otter	*Lutrogale perspicillata*	Vulnerable	Schedule II
9	Asian small-clawed Otter	*Aonyx cinereus*	Vulnerable	Schedule I
10	Indian flying fox	*Pteropus medius*	Least concern	Schedule IV
12	Dog faced water snake	*Cerberus rynchops*	Endangered	Schedule II
13	Bengal monitor lizard	*Varanus bengalensis*	Least concern	Schedule I (Part II)
14	Checkered keelback	*Xenochrophis piscato*	Least concern	Schedule II (Part II)
15	Indian jackal	*Canis aureus indicus*	Least concern	Schedule II (Part I)

3.11 Avifauna

The State of Goa harbors more than 450 species of avifauna diversity with 16 species which are endemic to the Western Ghats. Intertidal mudflats, sandybeaches and rocky beaches are the different habitats in the Zuari estuary which hosts crustaceans, worms, molluscs, fishes and insects provides suitable feeding ground for waders and other aquatic birds. Mangrove vegetation provides a suitable niche for the local residents as well as migrant passage birds. It provides roosting, feeding and breeding grounds for birds such as Kingfishers, Plovers, stints, Heron's, Storks, and Egrets etc. Other than wader, surrounding mangroves and nearby grass and mangrove associated plants also hosts habitat to forest and grassland birds such as bee-eaters, Munia's, Prinia's and birds of prey. The list of birds which are found in the Zuari estuary is listed in the (Table 3.11). Hunting of birds which falls under Schedule-I species is strictly prohibited (Act No.09 of wildlife Protection Act, 1972)

Eurasian spoonbill falls under schedule I species in the list. All birds of prey in India are categorized has Schedule-I Species which includes, White bellied sea Eagle, Brahminy kite, Black kite and Osprey.

Table 3.11: List of Bird species around Zuari estuary

Sr.No.	Common name	Scientific name	IUCN status	Wildlife Protection Act 1972
1	Collared Kingfisher	*Todiramphus chloris*	Least Concern	Schedule IV
2	Pied kingfisher	*Ceryle rudis*	Least Concern	Schedule IV
3	Brahminy Kite	*Haliastur indus*	Least Concern	Schedule I
4	Black kite	*Milvus migrans*	Least Concern	Schedule I
5	White wagtail	*Motacilla alba*	Least Concern	Schedule IV
6	Indian Cormorant	*Phalacrocorax fuscicollis*	Least Concern	Schedule IV
7	Little Cormorant	*Microcarbo niger*	Least Concern	Schedule IV
8	Chestnut-headed bee-eater	*Merops leschenaulti*	Least Concern	Schedule IV
9	Blue-bearded Bee-eater	*Nyctyornis athertoni*	Least Concern	Schedule IV
10	Small green bee eater	*Merops orientalis*	Least Concern	Schedule IV
11	White-throated Kingfisher	*Halcyon smyrnensis*	Least Concern	Schedule IV
12	Stork billed kingfisher	*Pelargopsis capensis*	Least Concern	Schedule IV
13	White breasted waterhen	*Amaurornis phoenicurus*	Least Concern	Schedule IV
14	Striated Heron	*Butorides striata*	Least Concern	Schedule IV
15	Indian Pond-Heron	*Ardeola grayii*	Least Concern	Schedule IV
16	Purple Heron	*Ardea purpurea*	Least Concern	Schedule IV
17	Grey Heron	*Ardea cinerea*	Least Concern	Schedule IV
18	Black crowned night heron	*Nycticorax nycticorax*	Least Concern	Schedule IV
19	Lesser whistling duck	Dendrocygna javanica	Least Concern	Schedule IV
20	Black-tailed Godwit	*Limosa limosa*	Near threatened	Schedule IV
21	Eurasian curlew	*Numenius arquata*	Near	Schedule IV

			threatened	
22	Yellow-wattled Lapwing	*Vanellus malabaricus*	Least Concern	Schedule IV
23	Red-wattled Lapwing	*Vanellus indicus*	Least Concern	Schedule IV
24	Common Redshank	*Tringa totanus*	Least Concern	Schedule IV
25	Intermediate Egret	*Ardea intermedia*	Least Concern	Schedule IV
26	Greater Racket-tailed Drongo	*Dicrurus paradiseus*	Least Concern	Schedule IV
27	Little Egret	*Egretta garzetta*	Least Concern	Schedule IV
28	White ibis	*Threskiornis melanocephalus*	Near Threatened	Schedule IV
29	Little grebe	*Tachybaptus ruficollis*	Least Concern	Schedule IV
30	Cinnamon bittern	*Ixobrychus cinnamomeus*	Least Concern	Schedule IV
31	Glossy ibis	*Plegadis falcinellus*	Least Concern	Schedule IV
32	Eurasian spoonbill	*Platalea leucorodia*	Least Concern	Schedule I
33	Ruddy Turnstone	*Arenaria interpres*	Least Concern	Schedule IV
34	Common Sandpipers	*Actitis hypoleucos*	Least Concern	Schedule IV
35	Caspian Gull	*Larus cachinnas*	Least Concern	Schedule IV
36	Heuglin's Gull	*Larus heuglini*	Least Concern	Schedule IV
37	Steppe Gull	*Larus (heuglini) barabensis*	Least Concern	Schedule IV
38	Pallas's Gull	*Ichthyaetus ichthyaetus*	Least Concern	Schedule IV
39	Brown headed Gull	*Chroicocephalus brunnicephalus*	Least Concern	Schedule IV
40	Black headed Gull	*Chroicocephalus ridibundus*	Least Concern	Schedule IV
41	Gull-billed tern	*Gelochelidon nilotica*	Least Concern	Schedule IV
42	Greater Crested Tern	*Thalasseus bergii*	Least Concern	Schedule IV
43	Greater spotted eagle	*Clanga clanga*	Vulnerable	Schedule IV
44	White bellied Sea Eagle	*Haliaeetus leucogaster*	Least Concern	Schedule I
45	Osprey	*Pandion haliaetus*	Least	Schedule I

			Concern	
46	Common snipe	*Gallinago gallinago*	Least Concern	Schedule IV
47	Greater Painted snipe	*Rostratula benghalensis*	Least Concern	Schedule IV
48	Western Reef-egret	*Egretta gularis*	Least Concern	Schedule IV
49	Great Egret	*Ardea alba*	Least Concern	Schedule IV
50	Cattle Egret	*Bubulcus coromandus*	Least Concern	Schedule IV
51	Common Kestrel	*Falco tinnunculus*	Least Concern	Schedule IV
52	Kentish plover	*Charadrius alexandrinus*	Least Concern	Schedule IV
53	Lesser Sand Plover	*Charadrius mongolus*	Least Concern	Schedule IV
54	Greater Sand Plover	*Charadrius leschenaultii*	Least Concern	Schedule IV
55	Caspian Sand Plover	*Charadrius asiaticus*	Least Concern	Schedule IV
56	Common Redshank	*Tringa totanus*	Least Concern	Schedule IV
57	Common Greenshank	*Tringa nebularia*	Least Concern	Schedule IV
58	Common Sandpiper	*Actitis hypoleucos*	Least Concern	Schedule IV
59	Ruddy Turnstone	*Arenaria interpres*	Least Concern	Schedule IV
60	Terek sandpiper	*Xenus cinereus*	Least Concern	Schedule IV
61	Woolly-necked Stork.	*Ciconia episcopus*	Vulnerable	Schedule IV
62	Asian Openbill	*Anastomus oscitans*	Least Concern	Schedule IV
63	White stork	*Ciconia ciconia*	Least Concern	Schedule IV
64	Painted stork	*Mycteria leucocephala*	Near Threatened	Schedule IV
65	Lesser Adjutant	*Leptoptilos javanicus*	Vulnerable	Schedule IV
66	Brown fish owl	*Ketupa zeylonensis*	Least Concern	Schedule IV
67	Great cormorant	*Phalacrocorax carbo*	Least Concern	Schedule IV
68	Oriental darter	*Anhinga melanogaster*	Near Threatened	Schedule IV
69	Blue Tailed bee-eater	*Merops Philippnus*	Least Concern	Schedule IV
70	Indian spot-billed	*Anas poecilorhyncha*	Least	Schedule IV

	duck		Concern	
71	Brahminy duck	*Tadorna ferruginea*	Least Concern	Schedule IV
72	Common teal	*Anas crecca*	Least Concern	Schedule IV
73	Northern pintail	*Anas acuta*	Least Concern	Schedule IV
74	Northern Shoveler	*Spatula clypeata*	Least Concern	Schedule IV
75	Garganey	*Spatula querquedula*	Least Concern	Schedule IV
76	Eusrasian Wigeon	*Mareca penelope*	Least Concern	Schedule IV
77	Cotton Pygmy-goose	*Nettapus coromandelianus*	Least Concern	Schedule IV
78	Gadwall	*Marcea strepera*	Least Concern	Schedule IV
79	Spotted Owlet	*Athene brama*	Least Concern	Schedule IV
80	Ashy Prinia	*Prinia socialis*	Least Concern	Schedule IV
81	Plain Prinia	*Prinia inornata*	Least Concern	Schedule IV
82	Common Tailor bird	*Orthotomus sutoris*	Least Concern	Schedule IV
83	White rumped munia	*Lonchura striata*	Least Concern	Schedule IV
84	Tricoloured munia	*Lonchura malacca*	Least Concern	Schedule IV
85	Scaly breasted munia	*Lonchura punctulata*	Least Concern	Schedule IV
86	Wire tailed swallow	*Hirundo smithii*	Least Concern	Schedule IV
87	Red rumped swallow	*Cecropis daurica*	Least Concern	Schedule IV
88	Black winged Stilt	*Himantopus himantopus*	Least Concern	Schedule IV
89	Pied Avocet	*Recurvirostra avosetta*	Least Concern	Schedule IV
90	Wood sandpiper	*Tringa glareola*	Least Concern	Schedule IV
91	Marsh sandpiper	*Tringa stagnatilis*	Least Concern	Schedule IV
92	Red avadavat	*Amandava amandava*	Least Concern	Schedule IV
93	White browed wagtail	*Motacilla maderaspatensis*	Least Concern	Schedule IV
94	Western yellow	*Motacilla flava*	Least	Schedule IV

	wagtail		Concern	
95	Ruddy breasted crake	*Zapornia fusca*	Least Concern	Schedule IV
96	Common moorhen	*Gallinula chloropus*	Least Concern	Schedule IV
97	Watercock	*Gallicrex cinerea*	Least Concern	Schedule IV
98	Temminck's stint	*Calidris temminckii*	Least Concern	Schedule IV
99	Ruff	*Calidris pugnax*	Least Concern	Schedule IV
100	Whimrel	*Numenius phaeopus*	Least Concern	Schedule IV
101	Black-capped Kingfisher	*Halcyon pileata*	Least Concern	Schedule IV

Plate 3.7: Representative fauna along Zuari estuary

3.12 Riparian Vegetation

Riparian areas are the narrow strips of land adjacent to rivers, lakes, streams, ponds, and wetlands. These are characterized by plants that are adapted to an amphibious habitat than plant species that dominate drier, upland habitats. Riparian vegetation comprises plant communities that grow laterally to rivers and streams. They have multiple adaptations, which allow them to persist in these variable and dynamic habitats.

Though riparian vegetation comprises only a small area of the land, they play an extremely important role in healthy watersheds and ecological function. Riparian areas provide habitat for wildlife. The ecological benefits of riparian areas in relation to water are numerous such as acting as buffers between upland areas and open waters they help filter pollutants, reduce stream bank erosion and maintain stable stream channel geomorphology. These plants also provide shade, which helps to reduce water temperature and in turn supports higher dissolved oxygen levels crucial for maintaining productive fisheries.

One of the biggest threats to the diversity and abundance of riparian flora is anthropogenic activity (Stella and Bendix, 2019). These include conversion of natural lands for various purposes such as agricultural use, transformation into pastures, introduction of invasive species and deforestation (Vázquez et al, 2015, Rodríguez-Olarte et al, 2017, Gamarra-Torres et al., 2018). This along with climate change has strongly reduced the number of native species in these areas as well as putting many of them at risk of extinction and it has been predicted that impact of climate change on riparian vegetation will only increase in the future (Sabater et al., 2018).

Considerable change in the riparian zone of the river was evident. Increased urbanisation, especially in coastal area and along river fronts is visible along with increased road accessibility. Along with expansion of villages and increase in urban areas, forest cover has been reduced to give rise to orchards and plantations. In the upstream region of the river vegetation has been unsuccessful in protecting the banks from erosion as observed by fallen trees. In the stretches of the river where there are soft muddy and silty banks, erosion has taken away part of the land as well the riparian vegetation.

Downstream of the river which has a higher salinity compared to the upper stretches. Thus most of the areas have been protected by embankments traditionally. These embankments require constant repair and maintenance, as the terrestrial part of it is used for paddy cultivation and building houses. In downstream area many parts of the riparian zone have been intruded by salinity and now converted to saline marsh lands, mudflats or mangroves. The riparian vegetation along the banks of the river consists of tropical deciduous species typical to this region and the department of forest categorises this region under open forest.

The riparian vegetation along the banks of the river in the upstream stretches consists of typical tropical deciduous species typical to this region and the department of forest categorises this region under open forest (https://fsi.nic.in/isfr19/vol2/isfr-2019-vol-ii-goa.pdf). The area is predominantly planted with *Cocos nucifera* and mostly represented by species of *Terminalia* spp., *Ficus* spp., *Careya arborea*, *Mangifera indica*, *Anacardium occidentale*, *Xylia xylocarpa*, *Caesalpinia* spp. and *Bombax ceiba* along with several species of bamboos, shrubs, herbs and grasses.

The river bank in the upstream areas (with mostly narrow mudflats) has grasses which have ability to resist some salinity. Although grasses are known to offer protection from erosion, these grasses may not be able to resist strong current which is visible from the eroded bank stretches in the upstream regions which have also uprooted larger trees (mostly coconut palms).

There are few notable species which have invaded this region and may pose threat to the native vegetation in the long run. Some of the plants were *Chromolaena odorata, Cassia tora, Ageratina adenophora, Triumfetta rhomboidea* and *Acacia farnesiana* (https://fsi.nic.in/isfr19/vol2/isfr-2019-vol-ii-goa.pdf).

3.13 Khazan Land

Khazans are low lying agricultural lands that have been reclaimed by using salinity control structures from mangrove fringed estuaries. These saline low-lying, flat lands were originally mangrove swamps or mudflats lying along both the banks of the rivers of Goa. The presence of peat deposits at depths of 1.5- 2.5 m in these fields suggests they were covered with a thick growth of mangrove forests some 6000 years ago (Mascarenhas and Chauhan 1998). The early settlers who came to this place reclaimed these fertile lands by constructing bundhs all along the river and cultivating it. Similar coastal lands like khaznam with paddy cultivation and fish farming are found in other parts of India such as Khar in Maharashtra, gazzani in Karnataka and Pokkali in Kerala.

Khazan lands are carefully designed topo-hydro-engineered agricultural ecosystem. The important aspects of the structure of the land are based on the principle of salinity regulation and knowledge of tidal clock as well as distance from nearest watershed and tidal estuary. It is dependent upon the availability and flow of fresh water and saline water. Excess freshwater can cause growth of weeds and unwanted vegetation leading to eutrophication while surplus saline water flow make the land useless for agriculture. The balance of these factors promotes a system that allows for agriculture, fishing as well as a balanced flow to the land.

The Zuari estuary supports a number of Khazan lands along its banks in various places such as Marcaim, Cortalim, Panchwadi, Sancoale, Neura, Agassaim, Rachol, Shiroda etc. Khazan lands promote the economic upliftment of the local community through various economic activities such as fisheries, agriculture, horticulture, value added food production such as dried fish, salt production, recreation and tourism. These activities promote self-sufficiency to the local's dependant on them.

3.14 Seaweeds & Grass (Halotolerant)

Seaweed, or macroalgae, refers species of macroscopic, multicellular, non-flowering marine algae without root, stem and leaves; the term includes Rhodophyta (red), Phaeophyta (brown) and Chlorophyta (green) macroalgae. They vary vastly in size, shape and colour. Seaweed species such as kelps provide essential nursery habitat for fisheries and other marine species. On their part, the seaweeds derive nutrition through photosynthesis of sunlight and nutrients present in seawater. They release oxygen through every part of their bodies. Seeweeds, absorb excess nutrients from waterbodies which would otherwise have been toxic to marine life. Macrophytes including seaweeds, seagrass and mangroves act as blue-carbon sink as they capture atmospheric CO_2, sequester and store it in live tissue or sediment for longer durations. Macrophytic blue-carbon system is considered more efficient than terrestrial systems. The 2009 UNEP blue-carbon report states that coastal macrophytes account for less than 0.5% of the seabed community structure and sequester between 114 and 328 teragrams of carbon per year, or 1.6 to 4.6% of total anthropogenic emissions (7,200T g $year^{-1}$). Therefore, protecting and restoring the ocean's fringing vegetation should be a high priority. Seaweeds are the primary producers of marine ecosystem and have wider utility in agrichemicals, cosmetics, biomaterials, energy molecules in addition to their conventional utilization as edible food, feed ingredients and hydrocolloids.

Table 3.12: Seaweeds from Zuari estuary

Sr. No.	Species
	Rhodophyta
1.	*Acanthophora muscoides (Linnaeus) Bory de Saint-Vincent*
2.	*Amphiroa fragilissima* (Linnaeus) J.V. Lamouroux
3.	*Caloglossa leprieurii* (Montagne) G. Martens
4.	*Catenella repens*(Lightfoot) Batters
5.	*Centroceras clavulatum* (C. Agardh) Montagne

6.	*Ceramium cimbricum* H. E. Petersen
7.	*Ceramium fastigiatum* Harvey
8.	*Chondracanthus acicularis* (Roth) Fredericq
9.	*Gelidium pusillum* (Stackhouse) Le Jolis
10.	*Gracilaria corticata* (J.Agardh) J.Agardh
11.	*Hypnea musciformis* (Wulfen) J.V.Lamouroux
12.	*Hypnea spinella* (C.Agardh) Kützing
13.	*Hypnea valentiae* (Turner) Montagne
14.	*Pterocladia capillacea* (S.G.Gmelin) Bornet
	Chlorophyta
15.	*Boodlea composita* (Harvey) F.Brand
16.	*Bryopsis plumosa* (Hudson) C.Agardh
17.	*Caulerpa scalpelliformis* (R. Brown ex Turner) C. Agardh
18.	*Caulerpa verticillata* J. Agardh
19.	*Chaetomorpha spiralis* Okamura
20.	*Chlorodesmis hildebrandtii* A.Gepp & E.S.Gepp
21.	*Cladophora socialis* Kützing
22.	*Cladophoropsis sundanensis* Reinbold
23.	*Rhizoclonium riparium* (Roth) Harvey
24.	*Ulva clathrata* (Roth) C.Agardh
25.	*Ulva compressa*
26.	*Ulva fasciata* Delile
27.	*Ulva flexuosa* Wulfen
28.	*Ulva lactuca* Linnaeus
	Phaeophyta
29.	*Canistrocarpus cervicornis*(Kützing) De Paula & De Clerck
30.	*Chnoospora minima* (Hering) Papenfuss
31.	*Dictyota dichotoma* (Hudson) J.V.Lamouroux
32.	*Dictyota pinnatifida*
33.	*Padina gymnospora* (Kützing) Sonder
34.	*Padin apavonica* (Linnaeus) Thivy
35.	*Padina tetrastromatica* Hauck
36.	*Sargassum cinctum* J. Agardh
37.	*Sargassumglaucescens* J.Agardh
38.	*Sargassum ilicifolium* (Turner) C.Agardh
39.	*Sargassum tenerrimum* J. Agardh
40.	*Spatoglossum asperum* J.Agardh
41.	*Sphacelaria rigidula* Kützing
42.	*Vaucheria longicaulis* Hoppaugh

Plate 3.8: Representative flora along Zuari estuary

3.15 Sand Dune Vegetation

Sand dunes are a mount, hilly or ridge of sand formed mainly by Aeolian action that lies behind the beach affected by tides. They are formed over many years when windblown sand is trapped by beach grass or other stationary objects. Dune grasses anchor the dunes with their roots, holding them temporarily in place, while their leaves trap sand promoting dune expansion. Without vegetation, wind and waves regularly change the form and location of dunes. Sand dunes provide sand storage and supply for adjacent beaches. They also protect inland areas from storm surges, hurricanes, floodwater and wind and wave action that can damage property.

Sand dunes arrest blowing sand, deflect wind upwards, assist in the retention of fresh water and protect the hinterland from attack by waves and storm surges and thus obstruct the ingress of saline marine water into the hinterland and thus protecting the inland low-lying areas and terrestrial ecosystem from strong wave actions and tide surges. Dune vegetation helps in dune stability however, is vulnerable to even slightest interference due to its fragility. Moreover, sandy stretches including dune vegetation contain many species of specific flora (and fauna). Sand dunes, especially if covered by dune vegetation which acts as sand binders preclude loose sand from advancing inland on the coastal zone, thus menacing coastal populations and structures.

Sand dunes support an array of organisms by providing nesting habitat for coastal bird species including migratory birds. Sand dunes are also habitat for coastal halophilic vegetation. Increased tourism foot traffic, and removal of plant species can cause destruction of dunes and erosion. Sand dunes are of various sizes, shapes and the size depend on two factors, namely, physical and biotic factor. The physical factors are the speed of wind, the prevailing wind directions, wave regime, the amount of sand available, the size of the sand, the sand supply from the beach and offshore bars whereas the biotic factor are plant succession and grazing pressure.

3.16 Mangrove

A total of 69 species of mangroves belonging to 25 families and 43 genera have been reported from Indian coast. India has a 4827 km of mangroves cover and only 23% represents the west coast of India. Rich habitat is observed along Gujarat coast in gulf of Khambat and gulf of Kutch and accounts to about 80% of the mangrove cover of the west coast of Indi which itself is 23% of the mangrove cover in India. The mangrove cover in Gujarat is enormous compared to other states due to declaration of Marine National in 1983 and the mangrove cover thus has grown in the last two decades. Even though the mangrove cover is more in the state of Gujarat about 1058 km cover, the diversity is restricted at only nine species, whereas there is more mangrove diversity in the state of Maharashtra, Goa, Karnataka and Kerala. A Total of eight mangrove species and nine mangrove associates have been recorded from the Zuari estuary (Table 3.13).

Table 3.13: Mangroves and associated species found in Zuari estuary

Sr. No.	True mangrove species	Mangrove associate species
1	*Sonneartia alba*	*Acrostichum aureum*
2	*Acanthus ilicifolius*	*Derris heterophylla*
3	*Brugiera cylindrica*	*Derris trifoliata*
4	*Rhizophora mucronata*	*Cleredendron inerme*
5	*Avicennia marina*	*Doliochandrone spathacea*
6	*Avicennia officinalis*	*Ipomoea grandiflora*
7	*Aegicerus corniculatum*	*Operculina turpethum*
8	*Exoecaria agallocha*	*Cyperus malaccensis*
9		*Caesalpinia crista*

Plate 3.9: Mangroves along Zuari estuary

CHAPTER 4: CLIMATOLOGY & PHYSICAL PARAMETERS

The meteorological data is important to understand the meteorological and climatic conditions of the study area for the evaluation of impacts of the proposed project. Historical data on meteorological parameters also plays an important role in identifying the synoptic meteorological regime of the region.

Zuari originates in the Western Ghats and flows down the entire width of the State of Goa to discharge into the Arabian Sea (Figure 4.1). The Zuari watershed receives abundant rainfall from the southwest monsoon during the months of June to September.

Climate:

Goa has warm tropical climate with average annual temperature of 26.4 °C. December to February are coolest months. The temperature is extreme in months of April and May and lowest in January. Due to closeness of the State to the Arabian Sea, the humidity is excessive from beginning to end of the year. The relative humidity varies from 60% to 90%.

Winds:

Winds are strong and blow from west or south-west during the monsoon season. During October-December, the winds are generally moderate and blow from directions between north-east and south-west. In the three months from January to March the winds continue to be moderate and are predominantly from directions between south-west and north-west. Sometimes associated with cyclonic storms in the Arabian Sea in the post-monsoon months and to a lesser extent in May, the region experiences strong winds, occasionally reaching gale force with widespread heavy rain.

Soil:

Soil is one of the predominant non – renewable basic natural resources of the earth. The total geographical area of the state has been digitized (NBSS soil map), and reclassified. Goa has about 25 soil classifications and it is divided two major classes based on landform viz. Konkan coast soil and Central Sahydris soils groups. Konkan consists beaches, Mudflats, swamps and marshes, salt pans, fluvio – littoral plains and islands, conical hills, flat topped hills, hillside slope, undulating lands, narrow valleys. Central Sahydris comprises high hills, low hills, interhilly basins, and narrow valleys.

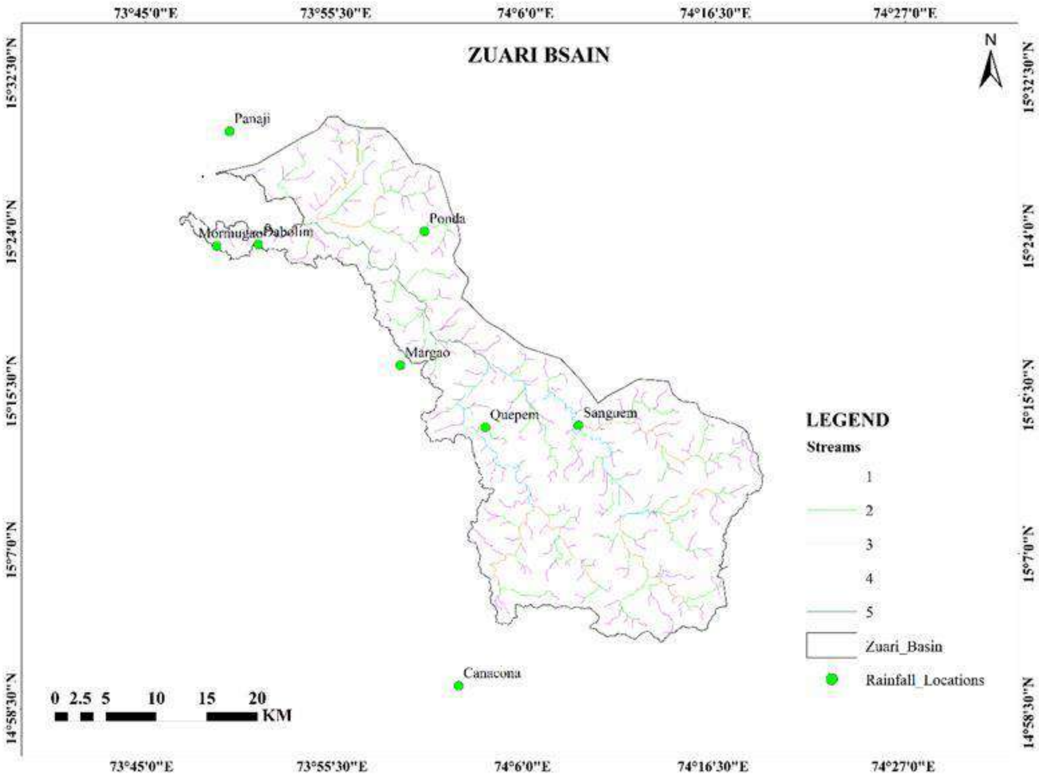


Figure 4.1: Stream orders in Zuari basin, Goa

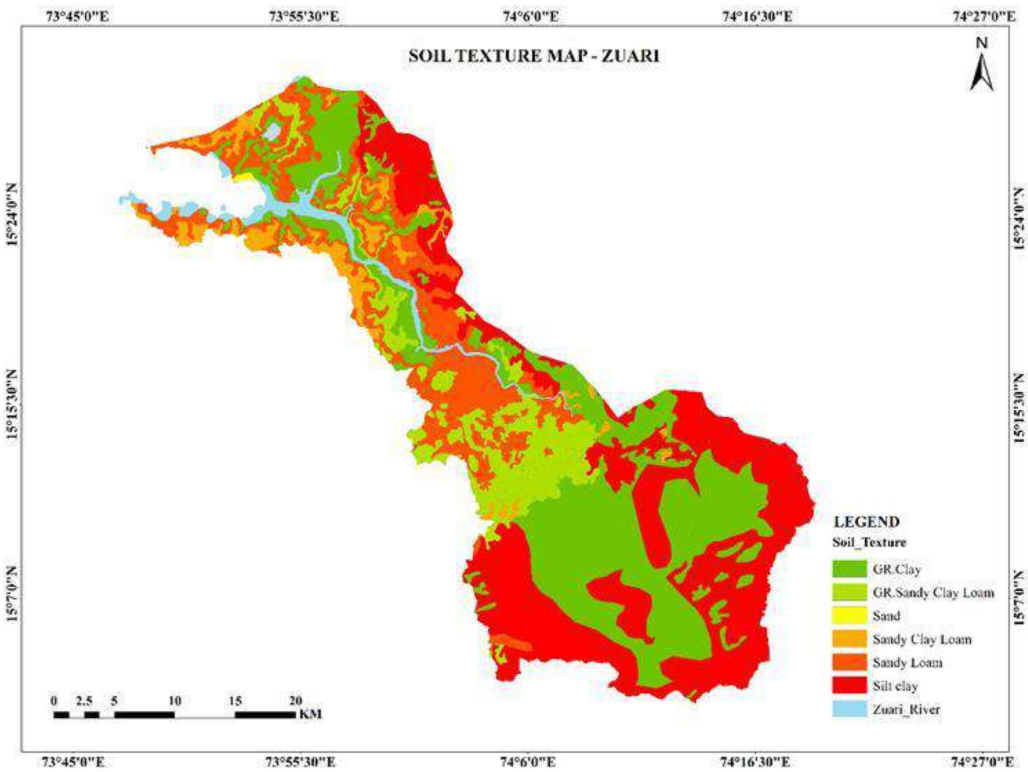


Figure 4.2: Soil texture map of Zuari basin, Goa

Figure 4.2 shows reclassified soil texture distribution of the Zuari basin. Loamy, sand, sandy clay, sandy loam, silt clay, gravelly clay, and gravelly sandy clay distributed over the study area. The Western Ghats regions occupied loamy and silt clay soils formations. Around 45% of the area is covered with silt clay and clay soils, these textures are dominant along the eastern part of the Zuari basin. Loamy, sand, and silt clay soil types are excessively drained and very less in drainage capacity. Sandy loam soil is widely distributed in the middle portion of this basin, along with clay also partially distributed.

Rainfall:

Eight rainfall Stations were chosen for the Study. Daily Rainfall data for 10 consecutive years have been used for the years from 2010 to 2019. IMD Rainfall data has been analysed and accordingly seasonal and annual mean calculated (Figure 4.3).

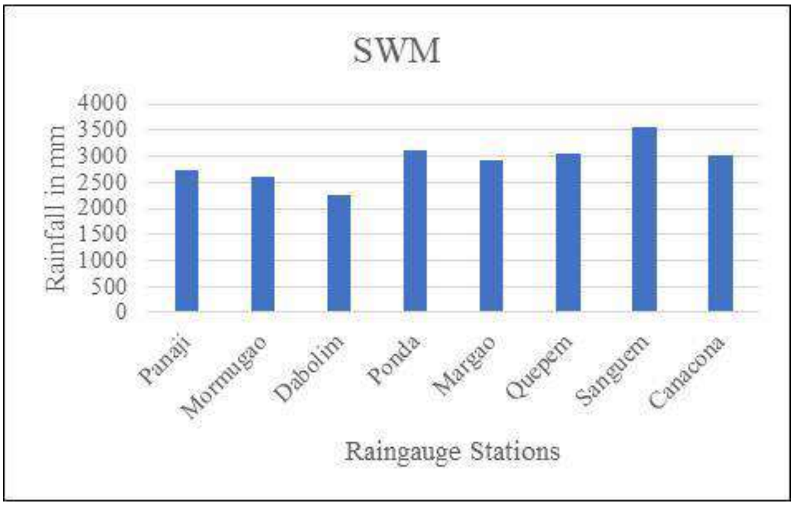
The Sahydris hills plays significant role in the rainfall distribution in Goa. The State receives high rainfall during south-west monsoon period. The mean annual rainfall for this basin is 3192 mm, which may vary from 3912 mm (Sanguem) to 2503 mm (Dabolim). About 90% of the annual rainfall receives during south–west monsoon period.

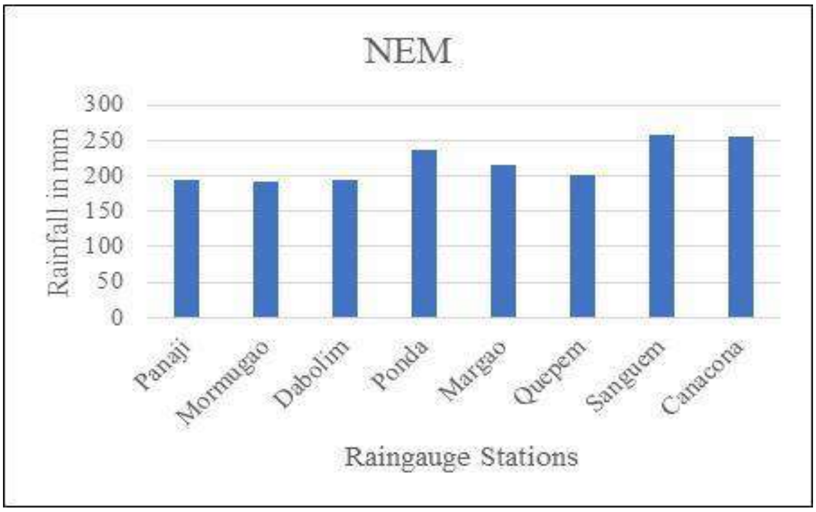
South – West Monsoon (SWM)

The State receives rainfall mainly from the June to September. Sanguem (3574 mm) station recorded maximum rainfall, followed by Ponda (3111 mm), Quepem (3061 mm) and Canacona (3014 mm). Highest rainfall is received during the month of July followed by a gradual decrease in subsequent monsoon months. Dabolim (2256 mm) has recorded lowest rainfall in this four-month season. Southern, south-eastern portions receive very high amount of rainfall.

North – East Monsoon (NEM)

During post monsoon the study area experiences adequate rainfall as compared to winter season and summer season. Eastern part of the study area rainfall intensity gradually increases and coastal region receives less amount of rainfall distribution. Maximum rainfall has been recorded in Sanguem which is located in the South eastern part of the study area and very low rainfall has been recorded at Mormugao (192 mm) and Panaji (193 mm) station which lies in the North western part of study area.





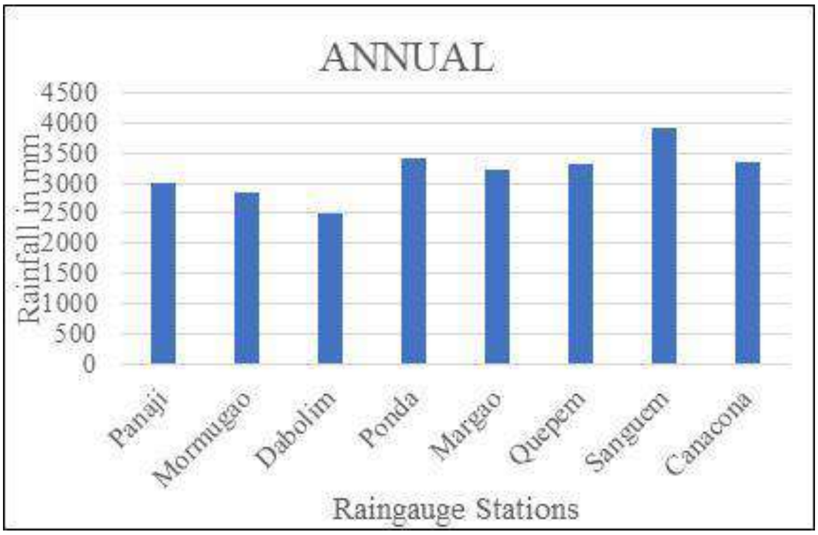


Figure 4.3: Mean rainfall distribution of Raingauge Stations

Physical parameters

This chapter comprises of the physical measurements carried out at Zuari Estuary for the validation of numerical model.

Results

The results of the current measurements carried out in the study region are presented in this section. Water level measurement results are presented and validated in the next chapter.

Currents

Current measurement was carried out at locations ZC1 and ZC2 in Zuari Estuary during July-August 2020, and March-April 2021. The current meter was placed at mid-water depth. The measured current speed and direction during monsoon are shown in Figure 4.4. The current is mainly towards north-west (NW) with maximum current speed 1.51 m/s and average current speed 0.64 m/s during measuring period at ZC1. In Figures 4.5, the measured current speed and direction are presented for ZC2 during non-monsoon. From the Fig., it is observed that the maximum current speed was 0.75 m/s and the average current speeds was 0.29 m/s at ZC2 during non-monsoon measuring period. The current is mainly towards north-west (NW) and south-east (SE) at MC2.

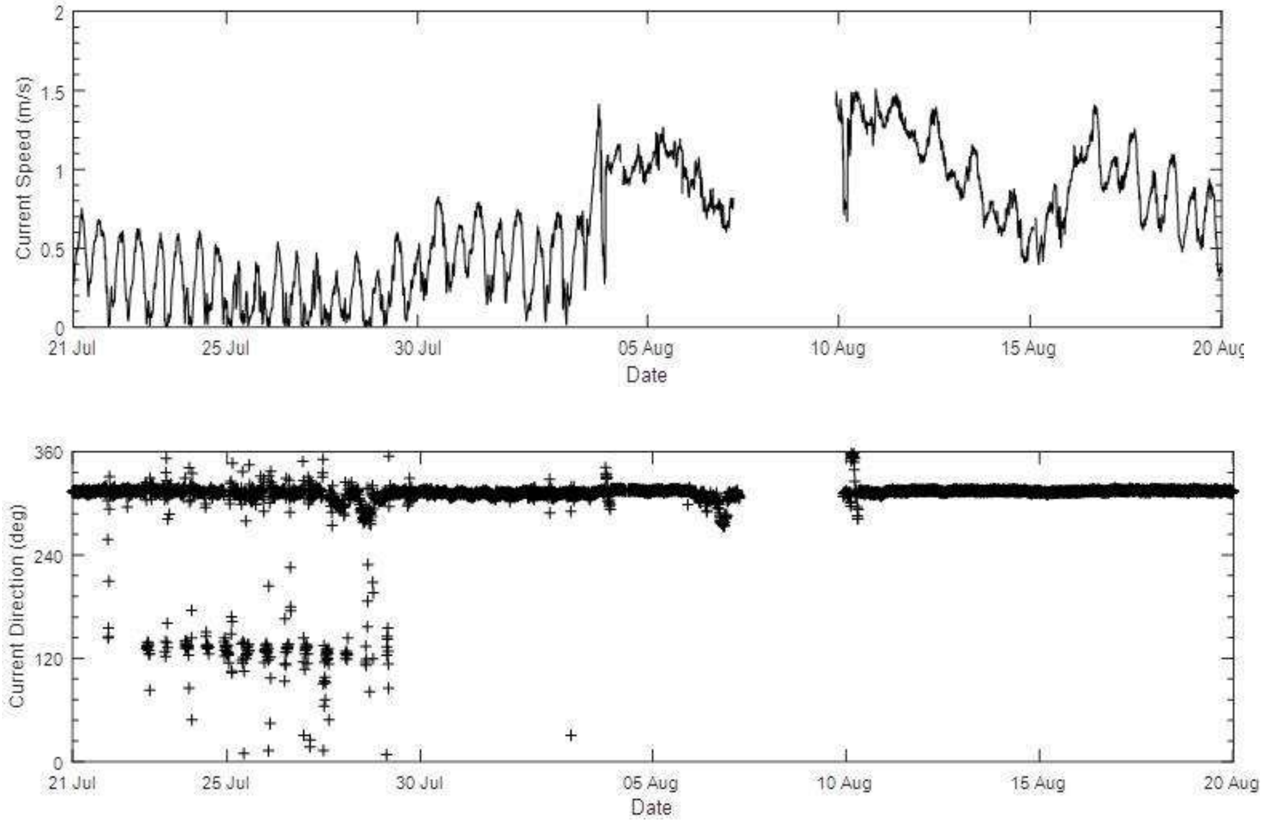


Figure 4.4: Variation of measured current speed and directions at ZC1 in monsoon, 2020

Table 4.1: Maximum and average value of Current speed (m/s) in Zuari			
Current Parameter	**Location**	**Maximum Speed (m/s)**	**Average speed (m/s)**
Current Speed (m/s) (monsoon)	ZC1	1.51	0.64
Current Speed (m/s) (non-monsoon)	ZC2	0.75	0.29

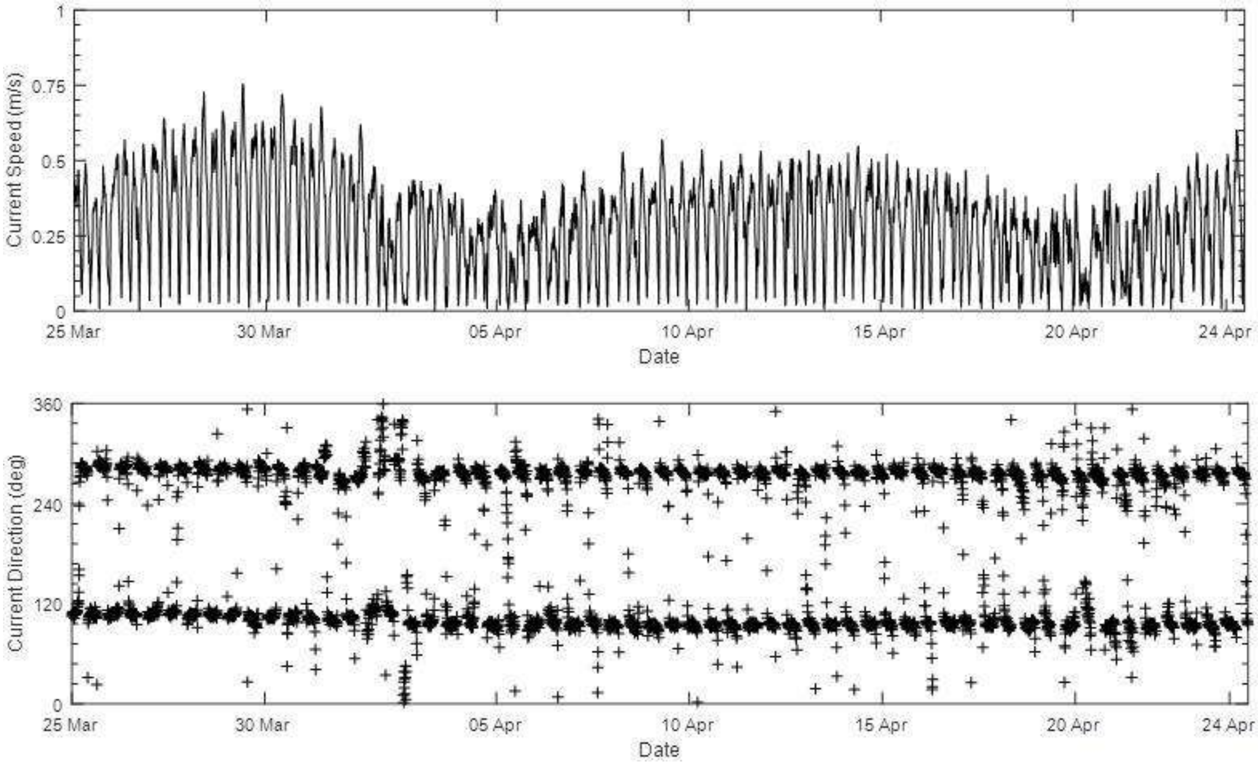


Figure 4.5: Variation of measured current speed and directions at ZC2 in non-monsoon 2021

CHAPTER 5: NUMERICAL MODELLING STUDIES

Introduction

In order to simulate the coupled hydrodynamics and morphology in the study region, a state-of-the-art numerical modelling software suite (MIKE by DHI) is used. The flow model FM comprising of flow model, and sediment transport model is used to study the hydrodynamics and morphology impact in the region due to different mining scenario. All these models take feedback from each other as well as provide inputs to each other. The sediment transport models also utilise the flow parameters from the hydrodynamics model. In this manner, the coupled model provides output of modified flow, and changes in the bed morphology in the study region.

Coupled model

The MIKE 21 flow model FM is used in this study which dynamically couples the flow and sediment transport calculations. Full feedback of bed level changes on flow calculations is included in this formulation. The flow model FM is mostly used for investigating the morphological evolution of the near shore bathymetry due to the impact of engineering works (coastal structures, mining, dredging works etc.) and also to study the morphological evolution of tidal inlets and rivers. It is most suitable for medium-term morphological investigations (several weeks to months) over a limited study area. The computational effort can become quite large for long-term simulations, or for larger areas. The different models used in the flow model FM are briefly described below.

Hydrodynamic model

The Hydrodynamic Module is the basic computational component of the entire MIKE21 Flow Model FM modelling system. The MIKE 21 Flow Model FM is a modelling system based on a flexible mesh approach providing the hydrodynamic basis for the Sediment transport Module.

The modelling system is based on the numerical solution of the two-dimensional shallow water equations i.e., depth-integrated incompressible Reynolds Averaged Navier-Stokes equations. Thus, the model consists of continuity, momentum, temperature, salinity and density equations. In the horizontal domain both Cartesian and spherical coordinates can be used. The spatial discretization of the basic equations is performed using a cell-centred finite volume method wherein the spatial domain is discretized by subdivision of the continuum into non-overlapping element/cells. An unstructured grid comprising of triangles or quadrilateral element is used in the horizontal plane. An approximate Riemann solver is used for computation of the convective fluxes, which makes it possible for MIKE21 FM model to handle discontinuous solutions. For the time integration an explicit scheme is used. Coriolis term, eddy viscosity using Smagoransky formulation and bed friction are included in the model. For more details of the MIKE 21 FM module and its validation, the scientific manual can be referred.

The model domain (Case 1) used in this study is shown in Figure 5.1. This model domain was further used for all simulations. In this study, a sand mining case scenario (Case 2) is studied by deepening existing bathymetry at different sections (A-F) (see Figure 5.2) along Zuari estuary. The model domain for post sand mining case is shown in Figure 5.3.

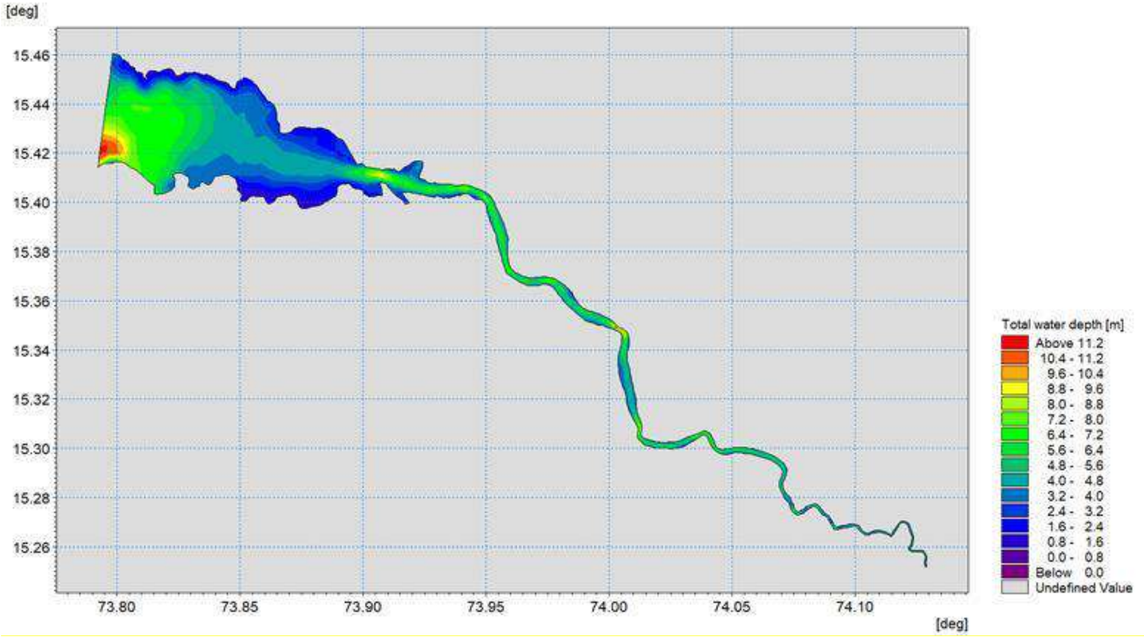


Figure 5.1: Model domain for original bathymetry of the Zuari estuary

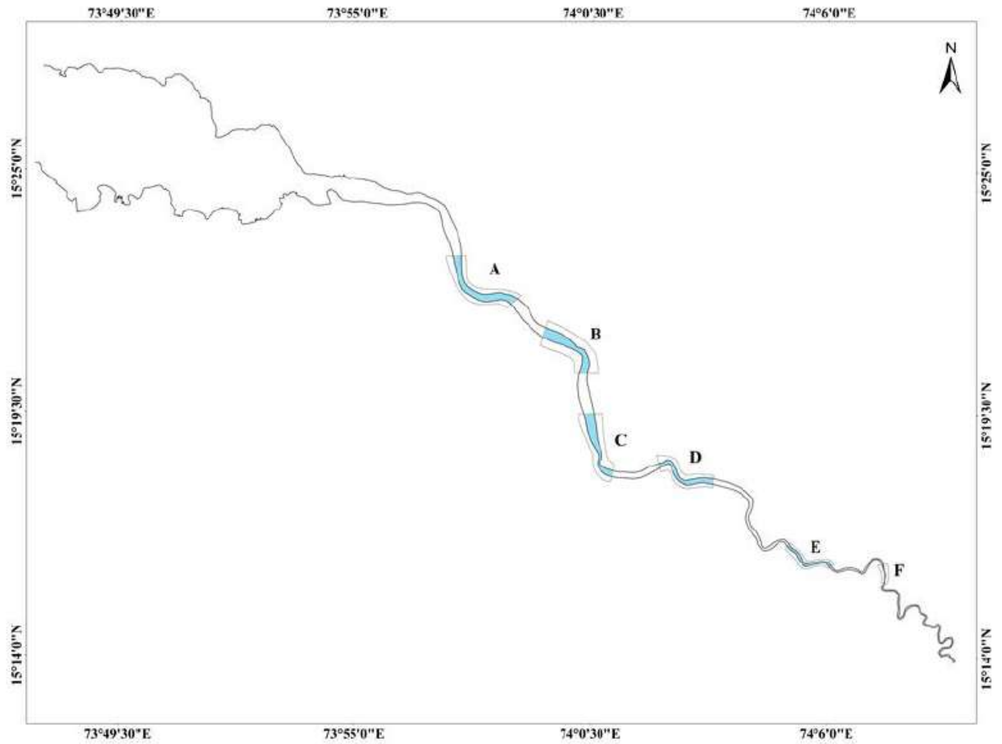


Figure 5.2: Figure showing nine different sections (A-F) in the model domain

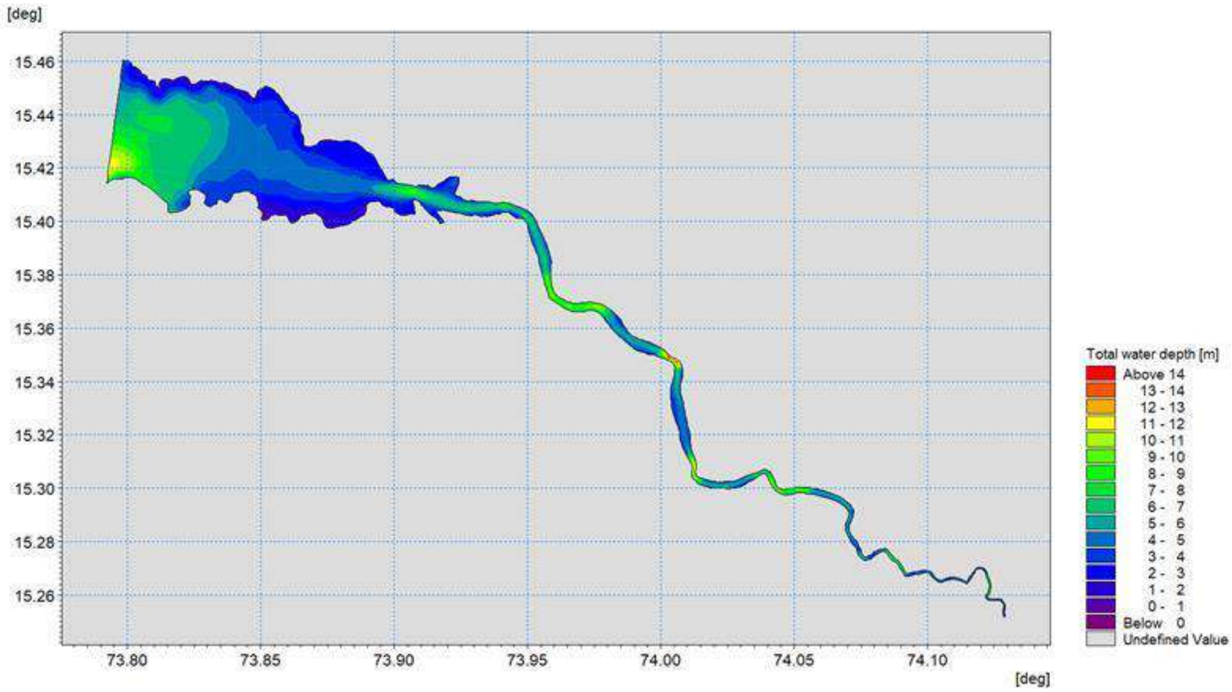
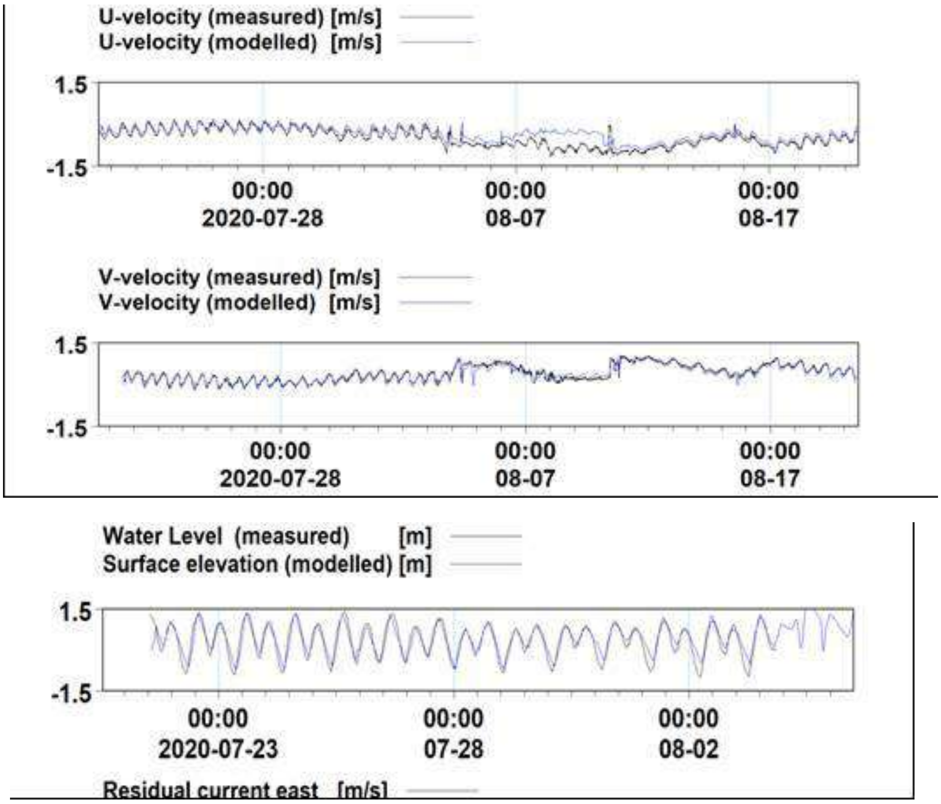
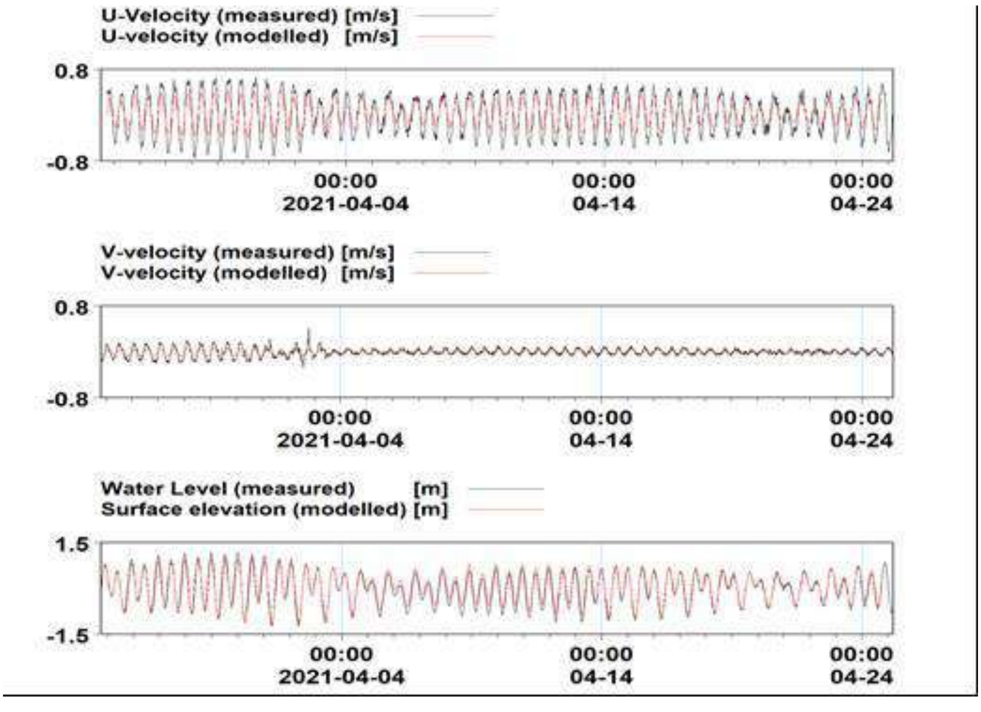


Figure 5.3: Model domain for modified bathymetry increasing depth by 3 m at different sections (A-F)


U-velocity (measured) [m/s]
U-velocity (modelled) [m/s]
1.5
-1.5
00:00
2020-07-28
00:00
08-07
00:00
08-17
V-velocity (measured) [m/s]
V-velocity (modelled) [m/s]
1.5
-1.5
00:00
2020-07-28
00:00
08-07
00:00
08-17
Water Level (measured) [m]
Surface elevation (modelled) [m]
1.5
-1.5
00:00
2020-07-23
00:00
07-28
00:00
08-02
Residual current east [m/s]

(a)


U-Velocity (measured) [m/s]
U-velocity (modelled) [m/s]
0.8
-0.8
00:00
2021-04-04
00:00
04-14
00:00
04-24
V-velocity (measured) [m/s]
V-velocity (modelled) [m/s]
0.8
-0.8
00:00
2021-04-04
00:00
04-14
00:00
04-24
Water Level (measured) [m]
Surface elevation (modelled) [m]
1.5
-1.5
00:00
2021-04-04
00:00
04-14
00:00
04-24

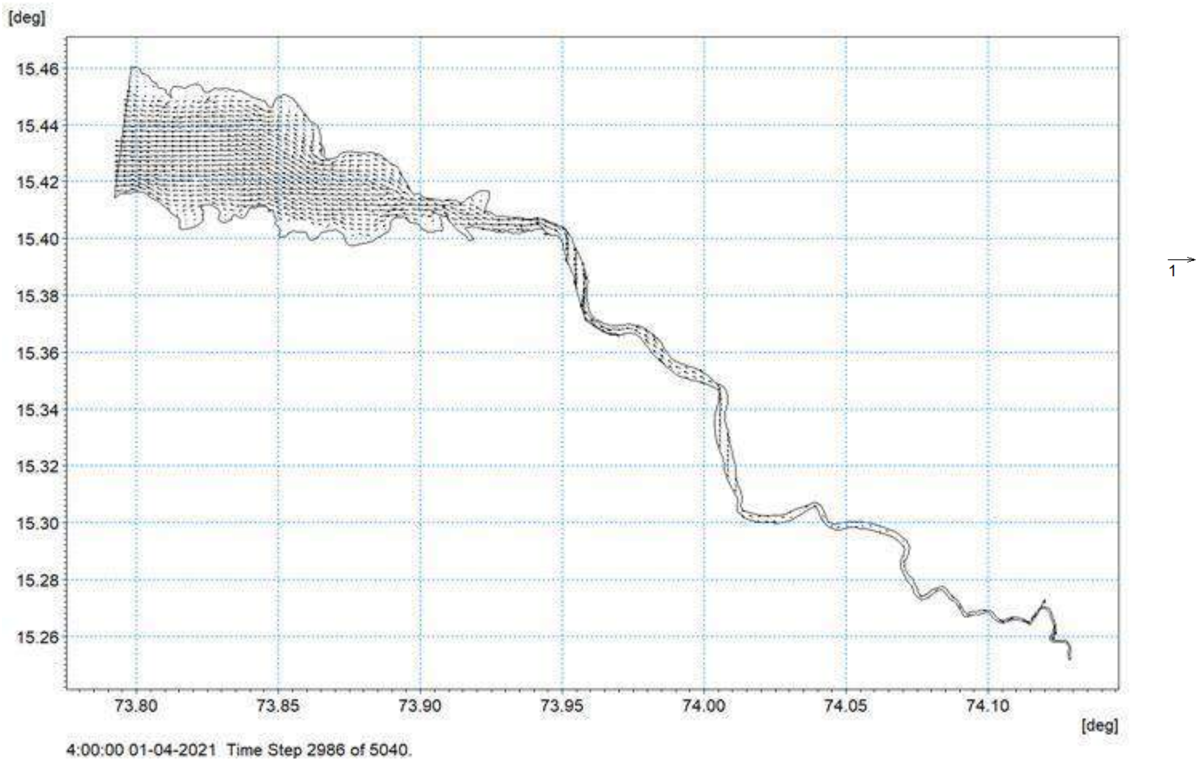
(b)

Figure 5.4. Comparison between measured and modelled U&V component of current and water level during (a) monsoon at ZC1 and (b) non-monsoon at ZC2

A comparison between the model derived and measured surface elevations and currents (at ZC1 & ZC2) have been carried out in Figure 5.4. It is observed that the surface elevations and currents are well predicted by the model.

Sediment transport model

The sediment transport module calculates the resulting transport of non-cohesive materials based on the flow conditions found in the hydrodynamic calculations. The model output consists of bed level changes, amongst other parameters. In this study, the current formulation of sediment transport is considered with the flow model providing the currents.



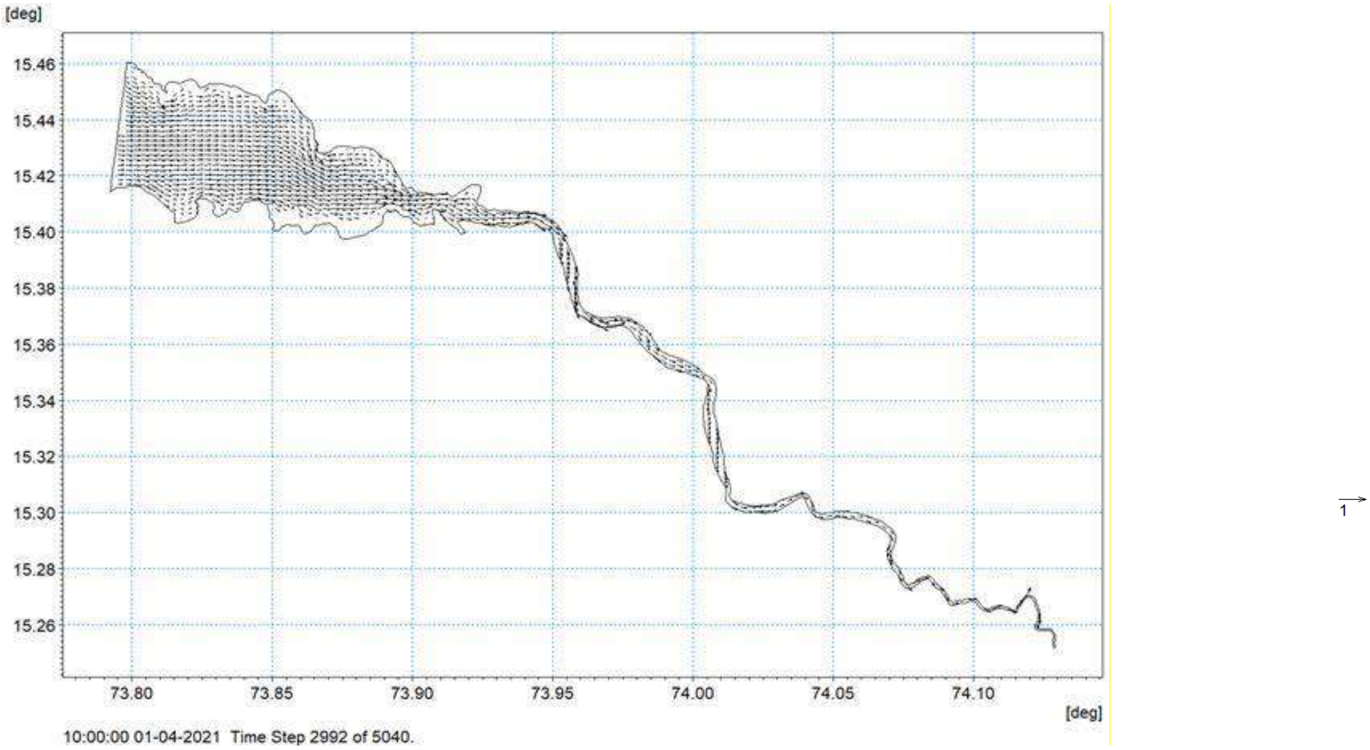


Figure 5.5: Typical ebb and flood current

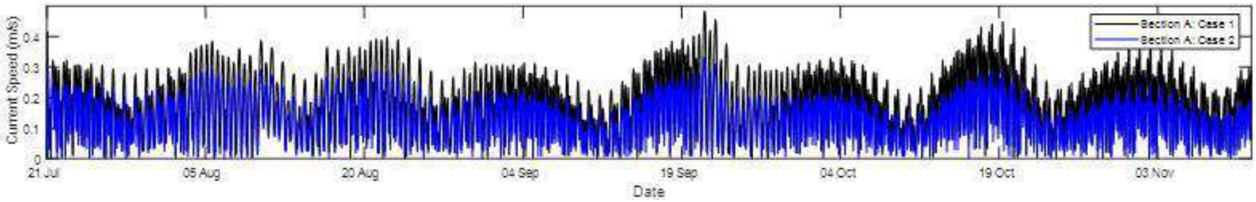
Results

The numerical model study results are presented in the following sections. The flow patterns in the study region for the Case 1 and Case 2 are presented in the hydrodynamic model results. The comparisons of the current speed during both monsoon and non-monsoon period, 2020-21 between Case 1 and Case 2 at each section A-F are presented. The comparisons of the bed level changes between Case 1 and Case 2, are also presented in the morphology model results.

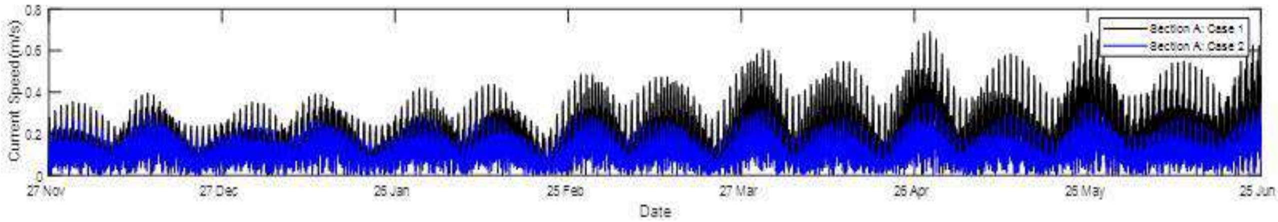
Hydrodynamics modelling

Hydrodynamic model validation is carried out with the measured currents and water levels in the study region. The comparison of water levels, u-component and v-component of currents are presented in Figure 5.4. The model simulated water levels, and the current flow components well for both the east-west and north-south components. The typical flood and ebb currents are shown in Figure 5.5.

A comparison of current speeds between the Case-1 and Case-2 is carried out. A total of 6 points covering the six sections A to F as in Figure 5.2 are considered for comparing the currents. The comparison figures are presented in Figure 5.6 to Figure 5.11. Higher current speeds are observed for Case-1, than the Case-2 at the different sections A-F. The reduction in current speeds at these sections is mainly due to the change in the water depths.

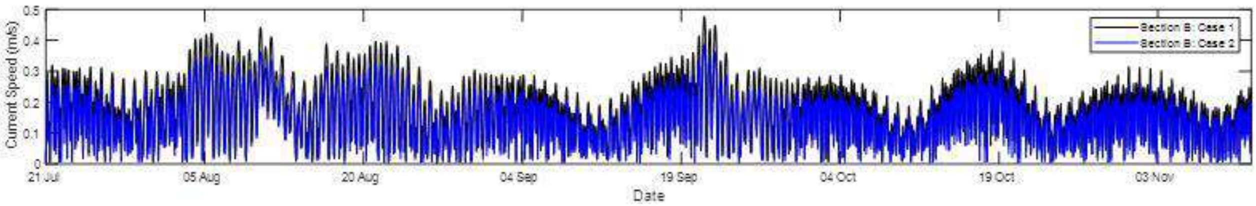


(a)

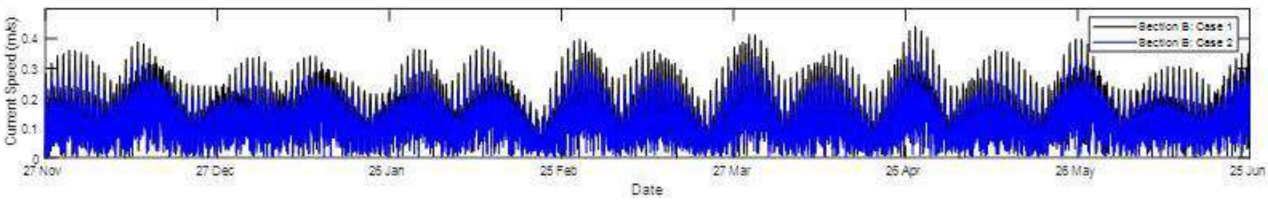


(b)

Figure 5.6: Comparison of current speed during (a) monsoon and (b) non-monsoon at section A for case 1 (existing) and case 2 (modified)

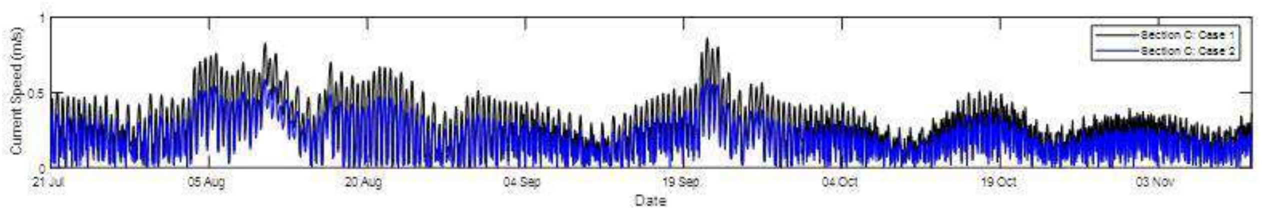


(a)

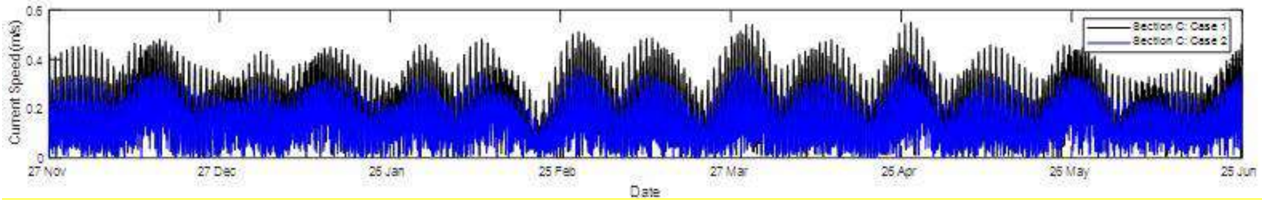


(b)

Figure 5.7: Comparison of current speed during (a) monsoon and (b) non-monsoon at section B for case 1 (exiting) and case 2 (modified)

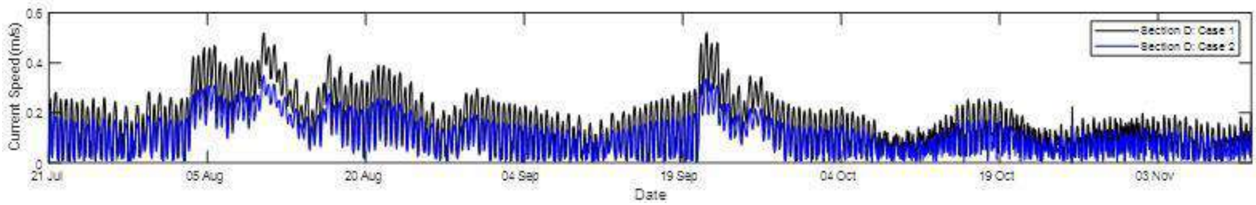


(a)

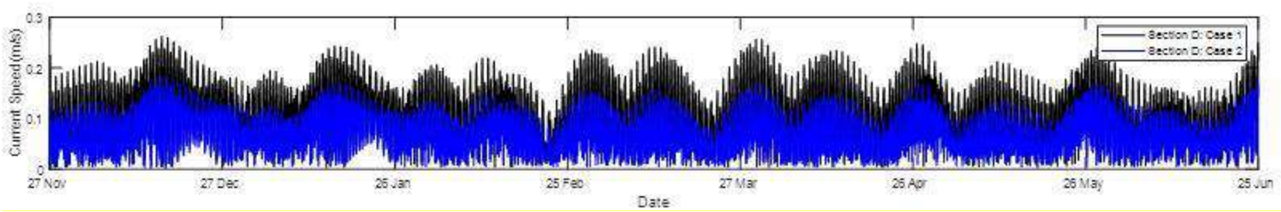


(b)

Figure 5.8: Comparison of current speed during (a) monsoon and (b) non-monsoon at section C for case 1 (existing) and case 2 (modified)

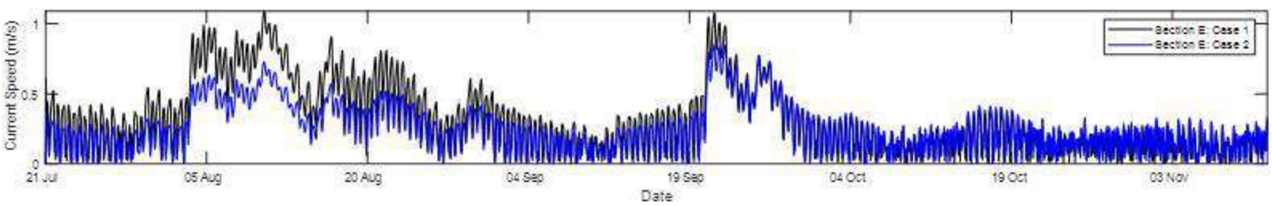


(a)

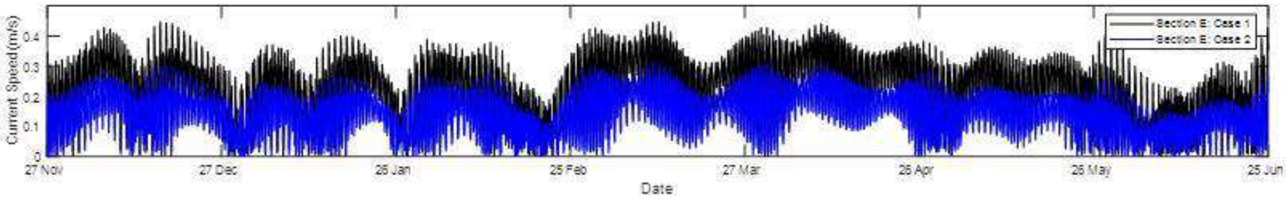


(b)

Figure 5.9: Comparison of current speed during (a) monsoon and (b) non-monsoon at section D for case 1 (existing) and case 2 (modified)

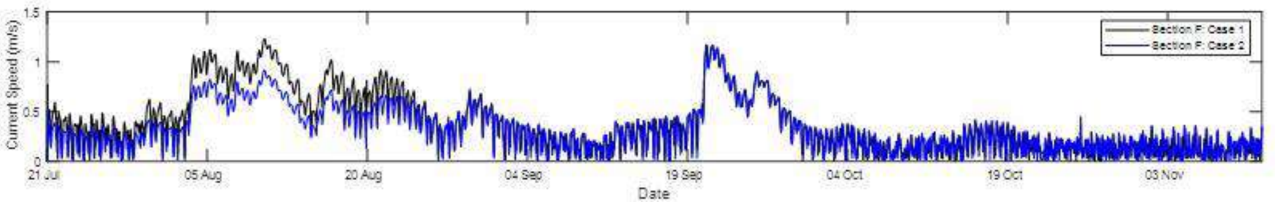


(a)

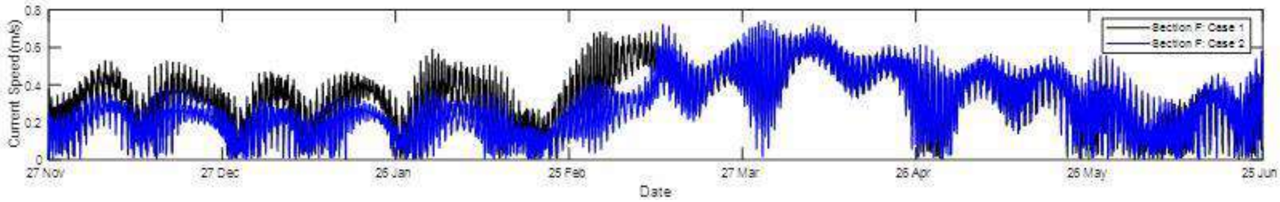


(b)

Figure 5.10: Comparison of current speed during (a) monsoon and (b) non-monsoon at section E for case 1 (existing) and case 2 (modified)



(a)



(b)

Figure 5.11: Comparison of current speed during (a) monsoon and (b) non-monsoon at section F for case 1 (existing) and case 2 (modified)

Bed level changes

The change in the bed level from the sediment transport model simulations provides accretion/erosion in the study region for the simulation period. This study is carried out assuming that the mined channel is stable and the flow dynamics are stabilized. For the sake of clarity, the Zuari estuary is divided into 8 strectehs (Part A to H) and the comparisons of bed level changes between the between the Case-1 and Case-2 models are shown. The changes in bed morphology at different sections of the river are highly dynamic and patchy in nature. Negligible sediment deposition is observed at Part A while high sediment deposition is observed at around Part B. During non-monsoon period, the sediment deposition around Part B is more than the monsoon period. It is observed that Part C-D experience higher erosion due to modified bathymetry (Case-2). The upstream of Zuari receives higher sediment deposition at monsoon than non-monsoon. During monsoon, at and around Part F, G and H, more sediment deposition is observed. Case 2 leads to higher deposition in Part F, G and H than Case 1. In the Zuari estuary the bed level changes for the post-mining scenario are mostly around -0.2 m to 0.5 m during both simulated monsoon (July-November, 2020) and non-monsoon period (November, 2020 - June, 2021). The changes in bed morphology in the post-mining scenario at different sections of the river are highly dynamic and patchy in nature. It is important to note that localized bed level changes caused due to abrupt change in the bed morphology.

Part A

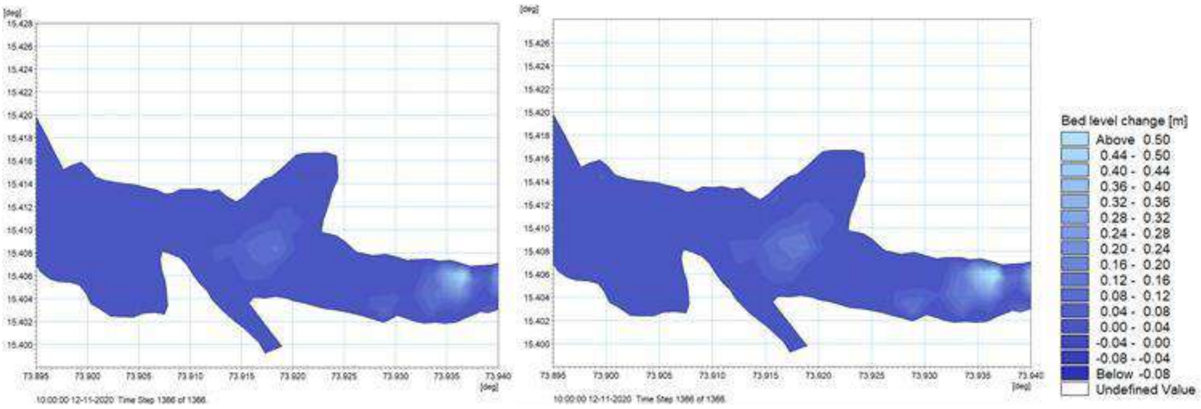


Figure 5.12: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Monsoon

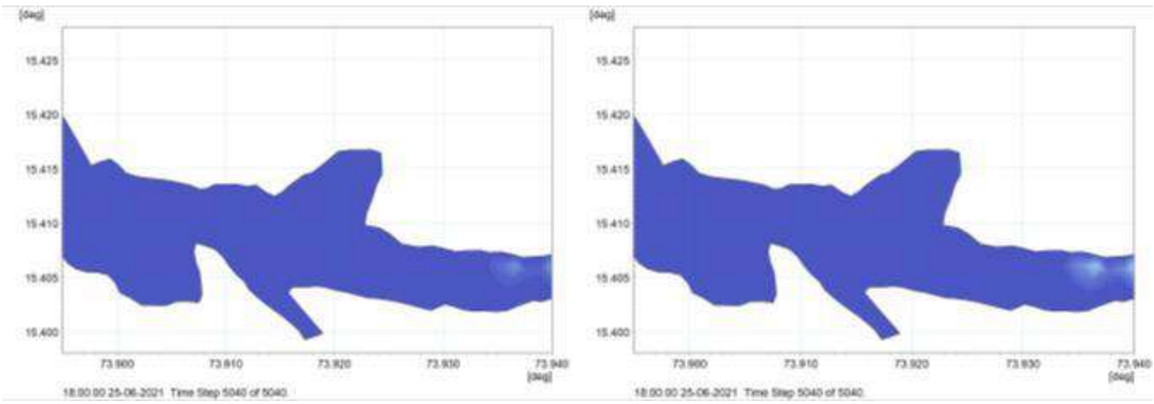


Figure 5.13: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Non-monsoon

Part B

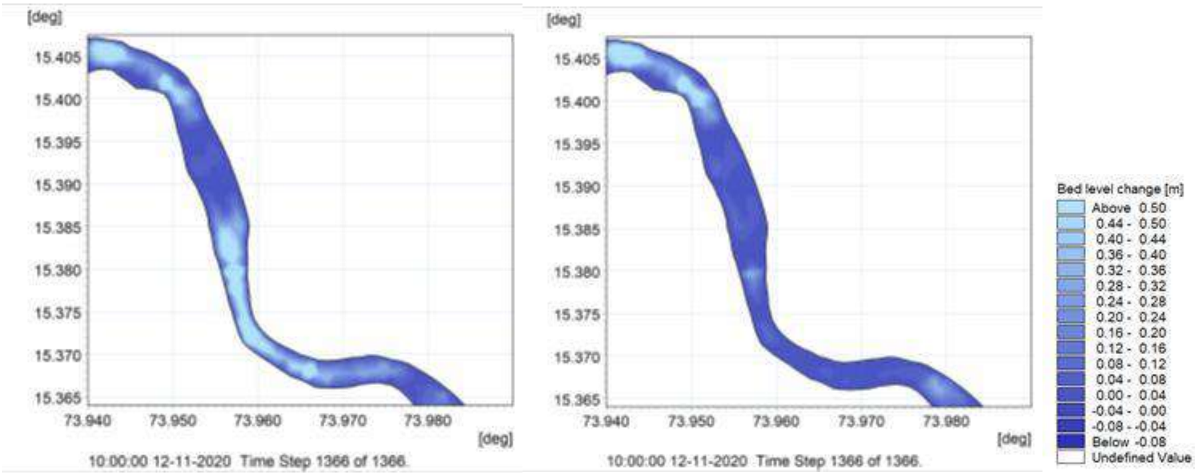


Figure 5.14: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Monsoon

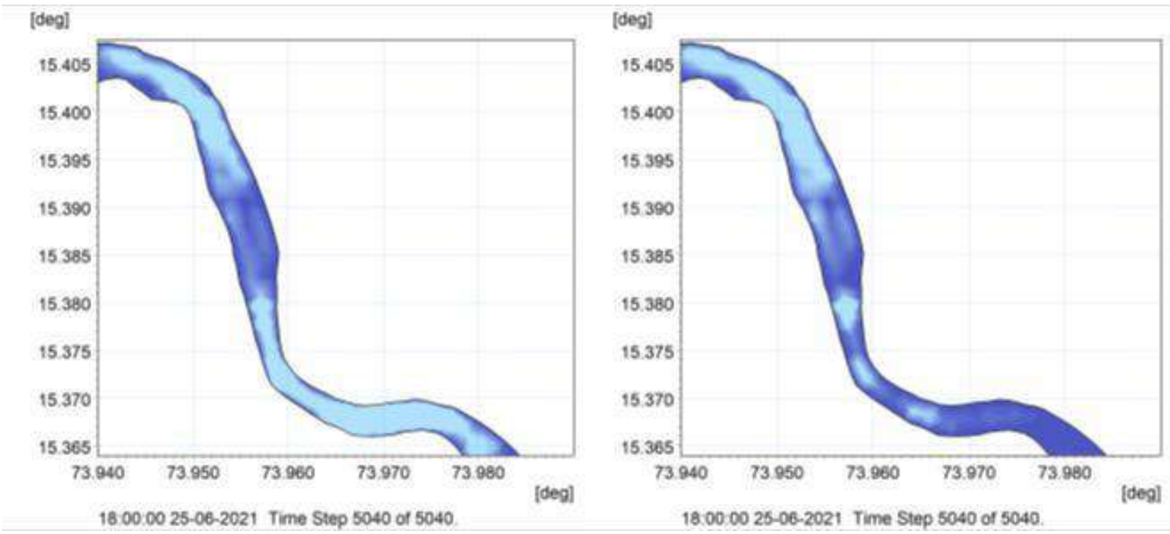


Figure 5.15: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Non-monsoon

Part C

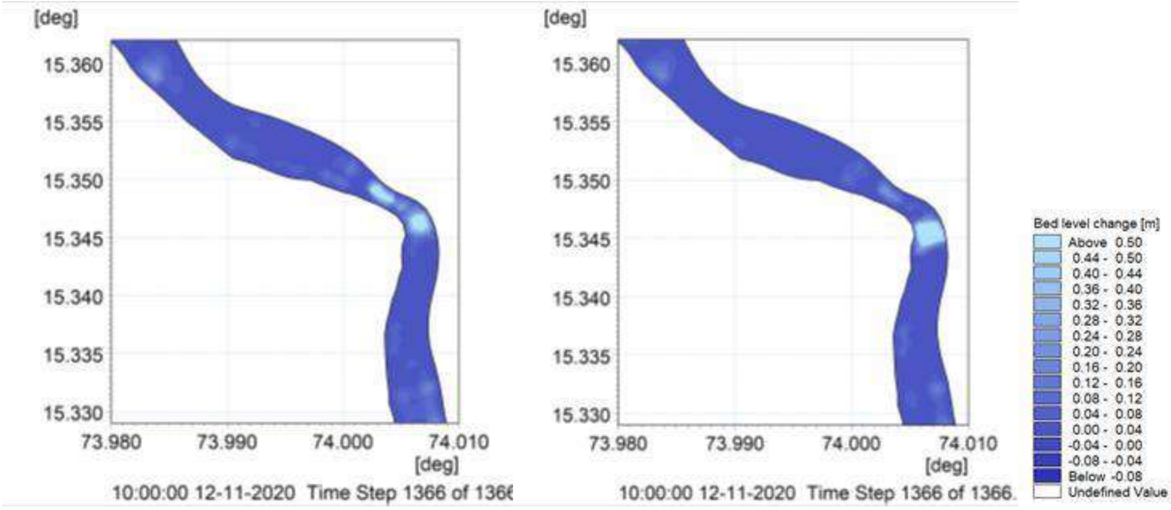


Figure 5.16: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Monsoon

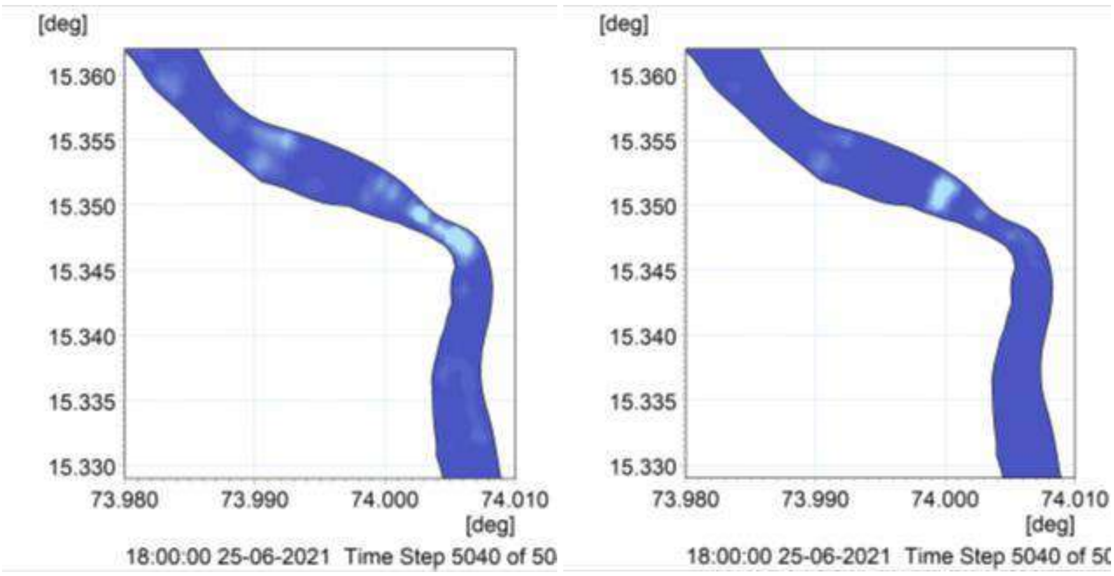


Figure 5.17: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Non-monsoon

Part D

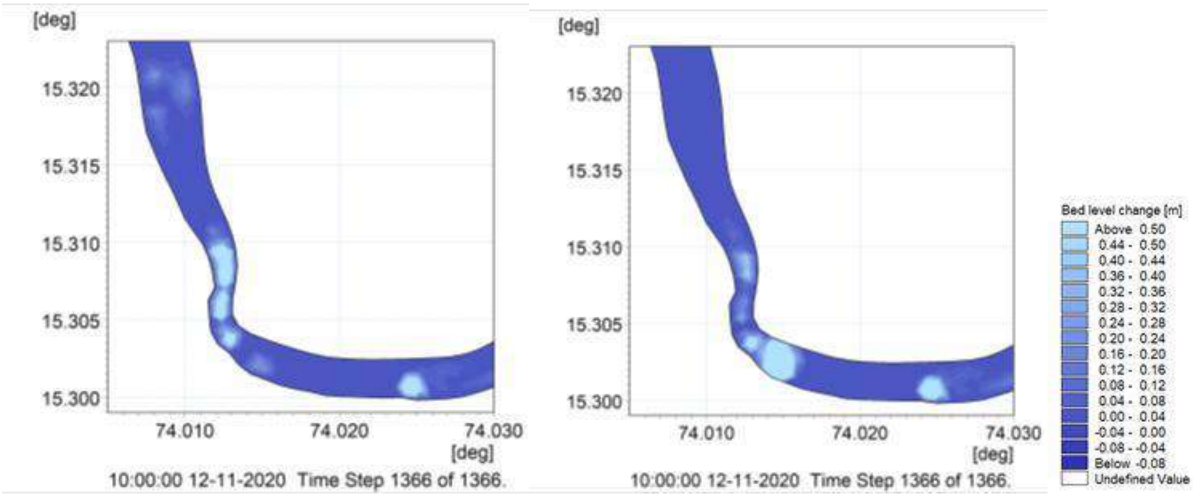


Figure 5.18: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Monsoon

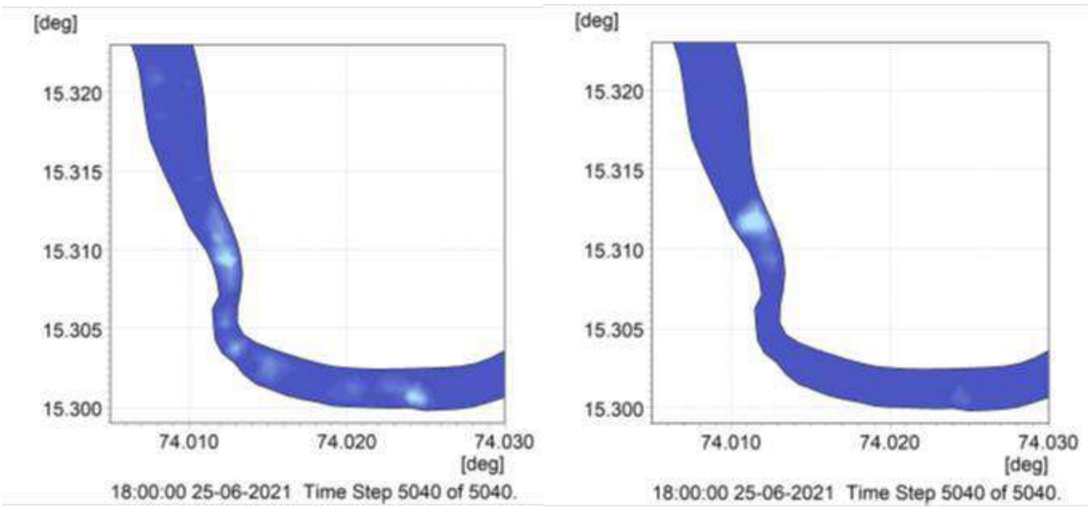


Figure 5.19: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Non-monsoon

Part E

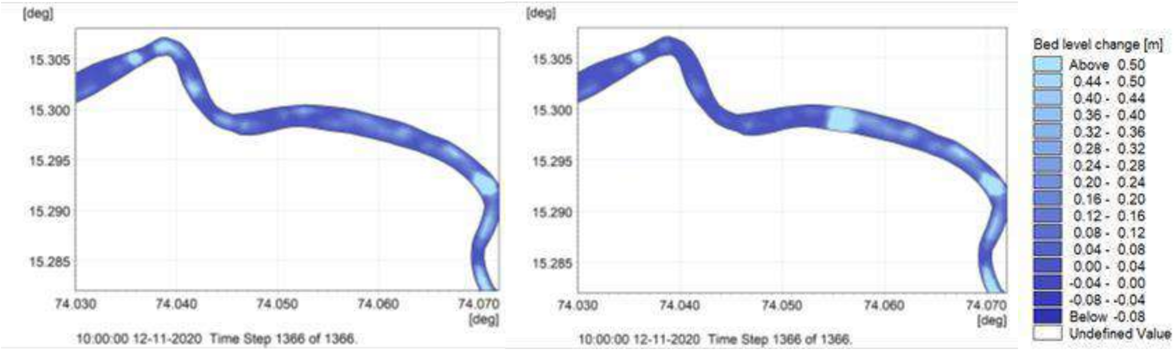


Figure 5.20: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Monsoon

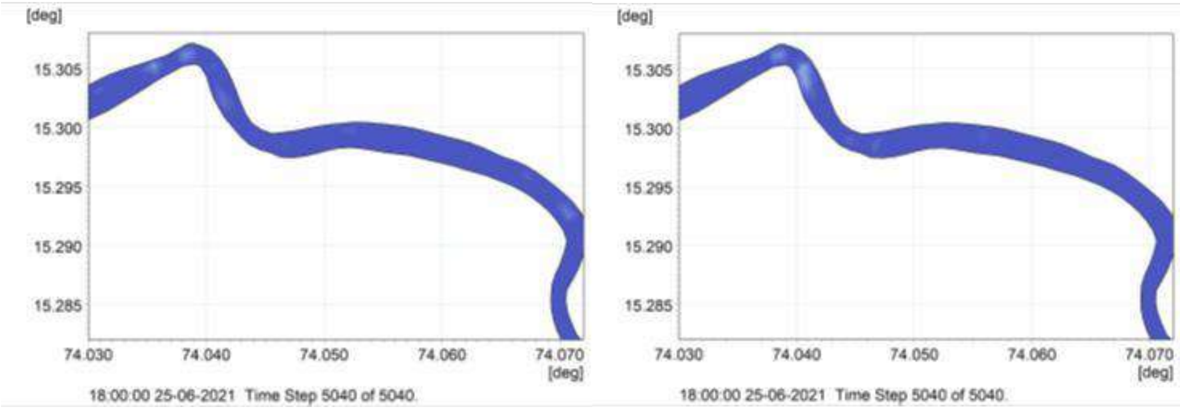


Figure 5.21: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Non-monsoon

Part F

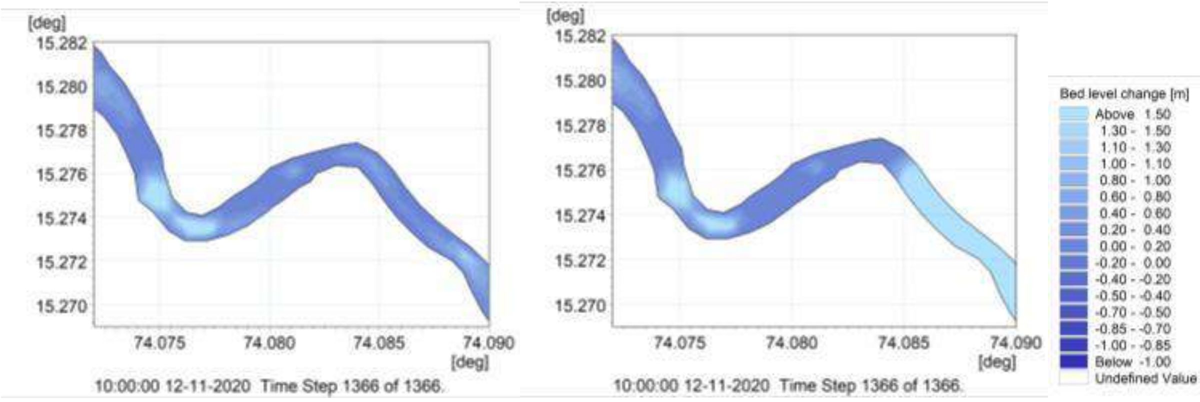


Figure 5.22: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Monsoon

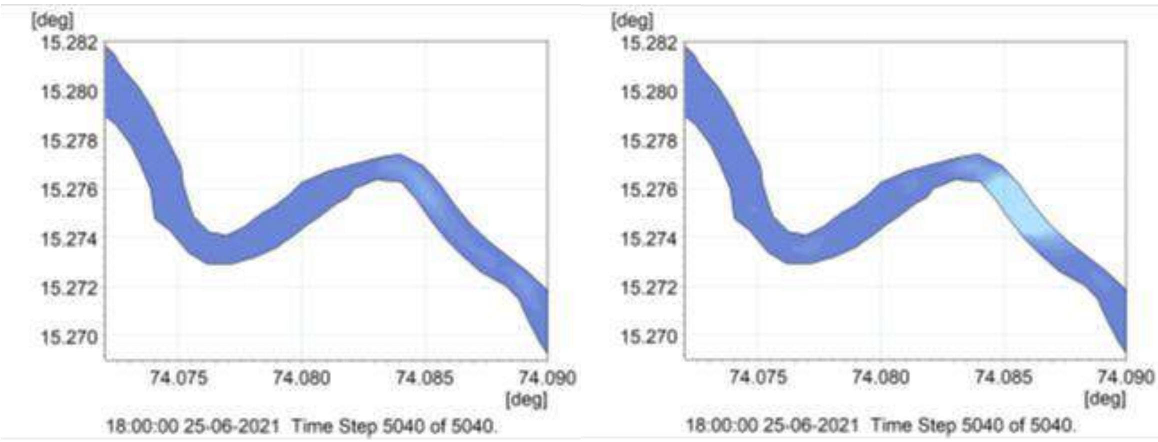


Figure 5.23: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Non-monsoon

Part G

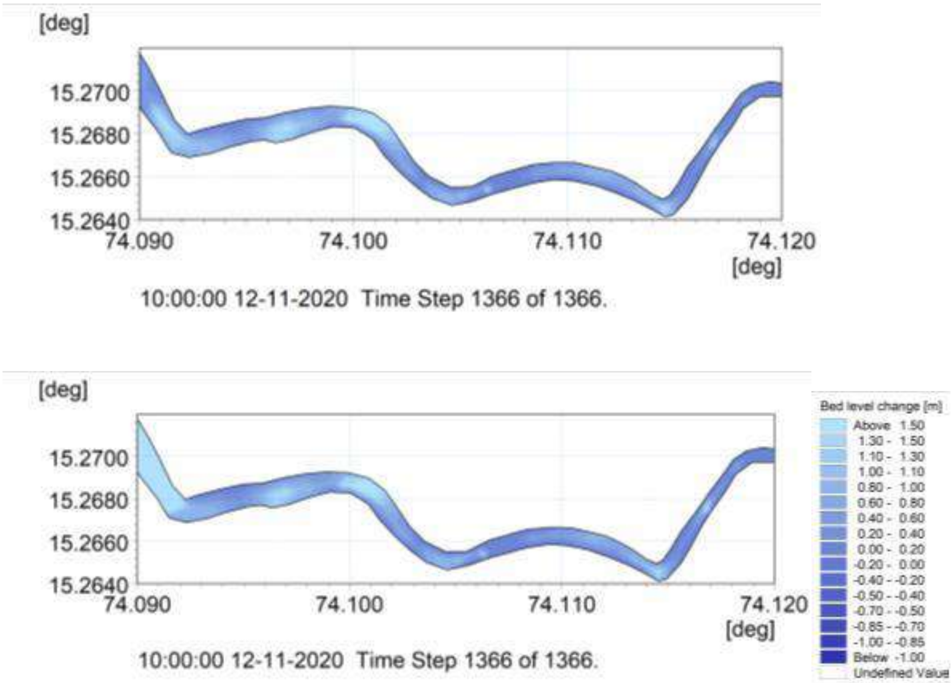


Figure 5.24: Bed level change at sections A and B with Case 1 (top), Case 2 (bottom) during Monsoon

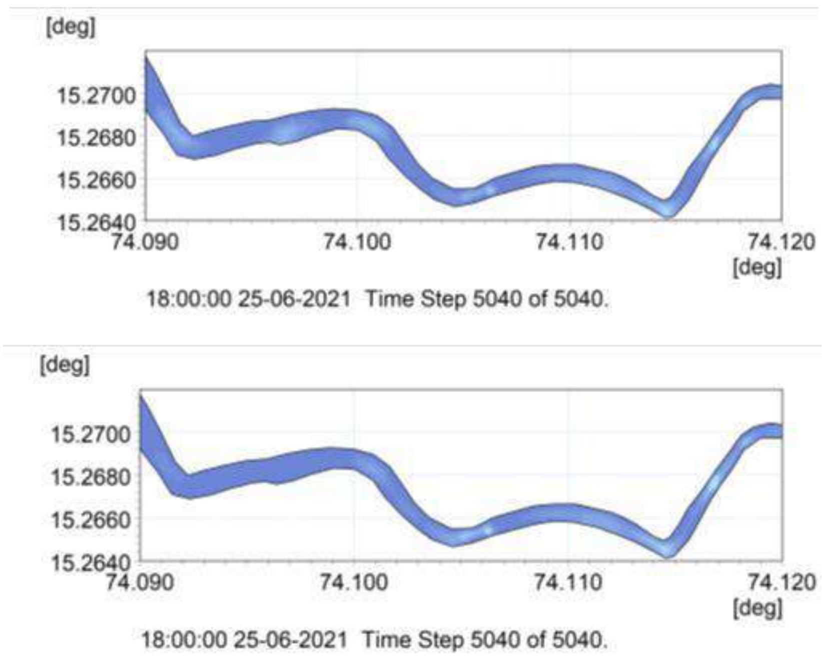


Figure 5.25: Bed level change at sections A and B with Case 1 (top), Case 2 (bottom) during Non-monsoon

Part H

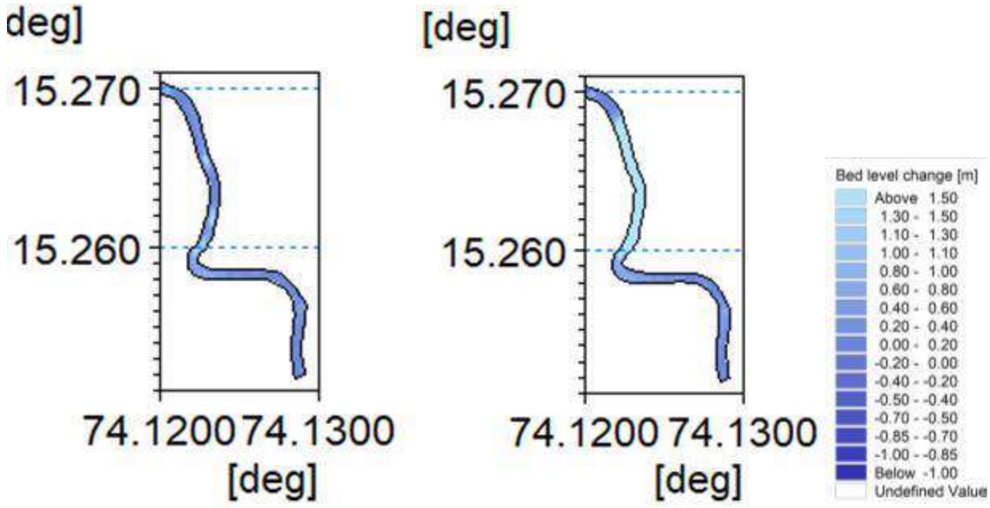


Figure 5.25: Bed level change at sections A and B with Case 1 (left), Case 2 (right) during Monsoon

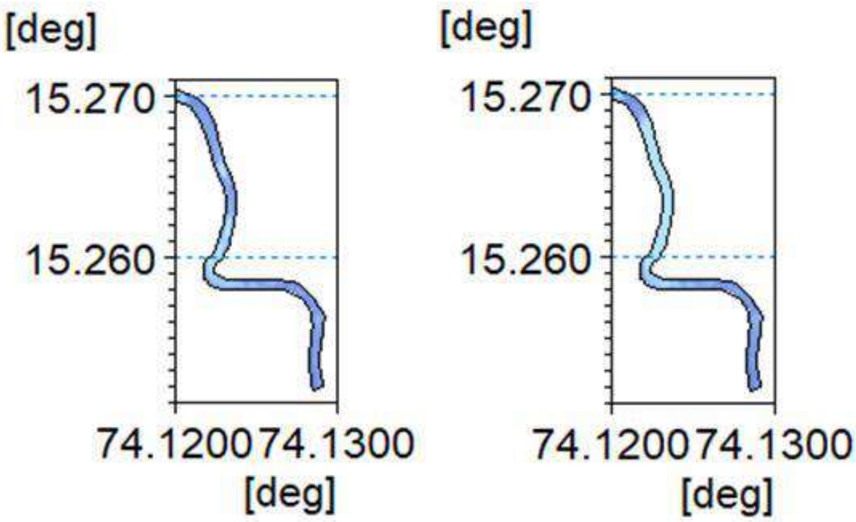


Figure 5.26: Bed level change at sections A and B with Case 1 (top), Case 2 (bottom) during Non-monsoon

CHAPTER 6: ANTICIPATED IMPACTS

The primary function of an environmental impact assessment study is to predict and quantify potential impacts and assess & evaluate the magnitude. Environmental impacts could be positive or negative, direct or indirect, local or regional and also reversible or irreversible. For each identified environmental impact, the associated risk is assessed based on its likelihood and significance.

Sand has become a very important mineral for our society due to its many uses. It is used for making concrete, filling roads, construction of buildings, brick-making, making glass, sandpapers, reclamations etc. The role of sand is very vital with regards to the protection of the coastal environment. It acts as a buffer against strong tidal waves and storm surges by reducing their impacts as they reach the shoreline. Sand is also a habitat for crustacean species and other related marine organisms. Individuals and private companies are increasingly demanding sand for construction purposes and this has placed immense pressure on sand resources. It is a practice that is becoming an environmental issue as the demand for sand increases in industry and construction.

Environmental Management Plan is a guiding document for environmental impacts associated with the proposed projects. It is a guiding document for management of good environmental condition on the site & surrounding of the proposed sand mining areas.

A scientific assessment of these impacts those are likely to influence the existing environmental scenario is needed. This could also facilitate in formulating a suitable environmental management plan depicting all mitigation measures. It can help in implementing the project in an eco-friendly manner. The project activities influencing the following environmental attributes have been studied and their impacts on the following attributes have been assessed.

The proposed project is to study impact of sand mining on the health of the Zuari Estuary. The projects seek to understand the geomorphology, bathymetry, sand budget and flow dynamic of the estuary and the impact of sand mining on environment and biodiversity of the estuary. The EIA seeks to ensure that the potential negatives impacts arising from sand mining are mitigated or minimised whilst at the same time maximising on the positive impacts. The potential impacts of the project have been identified through literature review and site-specific baseline. A variety of technical studies and investigations were also conducted. These include geo-morphological, modelling, physico-chemical and ecological studies.

6.1 Prediction & Assessment of impacts

Development projects such as sand mining have an impact on their surrounding environment. These impacts can be beneficial or harmful, depending on the effect it brings about in the status of air, land, water, natural systems, ecology, socio-cultural, lifestyles and economics.

Depending on the improvement or the deterioration it brings about in the status of air, water, land, ecology, natural systems, socio-cultural life styles and economics of the local population. The impacts are assessed for their importance based on the nature of activities and environmental screening.

Marine organisms are known for their adaptive nature to the environmental changes though they possess certain tolerance capacity. Crossing these tolerance limits could give rise to serious impact on their existence which will ultimately result in ecological damage to the environment. The extent to which the baseline conditions can be altered by sand mining needs to be thoroughly analysed, and adequate mitigation measures need to be adopted so as to minimise the damage, if any to environment. Impacts to biological resources from physical and chemical environmental alterations are associated with sand mining activities. Major classes of alteration include suspended sediments, sedimentation, chemical release, flow patterns, topography. The biological impacts of marine sediments extraction are the disturbance and removal of benthic epifauna and infauna and alteration of the substance upon which the colonization depends. This in turn affect its stability as a fish or shellfish food habitat where the remnant substrate is identical to the surficial sediment, disturbance is unlikely to be permanent and the extraction area will be re-colonized, although the time scale will vary depending on the nature and location of the deposit.

Sand mining is the physical activity in the proposed project and it is known and increased sand mining has an adverse impact on the biodiversity by disturbing the biological community structure. Furthermore, sand mining activities potentially affect not only the site itself but also the surrounding areas. The major impact of sand mining will be habitat destruction due to dislodging of sediment. The important parameters that influence the impacts are the scale of sand mining, its extent and duration.

Based on the present study and using available information, following major threats to the environment in the study area of the estuarine system have been identified.

6.1.1 Impact on physical environment

- Large-scale extraction of streambed materials, mining below the existing stream bed and the alteration of channel-bed form and shape may lead to several impacts such as erosion of channel bed and banks, increase in channel slope, and change in channel morphology.
- Undercutting and collapse of river banks.
- Loss of adjacent land and/or structures.
- Upstream erosion as a result of an increase in channel slope and changes in flow velocity.
- Formation of deep pits in the channel bed produce slower flow velocities and lower flow energies, causing sediment transported from upstream to deposit at mine site.
- Alteration of the bed can have a high erosive effect on the river banks.
- It can result bank erosion and damages to existing structures in the downstream.

6.1.2 Impact on traffic

- Mining contractor uses the same main roads to transport product out of the zone and through road networks. This may result in an increase in the number of trucks utilising the road.
- Traffic congestion may occur due to narrow width of road and damage to roads due to plying of heavy vehicles further disturbing local well-being and increasing the maintenance cost.

6.1.3 Impact on Air Environment

- Dust generation may occur due to loading, screening and transportation operations. This dust becomes air borne and gets carried away to surrounding areas.
- The impact on air will be localized in nature as large sized dust particles settle down after travelling short distance.
- Combined impact of air borne dust from the mining lease areas may give a relatively larger picture of fugitive dust emission in the area.
- Collection and lifting of material are to be done manually without any blasting. Therefore, the dust generated is insignificant as compared to mining process of other hard minerals like the process of drilling, blasting, mechanized loading etc.

6.1.4 Impact on Water environment

- Sand mining activities may have impact on the river's water quality. Impacts include increased short-term turbidity at the mining site due to re-suspension of sediment, and dumping of excess mining materials, oil spills or leakage from transportation vehicles and washing of vehicles in the river.
- Suspended solids may adversely affect water towards downstream and aquatic ecosystems. The impact is particularly significant if water toward downstream of the site are abstracting water for domestic and irrigation purposes etc.
- Excessive mining may reduce the thickness of the natural filter materials (sediments) through which the groundwater is recharged. The pollutants due to mining, such as washing of mining materials, wastes disposal, diesel and vehicular oil lubricants and other human activities may pollute the groundwater.

6.1.5 Plume generation

- At the proposed sites of river/estuary, a turbid plume would eventuate as material is released to the water column during sand mining operations.
- Increased turbidity results in decreased primary productivity in the water column.
- Sand mining activity changes the nutrient regime of the water column and results in increased pollutant such as particulate associated pollutants, Polyhydrocarbons (PHC), oil and grease (O&G), heavy metals, organic matter and other contaminants and toxins from the sediment.
- The turbidity plume generated may have localized dispersal due to tidal action and riverine flux, thus the overall impacts may be localized and not of chronic nature.
- The size and duration of plume depends on the scale and periodicity of the mining.

6.1.6 Impact on Pelagic environment

- The increased turbidity leads to decrease in dissolved oxygen (DO) in the water column during sand mining operations. These sediments contain highly variable levels of nutrients, typically an order of magnitude several hundred to several thousand.
- Increase in suspended sediment loads and turbidity level due to sand mining could have adverse impacts on marine producers and consumers by reducing euphotic zone of water column.

- This increased load not only limits light penetration in water but also affects filter feeding organisms such zooplankton and bivalves.
- Reduced DO can cause the loss of micro-eukaryotic biomass, decrease aerobic bacteria and increase sulphate-reducing bacteria.
- Loss or reduction of bacteria means the remineralisation of matter will be significantly slower affecting the invertebrate grazers, predators and fish community.
- Nutrients such as phosphate released from the bottom churning of the sediments during sand mining will increase surface phytoplankton bloom that may clog membranes of filter feeding zooplankton and larval fish.

6.1.7 Impact on planktons

- Sand mining causes resuspension of sediments in the water column during extraction. The increase in turbidity would decrease light penetration and reduce photosynthesis, thereby causing changes in phytoplankton community structure and the food web. Many bottom dwelling pinnate phytoplankton and zooplankton groups such as bivalves could be impacted or translocated. The suspended solids would also release excessive material such as nitrates during mining. This could lead to blooms of dinoflagellates. Since the activity does not involve long distance vessel movement, the chances of exotic/weed/invasive species to be introduced would be negligible.
- One of the main concerns of sand mining is the suspension of fine sediments into water column, causing short term increase in turbidity. This increased turbidity has short-lived effect on phytoplankton, which are light dependant, these are generally of low significance and temporary. However, the release of contaminants such as heavy metals associated with suspended sediments can lead to increased accumulation of contaminants in the food chain.

6.1.8 Impact on Fishery

- Common fish found in Zuari estuary are *Etroplus suratensis*, *Mugil cephalus, Sillago sihama, Lates calcarifer* and the overall fishery yield from the river is high. Thus the mining may have negative effects on fish population.
- Sand mining affects the area by limiting the ability of mined areas to function as a nursery area, and/or feeding ground for the fauna.

- Physiological stress to marine fish and commercially important species by creation of higher sediment loads in the water column.
- Increased bioaccumulation of contaminants in commercially important species.
- Reduction in habitat due to loss of benthic primary producer habitat.
- Change in fish catch may occur due to proposed activity.
- Increased turbidity and organic matter may change the microbial water quality at nearby sites and thus may affect the fish fauna. Increase in the population of undesirable species such as viruses and parasites.

6.1.9 Impact on Benthic environment

- During sand mining operations, the removal of material from the seabed also removes organisms living on and in sediments which are collectively termed as 'Benthos'.
- Initial reduction in abundance, species diversity, benthic biomass as well as recovery of the lost biota varies with scale and duration of disturbance, local hydrodynamics, and associated transport processes and lacks similarity to the habitat that existed prior to sand mining.
- Sand mining may result in complete removal of benthic surface biota at mining sites.
- Excessive and unplanned riverbed sand mining results in the destruction habitat through large changes in the channel morphology.
- Disturbance of the upper layers of the seabed causes short term re-suspension of sediments, re-mineralization of nutrients and contaminants and re-sorting of sediment particles. Direct removal damages, displaces or kills a portion of benthic flora and fauna. It also causes a short-term attraction of carrion consumers. It leads to alteration of habitat structure (e.g., removal of sand, flattening of wave forms, and removal of structures required by some organisms).
- Increased suspended sediment due to sand mining can affect the filter feeding organisms such as shellfishes by clogging and damaging their feeding and breathing physiology.
- Sand mining may lead to patchy distribution of organisms between mined and adjacent non-mined areas.

- Adult fish are likely to move away or avoid areas of sand mining sites, unless food supplies are increased in mining sites as result of increase in organic matter.
- Fauna was comprised of polychaetes & crustacean which constitute a major food source for benthic feeding fishes, these showed low population in the central regions of the river and thus lowered secondary benthic productivity.

6.1.10 Impact on channel

- Sand-and-gravel mining in stream channels can damage public and private property. Channel incision caused by sand/gravel mining can undermine bridge piers and expose buried pipelines and other infrastructure.
- Excavation of a mining pit in the active channel lowers the stream bed, creating a nick point that locally steepens channel slope and increases flow energy.
- Impacts include bed degradation, bed coarsening, and channel instability. This in turn can cause erosion of banks, embankments along fields leading to salt water intrusion and loss of land.

6.1.11 Impact on mangrove

- Mangroves are crucial habitats as they act as feeding and breeding grounds for many organisms. These are also an important site for crab fisheries. Mangroves could be affected by sustained inundation of pneumatophores and declining water quality which may lead to their death.
- In downstream areas, sand mining can lead to damage to embankments which cause saline water intrusion into fields which leads to abandonment of fields that are further colonized by mangroves.
- Damage to mangroves can also affect species (eg: *Meretrix* spp*, Polymesoda* spp.*,* other oysters and clams) that depend on mangroves for resources.
- However, the overall impacts to mangrove in the study area are of low concern as mangrove cover has shown steady increase in-turn showing indications of increasing its expanse.

6.1.12 Impact on mudflats

- Sand mining can cause increased scour, erosion and increase steepening of slopes thereby removing the mudflat habitat.

- Create a disturbed benthic community and possibly reduce the number and diversity of benthic species and affects larval recruitment negatively on mudflats.

6.1.13 Impact on sandflats

- In-stream mining lowers the stream bottom, which may lead to bank erosion. Depletion of sand in the streambed and along coastal areas causing deepening of rivers and estuaries, and the enlargement of river mouths and coastal inlets.

- Epifaunal and large in-faunal organisms will be most affected by sand mining. Crustacean spawning areas occur where sand banks meet rocky areas. It can cause extinction of commercially important species dependent on sand flats for eg: *Paphia* spp.

- Cumulative impacts may include undercutting and collapse of river banks, loss of adjacent land and/or structures, upstream erosion and uprooting of flora as a result of an increase in channel slope and changes in flow velocity. In the downstream region there is channel widening and deepening, undermining of engineering structures, dwindling of riverine habitats, damage to protective structure such as bandhs leading to salt water intrusions into paddy field.

6.1.14 Others

- The most likely adverse impact might be of cumulative nature and it will be hard to discern from any singular impact of new or old activity in the given location and period.

- There are crocodile and smooth coated otters found in the river which are protected under schedule I and II respectively by the Indian Wildlife Protection Act, 1972. Other mammals such as Otters, jackals, flying fox, wild cats, wild boar etc. visit mangroves for shelter, breeding or feeding. These species can face increased threats and can be harmed due to disturbance.

- Zuari estuary has a good diversity and abundance of avifauna. Birds gather on the mud flats of river Zuari for feeding. Several migratory birds visit these rivers during winter and use it as an important feeding ground. These are most sensitive to any sort of disturbance such as noise, use of mechanized vessels, change in turbidity, productivity or change in water quality. The disturbance by sand mining may affect foraging behavior of birds, mainly aquatic birds. These birds are likely to move away from such areas.

- Occurrence of unintended events such as vehicle collision, accidents, fire, fuel leaks and other inadvertent events may occur mainly due to lack of coordination, casual approach, un-managed activity and associated activities (e.g., fishing) and no timely communication within and between stakeholders involved in nearby areas. These events may also result in environmental disaster if there are no precautions taken.

- Oil spills due to any unplanned eventuality is one of the major long-term threats to the marine biota and can have a major long term irreversible loss depending on the extent, quantity and expanse of spillage. The likeliness of this occurrence will be very low if proper precautions and contingency plans are in place.

6.1.15 Positive anticipated impacts

- Sand mining can help the economy directly by generating jobs for extraction of sand and income from sale of sand.

6.2 Mining Sensitive Areas:

Estuaries are most dynamic and complex ecosystems known around the globe. They are made up of a wide range of different habitats, which exist in an ever-changing mosaic structure. Typical habitats that make up an estuary include sand banks, mudflats, mangroves, salt marshes, sand flats, and at their coastal edge sand dunes, small islands sandy beaches etc. They are prime importance for wildlife especially migrating and breeding birds and major values in terms of their rich natural resources (nursery grounds and commercially important fish). In addition, they also offer a wide range of ecosystem services such as shoreline stabilization, nutrient regulation, carbon sequestration, detoxification of polluted water and supply of food and energy resources.

To preserve and protect these habitats areas have been demarcated based on importance and in accordance with Sustainable Sand Mining and Management Guideline (2016). The entire region is divided into four different zones. Zone –I (Figure 6.1) (and Legends as per Table 6.1) is located at the mouth region, it ends at Durbhat village jurisdiction. The area consists of sensitive regions *viz.* Mangroves, riverside urban areas island, Ecological sensitive area and a bridge. Mud flats provide feeding habitat to a lot of migrating and local birds, if sand is excavated from zone-I (Figure 6.1) it is predicted to impact shoreline, change in geo-morphology, beach profile and grain size of sandy beach, which will potentially have adverse impact on birds feeding grounds. Further a bridge is present connecting Panjim (North Goa) and Vasco (South Goa), mining might damage this structure, stability or strength of the bridge. As per SSMMG, 2016, to avoid structural damage to any bridge, an area of 500 meters on both the sides of bridge is restricted for mining. West to the bridge an Island (St. Jacinto) covered with vegetationand settlement, further considering the Hon'ble NGT order (28/2015 (WZ) an area of 1000m (upstream and downstream) has to be restricted for mining. An ecologically sensitive and endangered species (*Placuna placenta*) inhabits the adjacent chicalim bay. East to the bridge lies mangrove forest, and as per SSMMG (2016), a 50m wide area from ecologically sensitive areas (such as mangroves) and 25m from the embankments are to be avoided for mining.

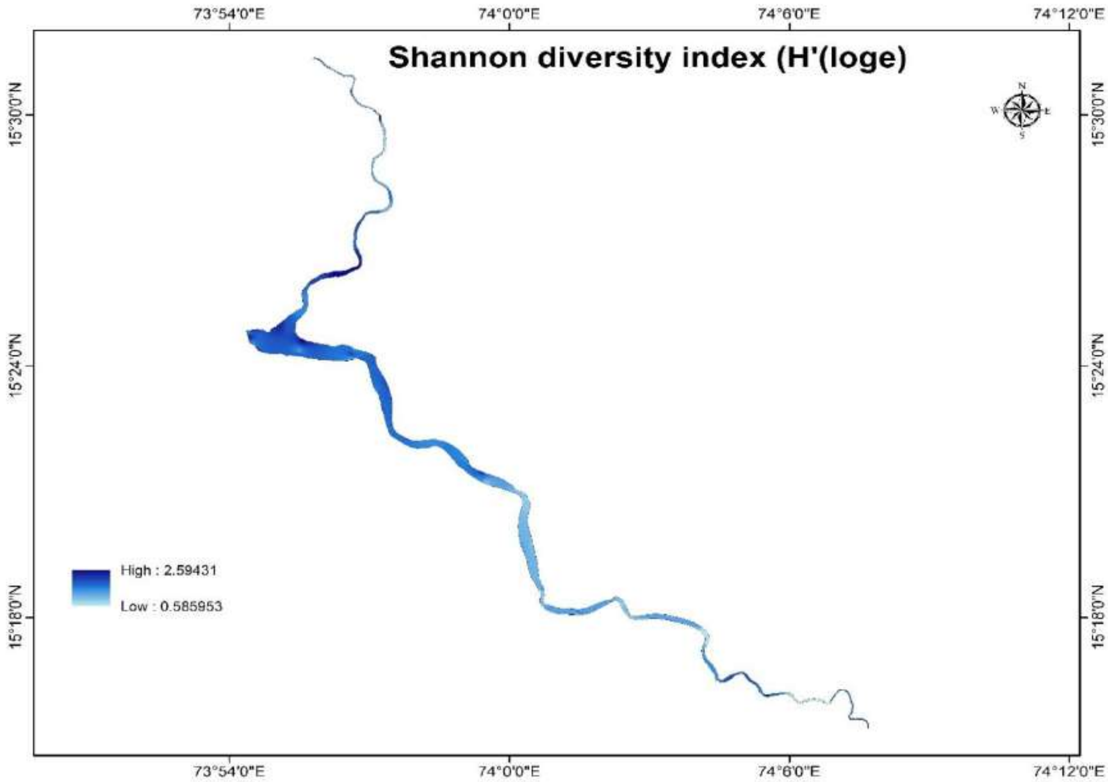
Next zone is considered from Durbhat to Macazana which consists of embankments and mangrove forests along both the banks, bridge and meandering towards east. The order of meandering bends are to be avoided as these may have major geo-morphological changes such as accretion which may lead to deposition and erosion at the upper/lower reaches pertaining to sand extraction. Mudflats and mangroves are also to be avoided as these serve as habitat, breeding ground and nursery for myriad of marine organisms. A flyover bridge is also present at the meandering point where an area of 500 m on both the sides is restricted for mining. Zone III (Figure 6.1) falls between Macazana to Churchorem, it consists of meandering and three bridges towards Churchorem. As per SSMMG (2016), 500m on either side of the bridge is restricted for mining.


Google Earth


Google Earth

Figure 6.1: Depicting mining sensitive zones for Zuari estuary

Table 6.1: Depicting type of sensitivity, colour code, width and guidelines referred			
Legend			
Colour	**Sensitive Areas**	**Width**	**Guideline**
(green)	Mudflats and Mangrove	50 m	Sustainable Sand Mining Management Guideline 2016
(pink)	Bridges	500 m	Sustainable Sand Mining Management Guideline 2016
(red)	Islands	1000 m	Sustainable Sand Mining Management Guideline 2016/ National Green Tribunal.
(yellow)	Meandering	200 m	Sustainable Sand Mining Management Guideline 2016
(brown)	Embankment	25 m	Sustainable Sand Mining Management Guideline 2016
(orange)		-	Eco-sensitive Zone



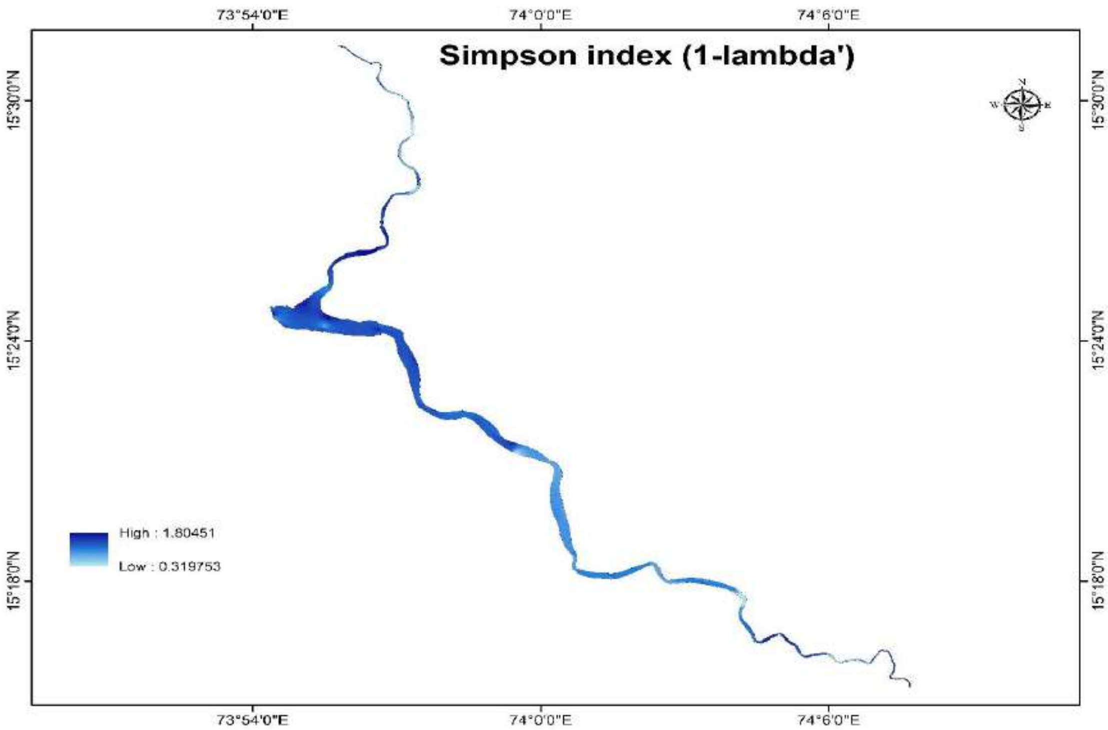
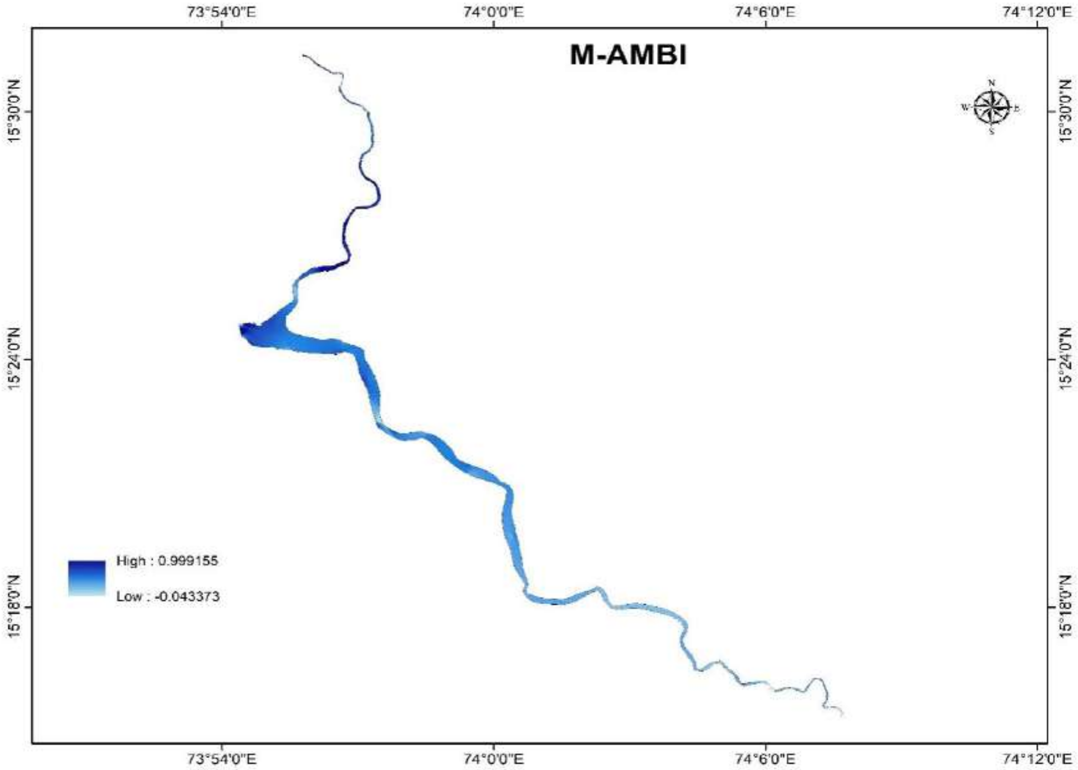


Figure 6.2: Shannon-Wieners and Simpsons Index depicted on the river stretches with encircled proposed sand extraction zones



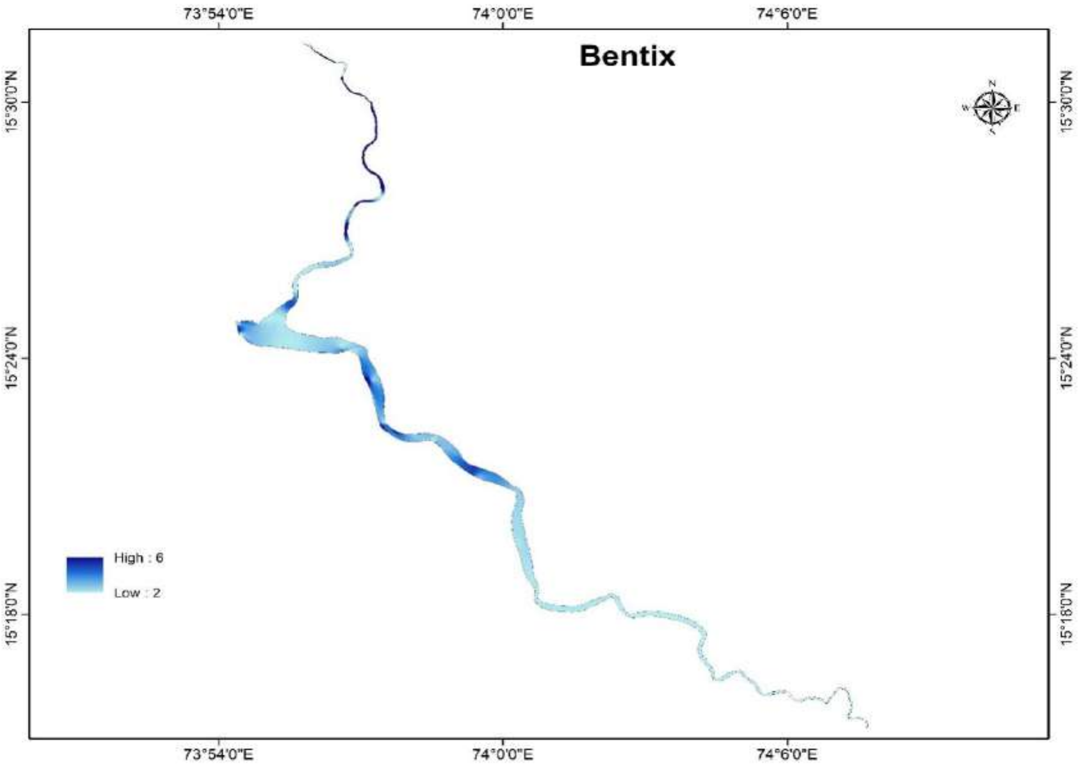


Figure 6.3: M-AMBI and BENTIX indices depicted on the river stretches with encircled proposed sand extraction zones

CHAPTER 7: MITIGATION MEASURES

The aim of the mitigation guidelines to ensure that the sand mining is carried out in an environmentally sustainable and socially responsible way, improve the effectiveness of monitoring of mining and transportation of mined out material, conservation of river equilibrium and it's ecosystem health, no obstruction of the river flow, water transport and restoring the riparian rights and in-stream habitats, to prevent river pollution and water quality deterioration. The extraction of sand and gravel from the river bodies has to be regulated and done with the adoption of required environmental safeguards. Mapping of the sand resources at the district level, identification of appropriate sites for extraction, appraisal of the extraction process, putting in place the required environmental safeguards and rigorous monitoring of the volume of extracted material is required to ensure the sustainability of the entire process. In broader sense, the impacts of sand mining can be reduced or avoided and mitigating it may only imply replenishment (which may happen over a course of time during which the magnitude and expanse of impacts might change thus making it difficult to comprehend).

7.1 Protection of river embankment

Site-specific evaluation is needed to evaluate each proposed operation to minimize disturbance and maximize the stability of the channel. In downstream areas, sand mining can lead to damage of bunds, which causes saline water intrusion into fields, leads to abandonment of fields. Mining lease should be preferably granted for those locations which have the least possibility of an impact on the environment and nearby habitation. Demarcation of the mining area with pillars and geo-referencing should be done before the start of mining to ensure that sand extraction is going on only within the permitted area. The permanent boundary pillars need to be erected after the identification of an area for deposition of mined sand outside the river bank at a safe location. The distance between boundary pillars on each side of the bank shall not be more than 100 m.

Sand and gravel shall not be allowed to be extracted where erosion may occur, such as at the concave bank. Sand and gravel shall not be extracted up to a distance of 1 kilometer (1 km) from major bridges and highways on both sides, or five times (5x) of the span (x) of a bridge/public civil structure (including water intake points) on up-stream side and ten times (10x) the span of such bridge on the down-stream side, subjected to a minimum of 250 meters on the upstream side and 500 meters on the downstream side as per the guidelines issued by Hon'able National Green Tribunal. The borrow area should preferably be located on the riverside of the proposed embankment because they get silted over time. For low embankment, less than 6 m in height, the borrow area should not be selected within 25 m from the toe/heel of the embankment. In the case of the higher embankment, the distance should not be less than 50 m. In order to obviate the development of flow parallels to the embankment, crossbars of width eight times the depth of borrow pits spaced 50 to 60 meter center-to-center should be left in the borrow pits.

River bed sand mining shall be restricted within the central 3/4th width of the river/rivulet or 7.5 meters (inward) from river banks but up to 10% of the width of the river. The mining area must be demarcated at a minimum distance of at least 50 m away from the river embankment on either side. The boundaries of the quarries may be fixed concerning the existing survey marks from the survey fields adjacent to the river. Sand quarrying lease area shall be demarcated on the ground with pucca stone or concrete pillars to show the present natural bed level, and the depth of mining allowed. The zone of river bed mining shall ensure that the objective to minimize the effects of riverbank erosion and consequential channel migration are achieved to the extent possible. In general, the area for removal of minerals shall not exceed 60% of the mine lease area.

7.2 Annual replenishment of sand

It is necessary to ascertain the rate of sand replenishment in the river bed. A regular replenishment study needs to be carried out to keep a balance between deposition and extraction. Replenishment would need to occur before subsequent extraction could take place. The concept of annual replenishment accounts for the episodic nature of sediment transport. For example, during monsoon, high stream flows result in a high contribution of sediment from hill slopes and tributaries, and during the dry periods, low stream flow led in little sediment supply. The use of monitoring data is essential in measuring when actual replenishment occurs.

The use of the concept of annual replenishment protects long-term channel stability as well as aquatic and riparian habitat by extracting a sustainable volume of sand. Sand mining must not be done on one site, but in alternating sites, to reduce over-extraction, which damages the environment beyond rehabilitation.

According to best practices, the distance between any two sand mining clusters should not be less to reduce the cluster formation. Mining lease should be defined in such a way that the total area of the mining leases in a cluster should not be large. After every year, a mandatory audit of the quantity extracted and quantity permitted along with the replenishment rate.

7.3 Maintenance of flood capacity

Flood capacity in the river should be maintained in areas where there are significant flood hazards to existing structures or infrastructure. Sand and gravel could be extracted from the downstream of the sand bar. Retaining the upstream one to two-thirds of the bar and riparian vegetation is accepted as a method to promote channel stability. Mining depth should be restricted to 3 meters, and distance from the bank should be ¼th or river width and should not be less than 7.5 meters.

7.4 Seasonal ban on sand mining activity

There shall be no river bed mining operation allowed in the monsoon period. The period as defined by IMD Nagpur for each state shall be adhered to. The cumulative riverine impact of all mining activity should be reviewed on an annual basis to minimize long-term impacts and inequities in permits between adjacent mining operations.

7.5 Limiting sediment impact

Minimize activities that release fine sediment to the river. No washing, crushing, screening, stockpiling, or plant operations should occur at or below the streams "average high-water elevation," or the dominant discharge. These and similar activities have the potential to release fine sediments into the stream, providing habitat conditions harmful to local fish.

7.6 Prevention and mitigation of pollution

Proper entry and exit points for the movement of loading vehicles in and out of the sand mining sites shall be carefully located, taking into consideration the habitations/settlements in the area. Construction of separate gravel roads for tipper trucks to reduce traffic congestion, accidents, as well as noise and air pollution, maybe consider. All the vehicles should be serviced regularly according to the existing Govt. guidelines to minimize noise and air pollution. The transportation route so selected should be verified by the Goa Government for its carrying capacity. Movement of heavy vehicles from public roads to pit sand, gravel, and river sand collection points need access roads. To prevent air pollution due to the dust during sand mining operations and safeguard the workforce in the sand mining and depot site, constant water sprinkling on the pathways and dust prone areas may be conducted. The sand loaded vehicles are to be covered with a tarpaulin before moving out of the quarries/depots. Plantation needs to be done with the consultation of the state forest department beside the sand transportation road to curtail the dust pollution.

The air and water quality should to be checked periodically to ensure that no pollution is caused due to sand transport operations. Safety gadgets such as earplugs, goggles, respiratory devices, luminescent vests may be provided to the workers at the sand mining site. First aid kit with all essentials shall be kept ready at all quarry/depot sites, in case of any emergency. Independent environmental auditsneed to be carried out at least once in a year for each mining site by reputed third party entity and report of such audit be placed in the public domain.

7.7 Protection and management of groundwater

To monitor the groundwater level during sand extraction operations, a network of existing wells may be established around the sand mining area, and new piezometers must be installed at all sand mining sites. The monitoring of groundwater quality in the vicinity (one Km radius from the sand mining site) shall be carried out once in two months. If, at any stage, it is observed that the groundwater table is getting depleted due to the mining activity, necessary corrective measures shall be carried out, which may include immediate stopping of the mining operation.

7.8 Soil management

Sand mining can cause weakening of soil in adjacent areas, which can lead to erosion of river banks. Sand mining destabilizes soil structure, river banks and often leaves isolated islands of trees; the subsequent flow will erode the banks and islands. Construction of soil conservation structures like river embankments/bundhs, extensive plantation drive, and mitigation of afforestation are some of the prerequisites to reduce soil erosion. Mangroves around the Zuari estuary are crucial habitats that serve as feeding and breeding ground to many ecologically and economically organisms like oysters and clams, crab, fishes. Mangroves also protect the river embankment and an excellent source of carbon sequestration. Hence, ultimate care needs to be taken to protect the mangrove habitat.

Soil salinity is a major global issue owing to its adverse impact on agricultural productivity and sustainability. It should be noted that no single approach can deliver a complete solution to fix/reclaim the soil salinity problem. Soil salinity undermines the resource by decreasing soil quality and can jeopardize the integrity of soil's self-regulatory capacity. Therefore, regular salinity mapping of the river bank may assist in taking necessary and timely actions to tackle the increased soil salinity and to avoid a further spread of soil salinity to a new area. Different methods, such as physical (levelling, salt scraping, tillage, subsoiling, and sanding); chemical (use of soil amendments such as elements, acids, gypsum to rectify soil sodicity problems and to improve soil health); hydrological (irrigation systems: Surface, flood, basin, drip, sprinkler, subsurface irrigation, leaching, and drainage), and biological (biosaline agriculture: Salt tolerant crops, and a serial biological concentration approach), may be employed to manage and prevent soil salinization.

7.9 Alternative resource generation

Promotion of manufactured sand, artificial sand, and alternative technologies in construction materials and processes are also required for reducing the dependence and demand on naturally occurring sand and gravel. Reusing and recycling of building material to reduce demand for river sand, pit sand, and gravel.

CHAPTER 8: ENVIRONMENTAL CONSERVATION AND MANAGEMENT PLAN

8.1 Background

Under the Environmental Impact Assessment notification of 2006 issued by the Ministry of Environment, Forests and Climate Change (MoEFCC), Govt. of India, which forms the legal basis for environmental impact assessment of development projects in India. In 2016, the Union Ministry of Mines (Ministry of Mines, India, 2016) released a press release addressing the administrative responsibilities associated with legal and illegal sand mining in rivers, stating that:

- Sand mining is regulated at the state level under powers granted by the Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act).
- States can grant mineral concessions for minor minerals and enact regulations to control these activities.
- The same Act empowers state governments to frame rules to prevent illegal mining, transportation and storage of mineral sands, and therefore the control of illegal activities is under the legislative and administrative jurisdiction of the state governments.

8.2 Legal requirements

As per the provisions of the EIA Notification issued on 14th September 2006 and subsequent amendments till date all projects and activities are broadly categorized in to two categories – Category A and Category B. Category 'A' in the Schedule requires prior environmental clearance from the MoEFCC and Category 'B' in the Schedule, from the State/Union Territory Environment Impact Assessment Authority (SEIAA).

Acts and legislations applicable for proposed activites

- The Mines Act 1952
- The Mines and Mineral (development and Regulation) Act 1957
- Mines Rules 1955
- Mineral Concession Rules 1960
- Mineral Conservation and Development Rules 1988
- The Environment (Protection) Act, 1986

- EIA Notification (and amendments) 2006
- Wildlife Protection Act, 1972
- The Forest (Conservation) Act, 1980
- Water (Prevention and Control of Pollution) Act (and subsequent amendments) 1974
- The Water (Prevention & Control of Pollution) Rules 1975, Cess Act 1977 & Cess Rules 1978
- Air (Prevention and Control of Pollution) Act (and subsequent amendments) 1981
- Solid Waste Management Rules, 2016
- CRZ notification 2019

8.3 Mining plan

A mining plan has to be prepared by each lease owner and accordingly the state/district level committee may issue the permits. The basic information required in the mining plan is given below which has to be prepared as per the guidelines of EIA Notification (2006).

- Location & Basic Information of the Mining Lease Area (quantities Haulage and Surface Transport Plan.
- Brief layout of mine working & layout mine faces.
- Demarcation of Mining Lease Area.
- Mining methodology (Should include tools and machinery used, energy requirement, water, manpower, waste [solid, liquid & air emissions].
- Yearly schedule of sand mining.
- Facilities and amenities for workers (Porta-cabins, toilets, fuel, health check-up as per Mines Rule 1955).
- Compensatory plantation and CSR activities.

Sustainable Sand Mining Management Guidelines, (2016) and Enforcement & Monitoring Guidelines for Sand Mining (2020) by MoEFCC are being followed for formulating this management and subsequent monitoring plan. Sustainable sand mining guidelines in India have been developed by the Ministry of Environment Forest and Climate Change (MoEFCC, 2016). The guidelines are based on the premise that sand extraction from rivers is required for construction, but it is also required for maintaining river health. The Guidelines recommend the following process be followed and included: identification of areas of deposition where mining can be allowed, identification of areas of erosion and proximity to infrastructural structures and installations where mining should be prohibited. Use of satellite imagery for identifying areas of sand deposit and quantity is done.

a) Calculation of annual rate of replenishment and allowing time for replenishment after mining in area.
b) Identifying ways of scientific and systematic mining.
c) Identifying measures for protection of environment and ecology.
d) Determining measures for protection of bank erosion.
e) A bench mark (BM) with respect to mean sea level (MSL) should be made essential to in mining channel reaches (MCR). Below which no mining shall be allowed.
f) Identifying steps for conservation of mineral.
g) Permanent gauging facilities (for discharge and sediment both) should be made compulsory for the sites having excessive mining in consultation with Central Water Commission or any competent State Agency.
h) Implementing safeguards for checking illegal and indiscrete mining.

Sand extraction from riverbanks and river channels areas causes local disruptions which can be anticipated and prevented through appropriate studies. After various environmental problems of river sand mining in various physiographic zones, an EIA was carried out to suggest appropriate Environmental Management Plan (EMP) for regulating the mining activities on a sustainable basis. The river environments in all the three physiographic zones such as highlands, midlands and lowlands are deteriorated drastically due to illicit scooping of sand even from prohibited areas close to bridges and water intake structures. Hence, an attempt has been made to analyse the environmental impacts caused by river sand mining to identify and address the key environmental issues that results in from the activity. The main intention of the effort is to mitigate the negative impacts and enhance the positive ones.

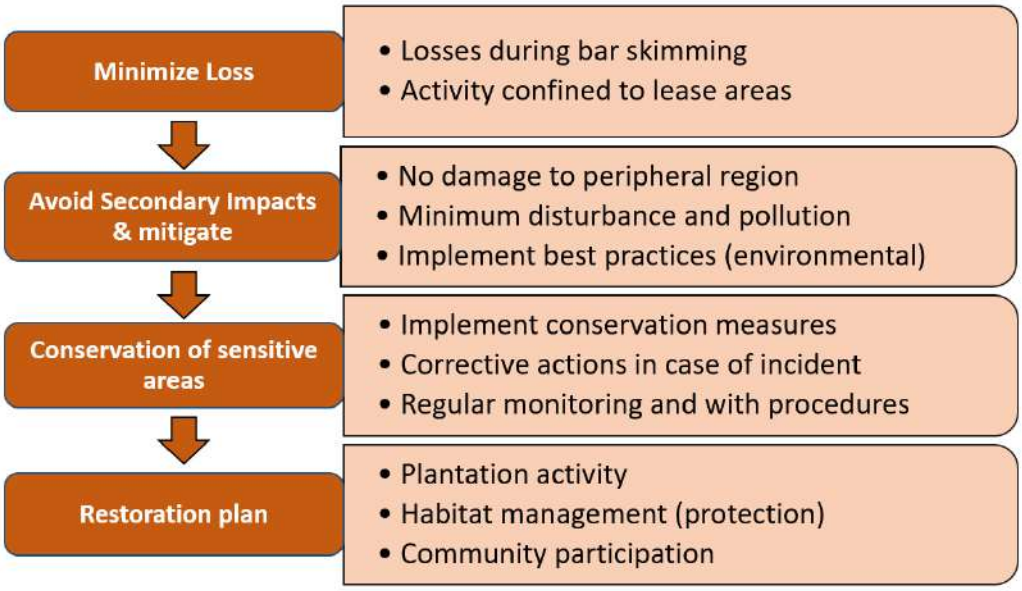


Figure 8.1: Schematic diagram of management of sand mining

8.4 Strategy for the management plan

Following requirements are suggested for defining a mechanism for monitoring of mining activities which will help in identification of mining which is operating either illegally or are violating the regulatory provisions. All precaution shall be taken to ensure that the water stream flows unhindered and process of natural river meandering doesn't get affected due to mining activity. Stretches shall be identified for species of significant importance in the river ecosystem. Such stretch with adequate buffer should be declared as no-mining zone and no mining shall be permitted. The regulatory authority as defined for granting Environmental Clearance, while considering the application of issuance of ToR and/or EC for the adjacent block (to non-mining zone) of mining shall take due precaution and impose requisite conditions to safeguard the interest of such species of importance.

District administration shall provide detailed information on its website about the sand mines in its district for public information, with an objective to extend all information in public domain so that the citizens are aware of the mining activities and can also report to the district administration on any deviation observed. Appropriate feedback and its redressal mechanism shall also be made operational. The details shall include, but not limited to, lease area, geo-coordinates of lease area and mineable area, transport routes, permitted capacity, regulatory conditions for operation including mining, environmental and social commitments etc. (Figure 8.1).

8.5 Management plans

a) River bed mining recommendations

Permit mining volume based on measured annual replenishment in the first year following adoption of the management plan, a volume equal to the estimated annual replenishment could be extracted from the reach of channel. Replenishment (up to the elevation of the selected channel configuration) would need to occur before subsequent extraction could take place. The concept of annual replenishment accounts for the episodic nature of sediment transport. For example, during wet periods with high stream flows, and a high contribution of sediment from hill slopes and tributaries, monitoring data would show that sand and gravel bars are replenished quickly. During drought periods with low stream flow, and little sediment supply or transport, monitoring data would likely show that bars were replenished at a slower rate.

The use of monitoring data is essential in measuring when actual replenishment occurs. The use of the concept of annual replenishment protects long-term channel stability as well as aquatic and riparian habitat by extracting a volume sustainable by watershed processes.

b) Establish an absolute elevation below which no extraction may occur (minimum enveloped level or redline)

The absolute elevation below which no mining could occur or "redline" would be surveyed on a site-specific basis in order to avoid impacts to structures such as bridges and to avoid vegetation impacts associated with down-cutting due to excessive removal of sediment. An extraction site can be determined after setting the deposition level at 1 m above natural channel thalweg elevation, as determined by the survey approved by mine plan approving authority.

c) Limit river bed extraction methods to bar skimming

If mining is limited to the downstream end of the bar with a riparian buffer on both the channel and hill slope (or floodplain) side, bar skimming would minimise impacts. Other methods such as excavation of trenches or pools in the low flow channel lower the local base level, and maximizes upstream (head cutting and incision) and downstream (widening and braiding) impacts.

d) Extraction of sand/ gravel from the downstream portion of the bar

Retaining the upstream one to two thirds of the bar and riparian vegetation while excavating from the downstream one to two third of the bar is accepted as a method to promote channel stability and protect the narrow width of the low flow channel necessary for aquatic life. Sand and gravel would be re-deposited in the excavated downstream one to two thirds of the bar (or downstream of the widest point of the bar) where an eddy would form during sediment transporting flows. In contrast, if excavation occurs on the entire bar after removing existing riparian vegetation, there is a greater potential for widening and braiding of the low flow channel.

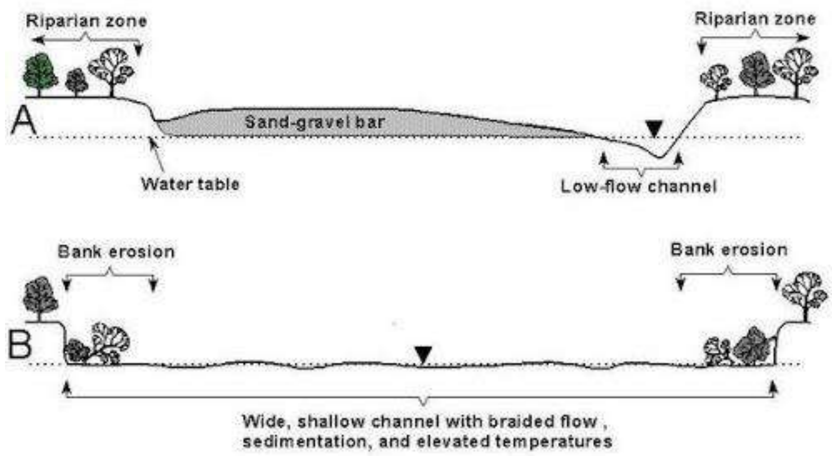


Figure 8.2: A typical sand-gravel bar in relation to the low-flow channel, riparian zone and water table, and (B) the wide shallow channel that results from unrestricted mining and that is characterized by bank erosion, braided flow, sedimentation, and increased water temperatures. (Source: http://threeissues.sdsu.edu/three_issues_sandminingfacts01.html)

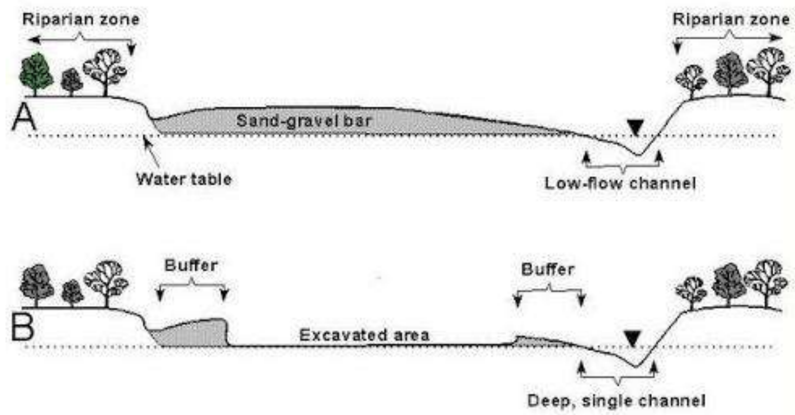


Figure 8.3: Diagram of channel cross sections showing (A)- A typical sand-gravel bar in relation to the low-flow channel, riparian zone and water table, and (B) the protected deep, single channel and channel banks when mining is restricted within a buffer of designated width and above the water table. (Source: http://threeissues.sdsu.edu/three_issues_sandminingfacts01.html)

e) Concentrate activities to minimise disturbance

River bed extraction activities should be concentrated or localised to a few bars rather than spread out over many bars. This localisation of extraction will minimise the area of disturbance of upstream and downstream effects. Skimming decreases habitat and species diversity – these effects should not be expanded over a large portion of the area.

f) Review cumulative effects of sand and gravel extraction

The cumulative impact of all mining proposals should be reviewed on an annual basis to determine if cumulative riverine effects or effects to the estuary are likely.

g) Maintain flood capacity

Flood capacity in the river should be maintained in areas where there are significant flood hazards to existing structures or infrastructure.

h) Establish a long-term monitoring program

Monitoring of changes in bed elevation and channel morphology, and aquatic and riparian habitat upstream and downstream of the extraction would identify any impacts of sand and gravel extraction to biological resources. Long-term data collected over a period of decades as sand and gravel extraction will provide data to be used in determining trends.

i) Minimise activities that release fine sediment to the river

No washing, crushing, screening, stockpiling, or plant operations should occur at or below the stream’s average high-water elevation, or the dominant discharge. These and similar activities have the potential to release fine sediments into the stream, providing habitat conditions harmful to local fish.

j) Retain vegetation buffer at edge of water and against river bank

Riparian vegetation performs several functions essential to the proper maintenance of geomorphic and biological processes in rivers. It shields river banks and bars from erosion. Additionally, riparian vegetation, including roots and downed trees, serves as cover for fish, provides food source, works as a filter against sediment inputs, and aids in nutrient cycling. More broadly, the riparian zone is necessary to the integrity of the ecosystem providing habitat for invertebrates, birds and other wildlife.

k) Seasonal ban in sand mining

The River bed mining should only be allowed during the dry season. No River bed mining should be permitted during rainy season.

l) An annual status and trends report

This report should review permitted extraction quantities in light of results of the monitoring program, or as improved estimates of replenishment become available. The report should document changes in bed elevation, channel morphology, and aquatic and riparian habitat. The report should also include a record of extraction volumes permitted, and excavation location. Finally, recommendations for reclamation, if needed should be documented.

m) Prevention and management of illegal mining

Prevention and mitigation to illegal mining can be achieved through close monitoring, cancellation of mining license of violators, imposing heavy penalties including long-term jail for mining on sensitive areas, and confiscation of mining machinery and vehicles. Department of Mines, law and order authorities need to restrict some areas for example, riverbanks, near schools, clinics, or residential areas. Only miners with licenses should be allowed into mining areas and stop illegal miners through tight security; additionally, 24x7 security to be employed to apprehend illegal miners daily. Night surveillance by night-vision drones may be employed to control illegal mining incidents. The committees formed to guard and monitor mining should control and restrict the number of truckloads per day. The districts/state sharing the boundary shall constitute the combined task force for monitoring of mined materials, mining activity.

n) Management of infrastructure

Temporary access roads or Katcha roads shall be formed between the banks of the river and the mining area with locally available bio-degradable materials such as sugarcane waste, hay, etc. The preliminary works such as the construction of temporary sheds, bio-toilets, drilling of bore wells, waste management facilities need to be developed before mining operations. CCTV cameras need to be installed at the entry and exit points. Cameras may be installed at all quarries/depots to monitor illegality if any is taking place. All such points should have 24X7 CCTV coverage of the footage of which should be made available to the district administration. The entry/exit points should have boom barriers which will record the vehicles entering and exiting the plot to reduce unrecorded dispatch.

o) Management of pollution

Proper entry and exit points for the movement of loading vehicles in and out of the sand mining sites shall be carefully located, taking into consideration the habitations/settlements in the area. Construction of separate gravel roads for tipper trucks to reduce traffic congestion, accidents, as well as noise and air pollution, maybe consider. All the vehicles should be serviced regularly to fulfil the existing legal framework to minimize noise and air pollution. The transportation route so selected should be verified by the Goa Government for its carrying capacity. Movement of heavy vehicles from public roads to pit sand, gravel, and river sand collection points need access roads. To prevent air pollution due to the dust during sand mining operations and safeguard the workforce in the sand mining and depot site, constant water sprinkling on the pathways and dust prone areas may be conducted. The sand loaded vehicles are to be covered with a tarpaulin before moving out of the quarries/depots. Plantation needs to be done with the consultation of the state forest department beside the sand transportation road to curtail the dust pollution.

The air and water quality may be checked periodically to ensure that no pollution is caused due to sand quarrying operations. Safety gadgets such as earplugs, goggles, respiratory devices, luminescent vests may be provided to the workers at the sand quarry site. First aid kit with all essentials shall be kept ready at all quarry/depot site, in case of any emergency. Independent labour camp and environmental and its need to be carried out at least once in a year for each mining site by reputed third party entity and report of such audit be placed in the public domain.

8.6 Development of green belts and Nursery

This helps in prevention of dust and screening noise, maintaining ecological balance, increasing aesthetic value, plantation to be carried out on both sides of the roads/river, saplings will be planted with recommended interval. Channel erosion often occurs on riverbanks with no or minimum vegetation cover; hence, plantation is prerequisite to improvement of river banks.

- Development of nursery can help in providing sapling for the region. It is recommended to cultivate nursery (for grasses, palms and other native tree including mangrove species) that are helpful in river bank protection and erosion control.
- A plantation plan developed by a plant ecologist familiar with the flora of the river for areas (in consultation with the Forest Dept.).
- River bank should be stabilized by means of compaction and then planting with vegetation.

- Any access routes without vegetation, especially if they are not beneficial to the local community should be ploughed and replanted with native species.
- Plantation along the riverbanks with no or minimal vegetation need to be conducted, irrespective of signs of erosion or not (ensure that species selected are indigenous).

8.7 Mangrove management and conservation

In Zuari, the mangroves are well represented in the middle and lower stretches of the river. Most of the mangroves are well grown and there has been a steady growth in the mangrove cover along this river.

There is no requirement of mangrove plantation in the study area but management of the existing mangrove vegetation is essential. The areas which are intruded by saline water need protection and the mudflats need to be maintained. Areas with newly recruited mangrove saplings can be blocked by restricting the tidal influx so that land use change can be avoided (from paddy fields to mangrove).

8.8 Embankment protection and restoration

This river is traditionally managed by construction of embankments so that floodplain can be used for paddy cultivation. The region is also represented by coconut plantation. Embankments have been constructed mostly by mud, silt and soil with protection of laterite bricks/boulders as lining between the estuarine river and land. Regular maintenance of embankments is an essential activity and failure to maintain results in saline water intrusion towards the landward side and turns the paddy fields into saline marshy areas rendering them uncultivable fallow lands.

- One saline surge can destroy the paddy fields and render them fallow lands as well as it can damage the houses; thus, it is imperative to protect the riverbank sensitivities constantly. In recent times there are few stretches of the river where construction of concrete embankments is completed.
- The areas adjacent to the river with paddy field and villages/ houses will require safeguarding from saline intrusion and flooding. Bunds have to be made with traditional means and should ensure maintenance. The authorities may also consider new methods that are innovative and sustainable for protection of bunds, restrict erosion and arrest saline intrusion.

- The vulnerable (soft sediment bank walls of the river) areas should be protected and no sand extraction shall be permissible in these regions.
- Provision of funds for maintaining embankments is essential.

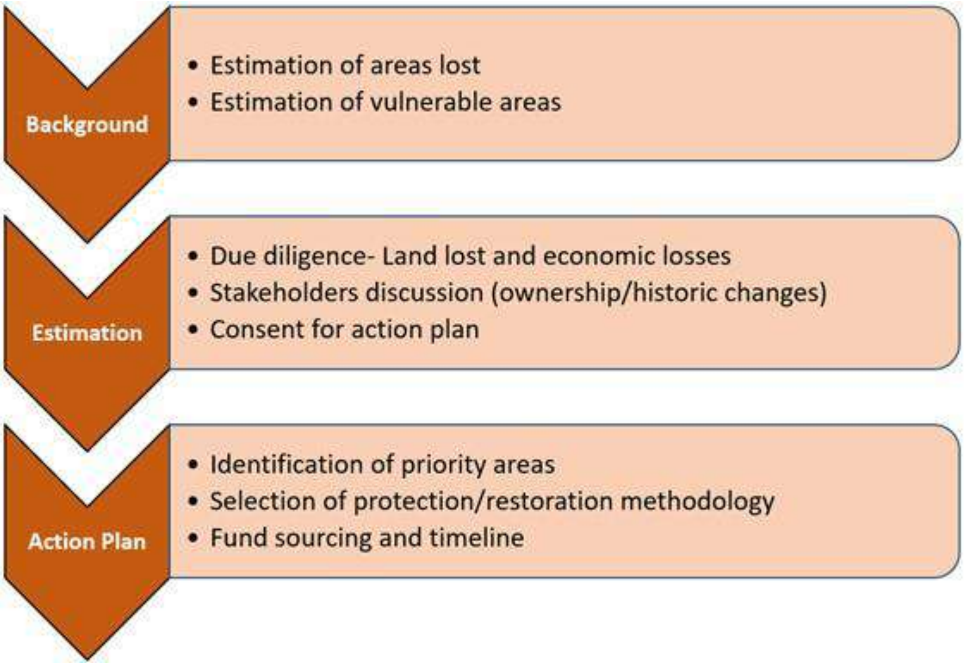


Figure 8.4: Schematic diagram of river bank protection and restoration plan

8.9 Biodiversity conservation & management plan

Several habitats in the study area are important habitats for several species of conservation importance. It is important to protect not only the species but the resources and habitats on which they are dependent. No doubt the proposed activities are deleterious to the ecosystem, no matter how sustainable we make it. Thus, to compensate the negative impacts, proactive conservation efforts have to be undertaken to minimize the impacts and to further enhance biodiversity, improve conservation and add ecosystem services.

Being an area of edible natural resources, necessary protection should be provided to promote the traditional fishing by public consultations and if necessary, through environmental protections.

Objectives

- To minimize direct and indirect disturbance to marine flora and fauna other than within the immediate works areas.

- To ensure turbid plumes from the works and re-suspension of material from the disposal site do not impact the long-term ecological values and integrity of the adjacent benthic assemblages and important faunal groups.
- To reduce the impacts to the intertidal sensitive habitats to the maximum extent possible.

8.9.1 Conservation plan for fauna

The estuarine region is a known habitat (based on secondary information) for Otters, Crocodiles, and Dolphins. Crocodiles are found near the mangrove forests and inland marshy areas. The otters inhabit the mangrove areas and frequent the river banks and sub-tidal estuarine waters for foraging. These species require minimal human disturbance therefore they thrive well if given protection and their habitat is well conserved. Several birds visit the river and adjoining habitats for foraging as well as nesting. There are few species that are long distant migrants (especially waders) as well as local migrants. Mangroves and banks of the rivers are used as nesting sites by several species.

Following measures have to be followed to ensure the conservation of marine fauna and their habitat:

- An on-site expert (observer) to be deployed for periodic monitoring of the important species in the entire stretch of the river which is being carried out in the region and the same activity can be extended to the proposed areas
- Vessel movement has to be regulated. Vessel movement has to be immediately halted at the sighting of any marine mammals/reptile in the active working zone. The excavation of sand as well has to halt until the animal leaves the area.
- Management of marine litter, garbage and plastic is one of the important aspects with respect to each active mining zone.
- Noise levels, air pollution and sewage discharge have to be kept at minimum and have to be within limits as prescribed by laws.
- Capture, trade or killing of any scheduled species has to be reported and accordingly non-conformance action has to be initiated by the team/committee.

8.9.2 Conservation & natural resource utilization

The estuarine region and river bed harbour important benthic faunal and floral diversity. In order to conserve these habitats, they are needed to be monitored regularly as they are dynamic habitat and are constantly exposed to anthropogenic pressures. Hence proper management plan for solid waste and oil pollution is needed to be followed and precautionary measures for any incident should be in place. The hard substratum within the study area is good for the growth of green mussel (*P. viridis*) and oyster (*Crassostrea madrasensis* and *C. gigas*). Shellfish in the study area are exploited due to its high price as a food source. Due to frequent localized extraction, and no scope of growth, shellfish size has decreased over the years and at many places, there population has been replaced by other species. Restoration and sustainable use of such species helps in good ecological and economic gains. Several species of clams of commercial importance occur in the study area. These clams mostly inhabit the mudflats/sandflats and preferably collected during the low tide. Species of *Paphia malabarica, Paphia textile, Meretrix meretrix, Meretrix casta, Villorita ceprenoides, Anadra* sp. and *Polymesoda erosa* are found in the mudflats, sand flats and mangrove sediments in the study area. These species have shown a drastic reduction in the population and their revival is very important. The team/committee appointed for this plan can further carry out these activities and should make village level teams for monitoring and implementation of all the activities. Following practices have to be followed for sustainable utilization of these resources:

- Harvest of the natural population requires regulation and regular restoration. It is necessary to block certain areas as no harvest zone, so as to ensure their population to replenish. Integrated sustainable aquaculture as given below (sub-sections of this plan) is to be implemented to harvest and rejuvenate these ecologically and economically important species.
- Quota system should be implemented by each village so that depletion of natural stock can be avoided.
- Cleaning programs, by participatory approach for sustainable resource utilization from mudflats, rocky shore is essential.
- There should be size restriction for each species wherein, care should be taken to harvest natural populations so that they attained reproductive size.
- The empty shells after extraction of edible flesh should be placed back in the same habitat as they serve as recruitment substratum for new spat. The cues from the dead shells attract larvae for settlement that aids in avoiding succession for establishment of another species as well.

- Conservation of habitat for the above mentioned commercially important species will also aid in conserving other species that are not commercially important but are ecologically very vital for sustenance of healthy and functional ecosystem.

8.9.3 Community participation

The existing mangrove management strategy is a combination of conservation through statutory compliance, community awareness and sustainable utilisation of natural resources through cooperative management. In 1952, Government of India (GoI) formulated National Forest Policy, which classified Indian forests into four classes, viz. i) Protected forests, ii) National forests, iii) Village forests and iv) Tree lands. Forest Conservation Act of 1980 encourages reasonable use of natural forest resources while National Forest Policy of 1988 invites community participation for the regeneration and management of forest through Joint Forest Management (JFM) program. This gives rights to local inhabitants to exploit forest resources to some extent like collection of fuel wood, fodder, fish, shrimp, honey and wax and thus provided mutual benefit to community and forest department. Presently, almost all mangrove habitats of India enjoy legal protection under Wildlife Protection Act of 1972 and Forest Conservation Act of 1980. Gadgil (2002) lists the following 6 factors as important considerations in a participatory assessment program;

- Motivating local people to revive and build on their traditional conservation practices;
- Establishing a positive relationship between local communities and government agencies;
- Identifying and establishing a system of positive incentives for local communities to adopt conservation management;
- Enhancing elements of good governance such as efficiency, participation and transparency;
- Incorporating local information into the formal system of scientific knowledge so as to make it richer and more immediately relevant; and
- Ensuring that folk knowledge of conservation management and sustainable resource use is preserved and at the same time giving recognition to the validity of such knowledge.

Based on the above concepts it is imperative to carry out the conservation, restoration and monitoring with community participation. Local village committee/ Biodiversity Management Committees (BMC are already formed by GSBB) to carry out the responsibilities of the restoration and conservation plan. These committees adhere to the people's biodiversity register (PBRs) and can form self-help groups (SHGs). A technical team of experts is usually attached for the smooth working and guidance from subject experts. These procedures will help to develop responsibility and equitable sharing of resources as well as conservation of the area (Goa State Biodiversity Board [GSBB] carries out these responsibilities regularly for the entire state).

Below mentioned techniques and methods are can be mostly financed by several existing governmental schemes. There are several schemes which provide training, start- up grant and technical guidance to carry out sustainable integrated fishery and cultivation. The schemes are fully or partially funded, wherein the role of technical team and experts is important to bridge the gap between the involved stakeholders. The financial support in case of a prerequisite can be taken up by the respective project proponent as part of their CSR.

8.10 Floodplain management (saline marshlands)

The areas with saline intrusion have been converted to saline marshlands followed by mangroves and many areas are at different stages of progression towards these habitats. If these areas are unattended, not maintained or taken care off, will be ultimately succeeded by mangroves. Once mangroves are established, the spread to adjoining areas is usual as they tend to accumulate more sediment and concurrently the embankments are penetrated by salinity due to natural deterioration of embankments. There are various reasons for the deterioration of embankments such as sea level rise, high tide surges, other extreme events and floods. Overall, over the time to come, if protection by embankments is penetrated by saline water more floodplain areas will be dominated by salinity.

Considering the present status of this river and the adjoining land use in the floodplain areas there is already intrusion of salinity, and it is important to manage these areas. Restoration of bunds should be undertaken on priority basis along with management and maintenance of sluice gates. Following activities are proposed for sustainable use of existing lands;

- There are developed varieties of saline resistant rice species. Such species can be recommended for cultivation in areas of saline intrusion.
- Various state level schemes and subsidies are available for carrying out the paddy cultivation which can be tapped via the committee members of this plan.
- Traditionally, paddy cultivation has been a community activity and the same can be extended to manage the saline marshland and its cultivation.

- Village level SHGs, BMCs, Farmer's group can be formed/ a sub-committee including members of concern state government officials and technical expertise as well for the smooth running of the schemes.

These areas which do not have mangroves can be utilized for sustainable aquaculture practices.

8.11 Development of sustainable integrated aquaculture

Several options are suitable for the rivers in Goa which have estuarine region with mangroves and mudflats, thus the suggestions given below are added after consultation with State Fisheries Dept., Goa and ICAR, Old Goa.

Integrated aquaculture is a technique of sustainable aquaculture which includes raising fish with combination of rice, pigs, and ducks as well as poultry which helps in rising family income. Since animal waste make good fertilizer it can save upto approximately 60 percent of the cost of fish farming which goes for feed. This technique includes different types of farming: paddy cum fish farming, composite culture and polyculture. Several species are available that give good economic gains and if a compatible mix species culture can be carried it reduces the risk of losses. The team for the plan can suggest the combination of species and the methods accordingly considering the site, locations, area, tidal regime, physico-chemical parameters and economics.

The important estuarine fish species caught are *Mugil cephalus, Johnieops* sp., *Sardinella* sp., *Secutor* sp., *Leiognathus* sp., *Parastromateus niger, Pampus chinensis, Pampus argenteus, Rastrelliger karagurata, Stolophorus indicus, Chirocentrus dorab, Opisthopterus tardoore, Lutjanus campechanus, Etroplus suratensis, Lates calcarifer, Polydactylus plebeius, Scomberomorus commerson, Scomberomorus guttatus, Arius* sp., *Cynoglossus arel, Penaeus monodon, Fenneropenaeus merguensi, Metapenaeus affinis, Metapenaeus dobsonii, Scylla serrata, Portunus pelagicus, Charybdis feriatus, Loligoduvauceli, Villorita cyprinoides, Polymesoda erosa, Meretrix meretrix, Meretrix casta, Paphia malabarica, Paphia textilis, Crassostrea madrasensis, Crassostrea gigas.*

From the available statistics, the approximate fish production from the east coast and west coast estuaries are 30,000 and 20,000 tonnes respectively. However, there is always a scope revising, reclassifying, and adding the estuarine systems in order to formulate an estuarine monitoring network along the Indian coast. Therefore, we would be able to understand the major gaps in the fisheries data of estuaries, which would enable us to focus on these ecosystems to explore its diversity, fish biomass and landing patterns.

Development of shrimp farming from a traditional activity to a highly commercial farming enterprise in a span of about one decade has been one of the most spectacular achievements of aquaculture in India. The government of India enacted the Coastal Aquaculture Authority Act, 2005, enabling the establishment of the Coastal Aquaculture Authority for enforcing proper regulatory measures for sustainable eco-friendly aquaculture. The Act encompasses all forms of aquaculture to be practiced in saline or brackish water in the coastal areas.

The brackish water aquaculture can also further go ahead with the means of diversification of species used in the farming practices. Seabass, *Lates calcarifer* is a fast growing, high valued carnivorous fish ideal for Indian conditions. The technologies are available for seed production and grow out culture. However, the demand for seed needs to be met through the development of more hatcheries along the coastal states. The total area under seabass farming is 2500 ha with a total production of 5000 tonnes. At present 30, 000 farmers are employed in this farming practice and project a huge potential for the future. The other candidate species for the brackishwater aquaculture are Milkfish (*Chanos chanos*), Pearlspot (*Etroplus suratensis*), Mud crab (*Scylla serrata*), and Grey mullet (*Mugil cephalus*), Red snapper (*Lutjanus argentimaculatus*), and Silver pompano (*Trachinotus blochii*) etc.

Apart from the species diversification, the diversification of aquaculture systems is essential to provide access to a large number of farmers to support their livelihood through brackish water aquaculture. Cage culture of finfish in brackish waters provides a great opportunity for farmers with access to open waters to adopt aquaculture as a livelihood option. However, the availability of the quality seed and feed are the major hurdles that need to be addressed through indigenous seed production systems to address the demand.

Goa state encompasses huge potential for fishery activities with a coastline of 105 km, continental shelf area of 10 million ha, estuarine area of 13,157 ha (covering 8 estuaries), brackishwater area of 3500 ha, Khazan land of 18,000 ha, 555 km length of rivers, 100 ha freshwater ponds, 3250 ha of reservoirs and mine reject pits of 200 ha. The fish production of state currently stands as 1.05 lakh tonnes of which 1 lakh comes from marine and 5000 comes from inland fisheries (95% from estuarine and brackishwater resources). On the other hand, inland fish production is gradually decreasing and there is ample scope for coastal aquaculture for further improvement in production on account of greater demand. The estuarine area of Goa is not utilised for development of coastal aquaculture. There are several culture systems that can be practiced in the estuaries of Goa, which has higher productivity and abundant natural seed resources. The government of Goa has introduced various schemes to encourage development of aquaculture in the state (Table 8.1).

Table 8.1: Schemes for aquaculture in Goa (Source: Fishery department)

1.	Financial Assistance to Brackish Water Aquaculture Pond	A. Financial Assistance for Construction and Renovation of Farms 25% subsidy limited to Rs.2.00 lakh per ha of which Rs.45, 000/- per ha will be the Central Share. Up to 2 ha after 5 years. B. Financial Assistance for purchase of farming equipments: 50% subsidy limited to Rs.1.00 lakh per ha. Up to 2 ha after 5 years. C. Financial Assistance for purchase of feed: 25% subsidy of the cost of feed limited to Rs. 30000/- per crop per ha for 2 crops in a yr. Eligible every year.
2.	Financial Assistance for setting up of Crab farming Unit in Goa	A. Financial Assistance for setting up of the crab culture unit: 25% of the actually cost limited to Rs.1,50,000/- per ha. Farmer will be eligible to 2 ha. B. Financial Assistance for purchase of seed and feed: 50% of the actual cost limited to Rs.75, 000/- ha. Limited to 2ha per yr.
3.	Financial Assistance to Freshwater Aquaculture farm	A. Financial Assistance for Construction and Renovation of Farm: 25% subsidy limited to Rs. 2.00Lakh per ha. Eligible every after 5 yr. B. Financial Assistance for purchase of seed and feed:

		25% subsidy limited to Rs.50,000/- per ha. Limited to 2 ha. Eligible on seed and feed once in every year. C. <u>Financial Assistance for purchase of Farm Equipments:</u> 50% limited to Rs. 60,000/- per ha. Eligible after every 5 years.
4.	Financial Assistance to Mussel Culture and Oyster Farming in Goa	A. <u>Setting up of unit in estuarine waters:</u> 50% subsidy limited to Rs. 25,000 per unit, maximum for 2 units. Each unit in the estuarine water will be of size 4 mtrs X 4 mtrs. B. <u>Setting up of unit in open sea</u> 50% limited to Rs. 40,000 per unit, max for 2 units. Each unit in the open sea will be of size 6 mtrs X 6 mtrs.
5.	Financial Assistance for setting up of Ornamental Fish Unit in Goa	A. For setting up of Breeding unit-50% of the actual cost limited to Rs.1, 50,000/-. B. For setting up of Rearing unit-50% of the actual cost limited to Rs.1, 50,000/-. C. For setting up of Rearing unit and Breeding unit-50% of the actual cost limited to Rs.2,50,000/-.

Following are some of the known aquaculture species that are well suitable for considering as small-scale business model.

8.11.1. Paddy cum fish farming (freshwater)

This system explained here produces mix species of fishes with paddy. Process of culture starts from growing two crops of paddy; the one which is tall variety and the other is high yielding variety in wet season and dry season respectively with single crop of fish. In freshwater, Rohu (*Labeo rohita*), Catla (*Catla catla*), Mrigal (*Cirrhinus cirrhosis*), and fast-growing species like Silver carp (*Hypophthalmichthys molitrix*), Grass carp (*Ctenopharyngodon idella*) and Common carp (*Cyprinu scarpio*) were used as pelagic, mid pelagic and benthic fishes. Prawns also grow well on paddy fish culture plots. Optimum stocking density that is usually practiced in case of carps is 6,000- 20,000 number of seeds per hectare.

Selection of site: Water holding capacity of selected plot should be good enough. Clay-loamy soils are suitable for paddy- fish culture. Low laying area with high rainfall is suitable for culture. Either side of the central line dug deep to act as main supply or drain canal. Each plot is bordered with bundhs with 0.3m height and 0.3m width. Dike or bundh is provided by inlet and outlet made up of bamboo shoots. These are placed in the middle and fitted with screens to avoid entry of predators as well as escape of cultured fishes.

Culture of paddy-fish together: Generally, this technique is practiced in moderate or low paddy fields where water source exists for 4-5 months naturally. Carps or other fishes like Tilapia are cultivated along with the rice.

Fish culture after harvesting rice: In this technique, fishes ate stoked after the harvesting of rice crops. This will provide 6-7 months of rearing fishes.

9.11.2. Oyster culture

Some Oysters are edible and its culture is widely practicing in India. Four species are commercially cultivated in India. They are**:** *Crassostrea madrasensis***,** *Crassostrea gryphoides***,** *Crassostrea rivularis and Saccostrea cuculata.*

Site selection: Site must have good water quality, open sea from strong wave action and salinity range should be 25-31 ppt. Avoid sites prone to toxic algal bloom.

Seed production: Seed requirement for culture is met either from wild or from hatcheries.

Spat fall prediction: Gonadal maturity stage helps in spat fall prediction. When 70% of female are with ripe gonad spat collectors used to collect the spat. If they are placed much earlier or after the spat, fall they get silted or fouled and make them unsuitable for spat settlement.

Intensive culture: Containerized production of oysters is referred in intensive culture. Containerized production includes floats, bags, rafts, long line system, racks etc. for predator protection. This system has to face impacts from storms, fouling organisms etc. Therefore, selection of site should be based on water quality, wave action and predation level. This type of culture is more expensive as it requires more labour for gear and product maintenance.

Extensive culture: This culture refers to spat on shell or clutched production. Oyster larvae from hatchery are set on clean oyster shell and planted directly on the bottom and grow out in clusters.

This method is not expensive as the other one but in this methods mortality, rates are higher as there is very less maintenance.

Feeding: Oysters feed on algae especially *Isochrysisgalbana* and *Chaetocero s*sp.

Farming methods: Seed oysters could be grown either on bottom or off bottom culture methods. Rate of production depends on culture methods. Bottom should be firm and free from predators and silting. There are different types of culture methods: Rack and Tray Method, Stake Method and Rack and String Method.

Rack and tray method: The young oysters are scrapped from the tiles and transferred to box type cages and covered with synthetic twine. After two months of rearing by suspending cages from racks, the grown oysters are transferred to rectangular trays. 20 trays each of 200 oysters are reared on rack and at the end of the year oysters attain length from 78mm-105mm. The approximate production rate in this method of culture is 120t/ha/year.

Stake method: Stake is a support used to keep spat on spat collector above bottom. It may be Casuarina or eucalyptus pole of 1.50m. To protect spat from predation pole can be covered with piece of fabric. Production rate may be 20t/ha/year.

Rack and string method: A string can hold six shells valves holding 80-100 spats and the strings are enclosed in a bag. These suspended from racks should keep in calm and good water movement site. After 2 months of rearing the bags are removed and the oysters are transferred to oyster farm. In this method the production rate is 80t/ha/year.

Threats: Pest and predators can cause considerable damage. Common predators are barnacles, serpulids, anemones, sponges and gastropods.

Harvesting: Harvesting season depends on spawning season which is March-April and August-September. Harvested oysters go through depuration which is cleaning and reducing the bacterial load on shellfish and shucking which is the process of removing meat from depurated oysters. Meats of the oysters are edible and shells are used in spar settling and manufacturing of calcium, lime etc.

8.11.3. Mussel culture

India has a long history of mussel farming that dates back to the 13^{th} century. They are considered as popularly eaten and delicious food by the people of West Cost. The main producers are India, China, Korea, Spain, France, New Zealand and Netherlands. Three different types of mussels are cultivated in India. They are: *Perna viridis* (Blue green mussel), *Mytilus edulis* (Blue mussel), *Modiolus metacalfie* (Brown mussel).

Site selection: Estuarine areas which are free from strong wave actions may be selected. Clear water with high plankton production is ideal for mussels. Depth of culture should be 2m and salinity should be 30-35 ppt. and should be free from industrial pollution.

Seed collection: Healthy seeds from natural habitat are collected. Seeds are healthier if they are from submerged tidal area. Size of the seed should be 20-25mm. Nylon rope or coir rope is used for seeding. Cotton cloth or cheap net is used to cover seeds on the rope. After placing the rope over the seed, the net is tightly stitched in such a way that seeds spread uniformly around the rope.

Culture methods: There are 3 main types of culture methods in mussels.

A. Deep Water Culture
   - Raft Culture
   - Long Line Culture

B. Intertidal and Shallow Water Culture
   - Rack Culture
     - Hanging Method
     - Stake Method
     - Tray Method
     - Buochot Method
     - Wigwarm Method

C. Bottom Culture

Raft culture: The depth of the site may vary from 5-10m and rafts measured 5×5m or 8×8m. Teakwood, Casuarina and bamboo shoots are used to make poles in raft construction. Empty oil drums are used as floats. Seeds of 2.6-2.8mm length are seeded on coir or rope. Depending on the depth length of the rope varies. Ropes are spaced 0.6-1m apart. Average growth rate is 9-11mm/month and can be harvest in 5-6 months. Production rate in this type of culture is high.

Long line culture: Long lines are long ropes anchored at each end supported by plastic barrels. Depth may be 10-15m. It can withstand severe climatic conditions. The rope is 60 m long with 20-24m thickness anchored at both the ends with 150kg concrete and barrels are fixed at 3m intervals. A long line unit of 60×60m rope can accommodate 12 horizontal ropes and 900-1000 seeded ropes. The production rate was 15.32kg/net bag/5 months.

Rack culture: Fixed structures are constructed ain the waters at the depth of 3 m. Bamboo or *Casurina* pole are driven at the bottom at 1-2m interval. Wooden frame built on ropes used to suspend seeded bags. Once the mussel seeds are placed the netting is wrapped and both the ends are stitched with cotton twines. In about six months' mussels reach around 65-77m length. The production rate is approximately 33.5kg/net bag/5 months.

Hanging method: Nylon ropes are threaded with coco fibres supported by empty oyster shells to collect spat. Piece of stone is attached at the end of the rope to prevent surface floating.

Stake method: Bamboo pole of 4-6 m length are staked at the bottom at the depth of 3 m. collected spats are allowed to grow for 6 months until they reach marketable size. Around 2000-3000 seeds are attached to 1 m stake below low water level.

Tray culture: Tray culture is limited to detached clusters of mussels. Bamboo or metal trays are used. They are either hang between pole of hanging or stake methods.

Bouchot culture: They are also called Pole Culture. Poles which are used are big branches of oak tree around 4-6 m which are staked 0.7m apart on soft, muddy bottom of intertidal zones. Mussel seeds are collected on coco fibers and are attached to oak branches in spiral fashion until they grow marketable size. Production was 14kg/pole of 15.7mm average length mussels.

Bottom culture: This method is widely practiced all over the world. Mussels are grown directly on the bottom. Firm bottom is required with adequate tidal flow with silt deposition and provide sufficient oxygen. If the natural ground is unsatisfactory then those seeds can be transferred to private farming ground. Natural conditions control quality and quantity of food as well as water flow. This type of culture requires minimum investment however it is prone to heavy predation such as oyster drills, crabs, starfish etc.

Harvesting: Harvesting takes place after 6 months and meats as well as shells are used in various fields.

8.11.4. Clam culture

Clams, as a general term, can be used to describe any bivalve mollusc species which buries itself in the sediment. There are numerous commercially important clam species which are cultivated in India. Some of the species are given below: *Villorita cyprinoides, Paphia malabarica, Meritrix casta, Anadara granosa* etc.

Site selection: Intertidal and sub-littoral locations are best. They are buried in the substrate. Their survival is better in sand or gravel substrates but it is possible to grow them in muddy areas too. Salinity should generally be above 25 ‰.

Cultural techniques: Their stocking density should be approximately 400 to 500 seed at 8mm shell length. Manual methods can be used for small-scale cultivation but mechanisation is needed for laying mesh and harvesting as scale of production is increased. Seed are available from commercial hatcheries at a range of sizes from 4 to 30 mm shell length. Clams are usually grown in plots under lengths of netting to protect them from predators. The edges of the netting should be buried in the substrate down to 10 cm and kept in place with rope stapled round the edges with metal hooks every 0.5 m pushed through the mesh into the substrate. It will be necessary to change the netting at least once during culture period increasing the mesh size since the clams will take around 3 years to grow to a harvest size. Clams can also be grown in oyster bags sunk into the sand in rectangular plots and staked into place leaving about 2.5 cm protruding above the sand.

Harvesting: Harvesting takes place when they reach marketable size.

8.11.5. Seabass culture

Pond culture of Asian Seabass (*Lates carifer*) is one of the commercially important finfish. This variety is much-in-demand with huge export potential. Small and marginal farmers can adopt this method of culture as it is cost-effective manner. This is a euryhaline fish, growing rapidly up to 3-5 kg within a growing period of 2-3 years in both freshwater and brackish water environments. It is a voracious carnivorous fish; juveniles are omnivorous, feeding mainly on crustaceans and other small fishes. It attains maturity at the age of 3-4 years at a length and weight range of 60 to 70 cm and 2.5 to 4.0 kg respectively.

Nursery: The main purpose of the nursery is to culture the fry from hatchery to juvenile size. During nursing period, the juveniles can be graded into different size groups and stocked in separate grow-out ponds. Nursing the fry in concrete tanks is not recommended as accumulation of excess feed on the bottom of the tank cannot be avoided. Such accumulation can cause bacterial disease.

Nursery pond: Nursery Pond size ranges from 500 to 2000 m^2 and water depth should be 50–80 cm. The pond has separate inlet and outlet gates which facilitate water exchange. Pond bottom should be flat and sloping towards the drainage gate.

Stocking: Stocking of 1 kg fish biomass/m3 is recommended for a 100 tonne of water.

Culture methods:

- Cage Culture
- Traditional Culture

Cage Culture: Seabass culture can be done in more organized manner as a large-scale activity in cages. The size of the cage may be 50 m (5 x 5 x 2 m) with mesh size depending upon the size of the fish to be stocked. In cage culture, both floating and stationary net cages are used.

Traditional culture: In ponds, juveniles of various sizes collected from estuarine areas are introduced and fed with the trash fishes like tilapia, shrimps and prawns. These ponds receive water from adjoining brackish water or freshwater canals or from monsoon flood. Harvesting is done after 6-8 months of culture. Production can go up to 2 ton/ha/7-8 months.

Pond culture: The two-week nursery reared fingerlings are ideal for pond culture. Pond can have concrete walls and a soft bottom with water depth of up to 2 m and salinity of 5-10 ppt. Seabass culture in ponds can be carried out either by monoculture or by polyculture method. Monoculture is that type of culture where a single species of animal is produced and Polyculture is method which involves incorporation of a species of forage fish with the main species in the pond. The choice of forage fish will depend on its ability to reproduce continuously in quantity sufficient to sustain the growth of seabass throughout the culture period. The forage fish must be such a species that could make use of natural food produced in the pond and does not compete with the main species in terms of feeding habit such as *Oreochromis mossambicus, Oreochromis niloticus* etc.

Pond preparation: The pond is at first dried, tilled, levelled and manured with raw cow dung @ 1000 kg/ha. If required, lime is added @ 50-200 kg/ha to maintain soil pH above 7. Sea water/fresh water is then filled to a depth of 60-70cm in the pond. When the pond water becomes light green in colour indicating sufficient development of algae in the pond, forage fishes are introduced.

Feeding: The fish feed methods have to be carried out as per the following. In the first method, the fish are fed exclusively with chopped trash fish and in the other; the food is made available in the pond in the form of forage fish like Tilapia **(***Oreochromis mossambi*cus**).** Pelletized feed can also be given.

Harvesting: Harvesting is done with the help of seine-netting the pond or by draining. After harvesting they are usually transported live in tanks by truck.

8.11.6. Shrimp culture

Shrimp is one of the most traded seafood commodities, and aquaculture of shrimp is considered to be one of the success stories of modern aquaculture. Shrimp farming generated millions of employments, and provides foreign exchange to developing countries. Modern practices with growth on scientific basis using hatchery produced seeds, formulated feeds water management methods have been initiated over the last 20 years. Although growth of shrimp aquaculture is remarkable, the sector has been facing several issues such as viral diseases, issues in marketing, and poor farm level performances. For optimum utilization of the resources and increased production, productivity and returns to the farmer, improvement in the existing technology is necessary. Such improvements should aim at the following:

a) Improved farm design – for operational ease

b) Optimum soil and water condition

c) Removal of pests and predators

d) Qualitative and quantitative aspects for stocking shrimp larvae

e) Supplementary feeding

f) Soil and water quality management

g) Monitoring of growth and health

h) Improved methods of harvesting post-harvest management

According to Brackish Water Fish Farmers Development Agencies (BFDA), the topography of Goa is ideally suited for prawn farming, as the seawater is regulated only on the basis of high and low tides and the flooding of water is almost negligible. The BFDA also claims that Goa has good tidal amplitude as well as spring-tides which facilitate natural flushing. Moreover, there are no turbulences or fast currents. Costal Aquaculture Authority (CAA) guidelines were formed to ensure orderly and sustainable development of shrimp aquaculture in the country. The guidelines are intended to lead to environmentally responsible and socially acceptable coastal aquaculture and also enhance the positive contributions that shrimp farming and other forms of aquaculture can make to socio-economic benefits, livelihood security and poverty alleviation in the coastal areas.

Stocking: The most suitable species for culture in India are the Indian white prawn *Penaeus indicus,* White leg shrimp *P. vannamei* and tiger prawn *P. monodon*. Apart from these candidate species other commercially important species such as *Metapenaeus ensis*, *M. monoceros*, *M. brevicornis*, *P. semisulcatus* and *P. merguiensis* are also potential species that can be grown in India.

Site selection

Selection for a suitable site is a critical activity and must be carefully determined before establishing of a shrimp farm. Site evaluation is not only undertaken to determine if a site is suitable for shrimp farming. It is also valuable in determining what modifications are needed concerning layout, engineering, and management practices to make shrimp farming possible at a given site. Factors involved during site selection are topography and climatic condition, infrastructure, accessibility, electricity, security, availability of labor and other factors, water supply, soilconditions. Besides these, the environmental and socio-economic aspects covering social, economic and legal issues are important parameters to be considered while finalizing the site for setting up a shrimp farm.

Pond design and construction: Shrimp Pond should be designed according to the characteristics of the selected site and the culture system. There is no unique design, but optimum and functional farm layout plan and design should be based on the physical and economic conditions prevailing in the locality.

Culture systems: There are three types of shrimp culture being practiced in most countries.

Traditional/extensive cultures: Extensive Freshwater Prawn Culture extensive culture means rearing in ponds (but also in other impoundments such as reservoirs, irrigation ponds and rice fields), which produce less than 500 kg/ha/yr of freshwater prawns. They are stocked, often from wild sources, with PL or juveniles at 1-4/m^2. There is no control of water quality; the growth or mortality of the prawns is not normally monitored; supplemental feeding is not normally supplied; and organic fertilisation is rarely applied.

Semi-intensive culture: Semi-intensive systems involve stocking PL or juvenile freshwater prawns (usually from hatcheries) at 4-20/m2 in ponds, and result in a range of productivity of more than 500 kg/ha/year and less than that defined as intensive in this box. Fertilisation is used and a balanced feed ration is supplied. Predators and competitors are controlled and water quality, prawn health and growth rate are monitored. This form of culture is the most common.

Intensive culture: The ponds are usually of 0.5-1 ha in size and are designed to keep the water at 1.5-2.0 m deep. A reservoir of at least 30 % of the pond area is usually required. High stocking density of 25-60 PL/m2 with feeding rate of 4-6 times daily and strong aeration is maintained.

Open system: This system requires a high supply of good quality water because it needs water, exchange of more than 20% of the total pond volume at one time, in order to reduce pond wastes and the density of the plankton. Seed can be stocked up to 60 PL/m2 and will grow to 25-35 grams within 120 days.

Re-circulation system: In order to avoid deterioration of the environmental conditions, several advanced and company run farms have adopted the re-circulation system to minimize contact with poor quality water from outside the farm. Farms must devote 40-50 % of the area for the construction of water storage/reservoir, sedimentation pond, and treatment pond and drainage canals. Stocking density for this system generally varies between 30-50 PL/m^2 and the culture period is between 110-130 days.

Minimal water exchange system: To reduce contact with the water from outside the farm, the minimal water exchange system or closed pond system is practiced in some countries, particularly in Thailand. The system involves filling up the pond with cleaned seawater, treating it with chemicals to eradicate predators and competitors. Then the shrimps are stocked up to 30 PL/m^2 and cultured for a period of less than 100 days to attain the average weight of 10-20 gm.

Ponds: Pond preparation is an essential part of culture practices during which the metabolite load and contaminants (chemical and biological) in the soil from the previous culture cycle is removed through tilling, ploughing and drying. During pond preparation, the pests and predators are removed and pH and nutrient levels in the water and soil are brought to optimal concentrations through application of lime, organic manures and inorganic fertilisers.

Water quality and its management: The quality of the water available in the site has a strong influence on the success of the shrimp farm. Water quality parameters like pH, salinity, dissolved oxygen (DO) and the presence of toxicants/ pollutants should be ascertained. The water source should be free from any industrial/ agricultural pollution. The presence of contaminants and their levels should be considered in the light of the tolerance and also sub-lethal effects on the species to be cultured.

Seed selection and stocking: Seed quality has a direct relationship with the survival and growth of the cultured shrimps and the stocking density has a strong bearing on the level of waste generated in the pond. Only healthy and pathogen-free seed from registered hatcheries should be used for stocking. Before stocking, seeds should be acclimatized to prevailing temperature, salinity and pH conditions in the pond by gradual mixing. In areas with very low salinity, salinity adjustments are to be made over a period of 4 –5 days and hence should be done at the hatchery itself.

Feed and feed management: Using good quality feed in reasonable quantities, water and soil quality in ponds remains in optimum conditions. This reduces stress on shrimp, there is less likelihood of disease, and they convert feed more efficiently to improve the feed conversion ratio and minimize feed costs.

Health management of shrimps: The health management approach includes reduced stocking of disease-free seed, better handling, maintenance of good pond environment, and optimal feed management to reduce the stress and prevent most infectious and non-infectious diseases. Disease should be diagnosed immediately with the help of trained pathologists/ microbiologists. Treatment should be undertaken only when a specific disease has been diagnosed and it is known that this disease is treatable.

Harvest and post-harvest: Successful harvesting can be achieved if the shrimp can be harvested in good condition within a short period of time. The harvesting technique should not damage or excessively contaminate the shrimp with waste. Rapid harvesting will reduce the risk of bacterial contamination and the shrimp will still be fresh when reaching the processor.

Methods of harvesting: Harvesting can be done by completely draining the pond either by gravity or through pumping and hand picking or trapping.

The water drained out for harvesting should be pumped into the waste stabilization ponds and kept for a few days for settlement before releasing into the open water. Icing should be done immediately after harvest.

8.11.7. Mud crab culture

Among the marine edible crustaceans, crabs are one of the most important shellfish by virtue of its delicacy, demand and price. Since 1987, live mud crabs (*Scylla* spp.) are exported to an extent of

1500 tons annually, valued at Rs. 30 crores. Most of the commercially important crabs belonged to the family Portunidae and they can be recognized by the presence of flattened last pair of legs, which help them in swimming in the columnar waters. Species belonging to genera *Scylla, Portunus* and *Charybdis* which grow to 0.2 to 2.3 kg are considered as commercially important portunid crabs as they are utilized for both local consumption and export trade.

Mud crabs stand first in the context of both capture and culture fisheries due to their larger size, great demand and higher price. Mud crab is one of the components in the traditional fish/shrimp farming system of Indian and Southeast Asian countries. Due to their great demand, monoculture of mud crabs is being practiced in most of the Southeast Asian countries. These mud crabs have a remarkable habit of remaining alive after capture for considerable time, say 5 to 8 days. There are only two species of mud crabs *Scylla serrata* and *Scylla tranquebarica* occurring in most of the Indian brackish water areas and inshore seas. They usually grow to a maximum size of 0.7 kg in case of *Scylla serrata.*

Though both the species co-exist in the same habitat, they differ in habits. The larger species remains buried under sand or mud. While the smaller species makes a deep burrow either at the bottom of estuary or in earthen bunds of canals/ponds. These differential habits make them more abundance in specified habitats. For example, the larger species is more abundant in the open inshore seas backwaters and coastal lakes, while the smaller species is more in number in mangrove areas.

The size-frequency studies indicated that male and female of mud crabs grew at rate of 9 and 10 mm in CW per month respectively. *Scylla serrata* attains a size of 0.7 kg. In an experimental field culture the early juvenile mud crabs (15 to 60 mm in CW (Carapace width)/3 to 20 g in total weight-TW) grew at a rate of 7 to 12 mm/3 to 13 g per month, while juvenile crabs (61 to 80 mm/25 to 70 g) exhibited a monthly growth of 1 to 12 mm/145 to 97 g. In the sub-adult and adult stages, the monthly growth worked out to 8 to 10 mm/100 to 130 g.

Mud-crab farming involves the following steps nursery rearing, soft-shell crab rearing, grow-out culture and fattening. Nursery rearing involves the rearing of megalopa (0.003 g)/crablets (0.03 g) to juveniles in two phases, namely, up to 3 g (in hapas) and 3 g to 25 g (in nursery ponds). Soft shell crab rearing includes the stocking of juvenile crabs (50 to 100 g of *S. serrata*) individually in small plastic cage till they moult. Grow-out culture refers to farming of nursery grown juveniles of about 25 g (seed crabs of *S. serrata*) for a period of 3-6 months to produce marketable size crabs. During this growth period, the crabs undergo several moults (shedding of old skeleton).

Fattening refers to the holding of marketable sized crabs for about 3 to 4 weeks' time, during which period, the stocked crabs gain weight. The live mud crab export from India has started in 1987-88 and exported mostly to south east Asian countries. The live crabs are packed in perforated carton boxes lined with thermocole sheets and air-lifted. In order to conserve and protect the natural stock from overexploitation and to meet the ever-increasing demand for local consumption and export trade, mud crab farming with hatchery produced seed will be the best option and as such collection of wild juvenile crab for farming/fattening needs to be discouraged.

In Goa due to low yields from salt-tolerant local varieties of paddy seeds like Korgutt and Azgo, Khazan fields in Goa are generally neglected by farmers. In order to provide farmers with alternative source of income, crab aquaculture can be taken up by these farmers. Goa has about 18,000 hectares of Khazan fields and there is huge opportunity for farmers to harness this to their benefit.

Site Selection: The mandatory guidelines enlisted for shrimp culture for the selection of sites for coastal farms should be strictly adhered to in the site selection for mud crab pond construction. In addition to the guide lines, there are other parameters should be addressed such as physiochemical condition, water quality, flow rate and temperature should be, appropriate for the species concerned. Other factors that must be considered for site selection are weather, shelter, depth and substrate.

Criteria for pen culture in mangrove areas: Mangrove areas should have sufficient supply of marine or brackish water throughout the year. Water depth at high tide should range between 0.3 to 1.0 m. Salinity should be ranging from 10 to 35 ppt and temperature between 25 and 30'C. The site must be free from big waves and pollution, protected from environmental hazards such as big waves and floods and secure from vandals and poachers.

Pond preparation: Pond preparation strategies generally employed in shrimp aquaculture can also be adopted in mud crab aquaculture. However, it is generally believed that meticulous and stringent pond preparation is not required. The installations like net fencing, earthen mounts should be considered. Pond should be drained and kept dry for 1 week to kill pests.

Nursery rearing: Nursery rearing in mud crabs is carried out in two stages as nursery phase - 1 and nursery phase - 2. During first phase, hatchery produced megalopa, which are very small in size are reared with maximum care to attain a size of about 3 g. These 3g sized crablets are further reared in second phase to attain a size of about 25 g.

Transport and stocking: Crab juveniles are relatively easy to transport by using cane basket, carton lined with moist sea weeds or mangrove leaves. Chelae are tied to prevent fighting among crabs. Stocking should be done with individuals having intact appendages, and without injury, further seeds should of uniform size. Different sizes leads to cannibalism. Stocking density has a major effect on crab growth, survival and production, and it is generally ranged between 0.5 and 3 crabs per square meter.

Nutrition and feeding: In grow out culture management, locally available cheap protein sources (trash fish, molluscs) at the rate of 8-10%W of biomass can be given. The crabs can be fed a mixed diet of 25% fish by catch (trash fish) and 75% fresh flesh of mollusc or crustacean.

Harvest and post-harvest: Culture period is generally 3 to 6 months and is dominated mainly by the size at stocking and the preference and demand, existing in the market. For *Scylla serrata*, culture duration will be 120 days with an initial size of 25 g and harvestable size of 200-300 g if the stocking density will be 1 crab per square meter. To obtain larger sizes (400-500 g), culture period can be extended to further 3 months. Partial harvest can be made with baited lift nets and bamboo cages. To have a total and complete harvest, crabs are to be handpicked after completely draining the culture pond. Crabs should be tied immediately after their capture in order to curb their movement and to avoid the fighting among them. The tied-up crabs are to be initially washed with fresh sea water and subsequently sent for local marketing after packing them in bamboo baskets.

8.11.8. Milkfish (*Chanos chanos*) culture

Semi-intensive pond farming of milkfish fingerlings of 7-15 cm size can be stocked @ 8000-10,000/ha and formulated grow-out feed can be applied. Periodical manuring can be done to facilitate the growth of phytoplankton, as food item for the cultured fish. In 5 to 8 months, this fish can attain 0.5 to 0.6 kg body weight and a production of 3 to 4 t ha-1 can be obtained. Milk fish can also be raised in cages and however, this method is not commonly adopted.

8.11.9. Pearlspot fish culture

Pearlspot, *Etroplus suratensis* (locally known as "Kalundar") is another important candidate species for culture in ponds, cages and tanks. Polyculture of pearlspot with other brackishwater fish species like milkfish, grey mullet or liza species is commonly practiced. Monoculture of pearl spot is commonly practiced in low volume cages. More recently, cage culture (2 to 4 m3 for 7 to 9 months) is commonly practiced by small scale farmers in estuarine waters and feeding can be carried out using locally prepared feed, agro waste and kitchen discards.

8.11.10. Grey Mullet (*Mugil cephalus*) culture

Grey mullet, *M. cephalus* (locally known as "shevto") can be culture in monoculture or polyculture with other brackish water species (Pearlspot and milk fish and other mullets such as like *Liza tade, L. parsia*) for about 8 months. Size of species stocked is more than 50 to 60 g, with a stocking density of 6000 to 8000 no. ha^{-1}. A total production of 2 to 3 t ha^{-1} can be expected from the system. Feeding is carried out by supplementary feeding and fertilisation of the pond.

8.11.11. Red snapperculture

Mangrove Red snapper (locally knows as "Tamso") can be cultured both in the pond and cages. Cage culture of *L. argentimaculatus* is being practiced in Karnataka and Maharashtra by stocking the wild collected seed in the cages/ponds either by monoculture or polyculture methods.

8.11.12. Ornamental fish culture

There are also some important ornamental fishes from the estuarine areas which can be promoted for domestic and international markets. Major species are silver-moony, *Monodactylus argenteus*, and orange chromide, *Etroplus maculatus*. At present, scarcity of seeds in adequate quantity is creating burden on the wild stock and increasing the price in the ornamental industry. Seed production technology is being standardised by various research institutes such ICAR-CIBA, that offer scope for development of the culture fisheries for these ornamental fish.

8.11.13. Seaweed farming

Seaweed is marine algal species that functions as renewable source of food, energy, bio-chemicals and medicines. It provides a valuable source of raw material for industries like health food, medicines, pharmaceuticals, textiles, fertilizers and animal feed. One of the most important uses of seaweed is for the production of agar, alginates & carrageenan. In India, currently sea weed farming is practiced in Mandapam, especially for the extraction of carrageenan and also to use as a bio-fertiliser. The cultivation of *Kappaphycus alvarezii* and other commercial seaweed are grown by the fishing community in Tamil Nadu specifically in Ramanathapuram, Thoothukudi, Pudukottai and Thanjavur region. Seaweed is grown in three different ways. One of the most popular in India is using the Single Rope Floating Raft (SRFR) method (Coir Rope & Nylon Rope). This involves building of tethered rafts and spreading them out in the sea. After around 45 days, the seaweed is harvested, dried and carrageenan is extracted from it. The second method is using a Fixed Bottom Long Line method (Coir Rope & Nylon Rope). And the third is the less practiced, and however, offer wide scope as a component of the Integrated Multi Trophic Aquaculture (IMTA) method. The input costs for sea weed farming are almost nil and from a single raft, the dried seaweed earns up to Rs. 86,000 annually.

8.11.14. Integrated Multi-Trophic Aquaculture (IMTA)

Coastal brackishwater systems face challenges of waste water management, which can be addressed through culture of species in multi-trophic levels a model Integrated Multi-Trophic Aquaculture can include combination of fish, seaweed and shellfish culture systems. Successful culture trials of Milkfish culture with other species like Shrimp (*P. monodon*), Tilapia (*Oreochromis niloticus*) and red seaweed (*Gracilaria* spp.) has been investigated and offer scope for the future prospects in this sector.

8.12. Development of eco-tourism

Ecotourism is now defined as "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education. Ecotourism is catering for holiday makers in the natural environment without damaging it or disturbing habitats. It is a form of tourism involving visiting fragile, pristine, and relatively undisturbed natural areas, intended as a low-impact and often small-scale alternative to standard commercial mass tourism. It means responsible travel to natural areas, conserving the environment, and improving the well-being of the local people. The origins of the term 'ecotourism' are not entirely clear, one of the first to use it appears to have been Hetzer (1965), who identified four pillars or principles of responsible tourism: minimizing environmental impacts, respecting host cultures, maximizing the benefits to local people, and maximizing tourist satisfaction. The major objectives of eco-tourism are as follows:

- Build environmental and cultural awareness and respect.
- Provide positive experiences for both visitors and hosts.
- Provide direct financial benefits for conservation.
- Generate financial benefits for both local people and private industry.
- Design, construct and operate low-impact facilities.
- Recognize the rights and spiritual beliefs of the native community and work in partnership with them to create empowerment.

Ecotourism in Goa: Goa is gifted with abundant natural beauty as it a part of the Western Ghats. Goa is rich with over 1512 documented species of plants, over 48 genera of animals, over 275 genera of birds, over 48 genera of animals and over 60 genera of reptiles along with very rich marine biodiversity.

The River Zuari has a good potential for development of ecotourism activities. These activities can not only help in employment generation it helps in the development of villages along the river.Small patches of beaches with diverse ecosystem include sandy, rocky beaches spread from Dona Paula to Siridao are considered as tourist spots Tourism activities such as crocodile Dundee and bird safari is established in Zuari estuary. Historic sites include Juve fort, Borim bridgewell-known tourist places such Sancoale, Rachol, Loutolim, Shiroda, etc. Water sports such as kayaking, river cruises in smaller boats. Nature trails can also be promoted. Recreational fishing and mangrove walks could be encouraged. Spice garden plantations and picnic spots can be developed. Cycling tourism, photography tourism, meditation and rejuvenation tourism, cultural tourism can also be developed.

The above tourism activities should employ people from the local communities, as it helps in the regions development. These activities should be sustainable and waste generation should be minimised by reuse, reduce and recycling materials. The government on its part to incentivize ecotourism should provide schemes and funding to interested people as well as training courses in various fields such as culture, language, management, identification of flora and fauna etc.

Guidelines to be adopted for sustainable ecotourism suggested by some experts specifically for Goa are as follows:

1. The management plan areas proposed for eco-tourism should be prepared through professional ecotourism experts and in consultation with the local community as well as other stakeholders.
2. To avoid conflicts, inclusive and integrated planning should be adopted.
3. The architectural programme for eco-tourism centers should include controlled access points and cabins, roads, self-guided nature trails. Transportation options, interpretive signs, observation towers, adequate but unpretentious lodging and dining facilities, water docks, garbage disposal facility etc.
4. Structures creating visual pollution, unaesthetic values and non-compatible architecture should be controlled.

5. Exclude development in geologically unstable zones and define development and buffer zones after proper environmental impact assessment. For example, on beaches Coastal Regulation Zone (CRZ) regulations must be followed.
6. Establish standards, building codes and other regulations.
7. Specify environmental, physical and social carrying capacities to limit development activities.
8. Ensure continuous monitoring of adverse effect of tourism activities and initiate suitable corrective measures.
9. Recognize and award quality labels to eco-tourism operators.
10. Provide visitor information and interpretation services covering particularly i) what to see ii) how to see iii) how to behave.
11. Prepare and widely distribute codes of conduct to all visitors.
12. Launch training programmes on eco-tourism to tourism administration planner's operators and general public.

8.13. Development of team and funds for the plan

For management, monitoring and smooth running of the entire plan which will be spread across the river-scape, a well-coordinated team is essential. As there are several activities involved pertaining to sand mining and environmental conservation it is imperative to have a multi-disciplinary team to undertaken activities as well as co-ordination between various stakeholders.

Stakes of all the interest groups is essential thus the team should have the representation of each group, community and related agencies, which also ensures discussion to reach consensus and transparency. This generic structure allows freedom to each of the bodies to discuss within themselves as well as with other bodies and decide the responsible team member. Given below is the structure of the team to be appointed after a consultative meeting (Figure 8.5).

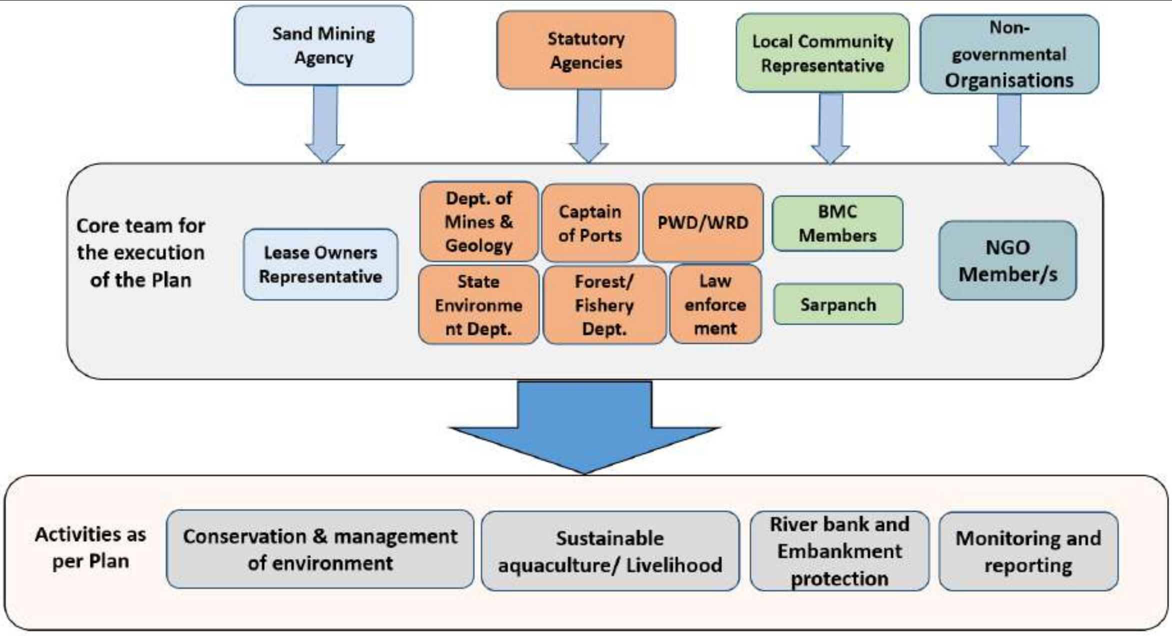


Figure 8.5. Schematic diagram depicts execution of management plan

8.13.1. Funds for the plan

A mechanism has to be formulated to impose minimum burden on the government for mitigating the impacts. Considering this perspective, as per the guideline provided by MoEFCC, the funds to carry out the activities to mitigate the impacts of sand mining, environmental safeguard and restoration need to be acquired from the lease holding agencies. A share of proportionate amount has to be assigned to carry out the aforementioned activities of the plan as part of CSR/CER.

Funds also have to be deviated towards sustainable aquaculture practices and eco-tourism, for which initial seed money can be provided from a corpus fund to bind with government schemes and subsidies. At the initial stage the interest group can also contribute for the small-scale businesses in which they would like to participate.

8.13.2 Role and responsibility of the team

The plan gives freedom to discuss and decide the roles and responsibilities of each of the member as well as the rights to the team to appoint additional team members as felt necessary. Following are the responsibilities of the team:

- Monitor all the sand mining lease holder’s activities and compliances.
- Carry out conservation activities and promote eco-tourism.

- As the expanse of the river spans across many villages with changing land use and activities, the team may appoint sub-teams to properly execute each activity. The sub-teams can be made or committees can be formed or SHGs can be formulated depending on the interests of the stakeholders and interest groups.
- Implement, supervise, monitor and take corrective actions for sustainable livelihood schemes as deemed fit considering the environmental conditions, available land, local expertise and willingness.
- The team has to monitor the activities of the sub-teams or the groups formed and weigh the achievement of work undertaken, suggest corrective measures and way forward for undertaken activity or projects.
- The team members (representatives of statutory agencies) shall help the activities by extending the available schemes and subsidies to the required stakeholders so as to support environmental conservation, sustainability and livelihood.
- Instruct actions to stop any environmental degradation (eg: tree cutting, garbage dumping, species decline/loss, embankment damage, saline intrusion etc).
- Carry out training for capacity building and to promote sustainable livelihood practices.
- The team is required to maintain all the records, handle complaints, incident and con-conformance and keep its record.

8.13.3 Corrective action/contingency plan

Any unlawful activity or failure to meet the performance criteria shall be recorded as a non-conformance incident and be reported. In the event of any incident, the team has to take immediate actions, document the incident, and report it to statutory authorities. This has to be followed by remedial actions as directed by the Dept. of Mine and Geology and Environment Department (eg: GSPCB/GSBB).

8.13.4 Documentation and record keeping

Efficient and accurate record-keeping is essential for the application of a plan. Following necessary aspects are to be considered for record keeping and documentation-the DPR & Management plan, list of important areas (in terms mine lease, ecological sensitivities etc.) and details of priority areas for action. According to the size of the lease and areas/expanse of each lease area, the team needs to formulate and document a manual for their own working which shall include: critical limit determination, analysis, procedures -e.g. standard operating procedures, corrective action procedure, work instructions, monitoring activities, deviations and associated corrective actions, verification procedures performed, modification to the plan, training undertaken, periodic records, visual inspection reports, team meeting records, processing records.

8.13.5 Complaint handling procedures

Every complaint is different but the steps for dealing with them should be the same. As well as having a complaint policy, comes under best practices which will have a procedure handling protocol prepared by the team. A complaint handling procedure ensures complaints are dealt with the same way every time (Fig 8.8).

8.13.6 Incident and non-conformance reporting

Non-Conformance report which is work done without approval of any concerned documents/not related to the standards (Construction Standards/Contract specification). Especially some works are not followed by the standards and specifications. Non-conformance report shows the exact possible error due to not following or deviate the procedure, while corrective action shows that, how the process or method will follow the right procedure. There is a formalized way of reporting environmental incidents i.e. uncontrolled events that have or could have had an impact on the environment, such as chemical/ oil spills; contamination of land, flora or fauna; damage to listed structures/building/embankments etc.

The objectives of the procedure are to:

- Ensure all relevant contractors are made aware of environmental incidents/ violation of lease granted and its handling procedure. Complaints can be forwarded to the appointed committee or to the office of Mamlatdar/ Dy. Collector/ Police.The complaint can be given manually or by electronic means to be devised by the committee.
- Ensure site workers and stakeholders understand the immediate environmental incident reporting requirements.
- Ensure all concerned stakeholders understand reporting timeframes, including statutory requirements.
- Ensure incidents are reported to enable monitoring, sharing of lessons learnt and response to emerging environmental incident trends.
- Comply with statutory obligations to report certain environmental incidents to regulators and other relevant government agencies for further action.

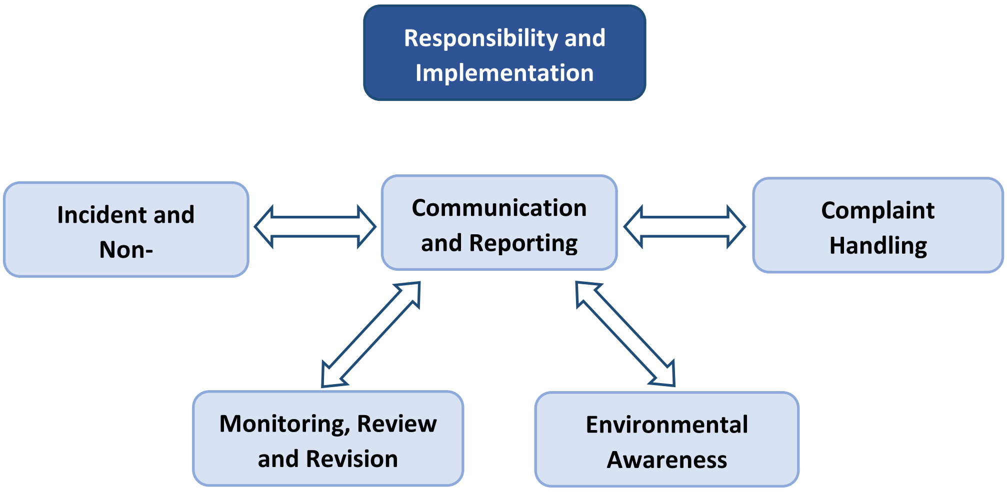


Figure 8.6. Schematic diagram of development and functioning of team

9.13.7 Attempts to deal with the illegal trade (WWF, 2018)

The Directorate of Mines & Geology, the Costal Police, the Captain of Ports and the District Magistrate, North Goa, shall ensure maintenance of regular vigil in the area. As suggested by Honourable NGT, CCTV camera installation is essential at important location that have been leased as well as other critical areas vulnerable for mining need to be monitored. Wherever the monitoring shows that the guidelines and legality is not followed or violated, actions shall be taken as directed by the Honourable NGT order date 12/12/2019 (No: 28/2015 (WZ)).

Numerous approaches have been adopted by District, State and the Central Government to attempt to curb the illegal mining and the associated environmental, ecological and social impacts, including:

- Development of sustainable sand mining guidelines. The guidelines provide detailed information and recommendations on how to extract sand sustainably, but they are non-binding.
- Completion of sediment audits to identify sustainable sediment extraction limits. This approach was applied to Kerala in 2015 and resulted in the banning of sand mining from six rivers with severe restrictions placed on others.

The establishment of a complaint cell to receive and investigate complaints regarding sand mining. Legal authorities have been instructed to conduct raids, seize vehicles that engage in the illegal activity and take custody of illegally mined sand for subsequent sale at government rates, and to provide armed police to provide protection for revenue squads (Jha, 2013).9.13.8 Alternatives to river sand mining (WWF, 2018)

Alternatives sources to river sand have been identified and adopted by most western countries, and similar shifts in developing countries could reduce pressure on the resource. However, without improved governance changing the primary sources of construction materials is difficult as alternatives are likely to cost more due to additional handling, processing and transport costs. Any increase in the cost of 'legal' sand as compared to illegally derived river sand drive an increase in illegal activities. Alternative sources and substitutes for sand in concrete is an area of active research. A literature review found the following examples.

8.13.8 Recycling of concrete for use as road bases (Smith, 2018)

Development of bacteria and fungi that can produce calcium carbonate can be used to repair existing concrete structures, increasing their lifespan. This may be particularly useful when applied to the huge highway systems of the world that are requiring repair or replacement (Smith, 2018). Replacement of sand with other materials should focus on the recycling of waste materials. It is notable that a web search of this topic returned many recent articles by Indian researchers, all of which highlight the need to identify replacement materials to diminish sand mining and its related environmental impacts. Examples (not all from India) include:

- Backfilling of mining voids using fly ash composites in place of river sand in India due to a decrease in the availability of river sand. Finding an alternative use for fly ash is also desirable as it would reduce landfill (Mishra &Karanamk, 2006).
    - Use of walnut shell and PET-fibres as a replacement for aggregate in lightweight shotcrete suitable for roadway or mine supports (Cheng, et al., 2017).
    - Use of fly ash and polypropylene or steel fibers to produce high quality concrete (Raut&Deo, 2017).
    - Use of rubber tyres and copper slag as aggregate in concrete (Blessen, et al., 2012).
    - Replacing aggregate with recycled concrete sand in masonry and mortar design for indoor use (Fernandex-Ledesma et al., 2016).
    - The use of residual materials such as kaolinitic waste, sewage sludge, schist fines and wasted glass to create light weight granules suitable for light concretes, road engineering and waste water treatment (Kanari et al., 2016).

- The use of crushed oil palm shell as a replacement for aggregated in concrete. Investigations have found that replacement rates of between 50% and 75% can be used to produce a lightweight concrete for use in non-load bearing structures, and structural concrete can be created at replacement rates of about 25% (Muthusamy et al., 2013).
- The replacement of river sand with manufactured (crushed) sand. Manufactured sand is a by-product of the production of coarse aggregate and has historically been used for road bases and land fill. Replacement of river sand with manufactured sand at a rate of 75% was found to produce concrete with properties suitable for use as high-performance concrete (Prasanna et al., 2017).
- Replacement of river sand with crushed waste stone, dust and polish slurry generated by the production of dimension stone (stone quarried and cut to specific sizes or shapes, e.g., ornamental stone). Replacement of 100% of river sand in concrete by 85% stone waste and 15% slurry waste resulted in a very high-quality concrete product (Rana et al., 2017).
- Use of iron-ore tailings to replace sand in concrete. The inclusion of the tailings reduced the workability of concrete, but all other strength modulus of elasticity data was consistently higher than conventional replacement at all levels of replacement (25% to 100%). The use of tailings is recommended to minimise environmental problems, cost and natural resource depletion (Shettima et al., 2016). Note, this approach would not be suitable for tailings containing sulfides.

CHAPTER 9: ENVIRONMENTAL MONITORING PLAN

Environmental monitoring program includes periodic analysis of air, soil, noise and water, flora and fauna. Environmental monitoring should be conducted on regular basis to assess the pollution level in the mining lease area as well in the surrounding areas. Therefore, regular monitoring program of the environmental parameters is essential to take into account the changes in the environment.

Mining of sand and all the activities listed out in the conservation and management plan require periodic monitoring. Considering the activities and the monitoring results the team may decide to suggest additional management strategies to be implemented as appropriate. Competent outsourced certified organization/laboratory (eg: GSPCB) should be appointed to conduct the monitoring parameters wherever there are samples involved.

9.1 Mining activity monitoring

1. Daily quantity of sand to be extracted from each lease should be based on the quantity given in the permit/ EC conditions.
2. De-casting from river beds should be monitored on a regular basis to keep a track of excavated quantity.
3. Every year, a mandatory audit of the quantity extracted and quantity permitted along with the replenishment rate should be carried out.
4. Depth should be up to 3.0m from the existing riverbed level and not less than one meter from the water level of the river channel.
5. Peizometer and eco-sounder (for depth measurement) should be used by each lease holder and daily records of these measurements should be made available to the monitoring team.
6. Monitoring team should ensure that sand mining activity in Monsoon season and during night time is not carried out.

9.2. Sand Transport Monitoring

1. Mandatory e-pass/ e-permit should be made available at each lease area for transportation of any sand by an GPS enabled vehicle with the provision of entering the vehicle number of the vehicle carrying sand and expected delivery address and customer name/ mobile number.

2. Documents should be made available for stockyards/ stockiest of sand. In the case of nomination based (controlled pricing) business model, the margin of private stockiest should be capped over a fixed percentage of notified prices.

3. At the stockyard, the stock supervisor should verify the authenticity of payment receipt before issuing the transit pass. The loading of sand should be monitored electronically and all transporting vehicles should pass through an electronically monitored weighbridge.

4. To make transportation monitoring effective and useful, all the sand carrying vehicles (tractors/ trucks) should be registered with the department and GPS equipment should be installed in all the sand carrying vehicles.

5. There shall be one entry and exit point provided for trucks/vehicles. The said entry point should have facilities as mentioned above. In case, it is necessary to have more than one entry/exit points, all such points shall have checkpoints with facilities as mentioned above. All other possible ways of entry/exit should be closed using barriers like compound, trench, etc. All provisions shall be made to not make it possible for any vehicle to enter or exit without entry into the computerized system.

6. The Project proponent has to enter the destination, distance between plot and destination, vehicle number etc in the system. After scanning, unique bar code number, invoice date time and validity date-time are generated by the software which gets printed individually on each TP Validity of TP is calculated based on the distance between plot and destination. After validity time is over the TP stands invalid.

7. Weighbridges with CCTV should be installed at all the stockyards, active reaches to ascertain the exact quantity of sand being transported in the vehicle. Check posts with CCTV cameras should be established near all major consumption centers to check if all the transporting vehicles are carrying a valid transport permit.

8. The transport permit generated should contain advanced security features so that one permit cannot be re-used by generating photocopies of the permit.

9. It is necessary to prevent any truck/vehicle from transporting sand out of the identified plot bypassing the strong IT enabled system. Therefore, at each of the sand plot, the following additional measures should be taken.

10. All such points should have 24X7 CCTV coverage; the footage should be made available online to the district administration. In cases, where sufficient internet bandwidth is not

available, it may be deposited with the district administration on a weekly basis. If possible, the entry/exit points should have boom barriers which will record the vehicles entering and exiting the plot.

9.3 Surveillance & monitoring

11. Constantly monitor mining with drones and if possible, night surveillance of mining activity through night- vision drones.

12. Project Proponent must ensure that CCTV camera, Personal Computer (PC) or laptop, Internet Connection, Power Back up, access control of mine lease site; and arrangement for weight or approximation of weight of mined out material on basis of volume of the trailer of vehicle used at mine lease site are made available for monitoring.

13. Even after all the regulatory procedure and policy being in place, there are instances where illegal mining is taking place. The monitoring agencies can monitor the sites remotely by using Unmanned Artificial Vehicles (UAVs)/Drone which are now a viable option. The drone can also be used for reserves estimation, quantity estimation, land use monitoring. Other options for the monitoring team may also be made available for possible use of IT/Satellite/Drone technology for effective monitoring of sand mining.
14. The officials involved in monitoring should be provided with mobile application and/or bar code scanners using which the TP can be checked anywhere on road. As soon as the bar or QR code on TP gets scanned through using the mobile application and/or scanner or vehicle number is entered into the application or sent by SMS to a predefined number, all details of TP such as plot details, vehicle details, validity time, etc. should be fetched from the server. This means if anything is re-written on TP and attempt is made to reuse the same, it can be traced immediately. Various reports can be generated using the system showing daily lifting reports and user performance report. This way the vehicles carrying sand can be tracked from source to destination.

15. The facility to fetch details using mobile app, website and SMS may be made available to the general public as well. If the citizen finds that the vehicle doesn't have such a permit, as ascertained from mobile app or website or SMS, he should alert local authorities, who shall then take further action as per the law.

16. Land contamination (by diesel, oil etc.) due to movement of site vehicles: Vendors of state pollution control board will be contracted for collection of hazardous waste (used oil) & oil spill kit will be provided with each vehicle used for transport. Monitoring team will ensure

the log books are updated and accordingly check any signs of violation, accidents, spillage etc.

17. Monitoring wells should be established adjacent to each excavation area to record changes in ground water levels. Measurements should be taken monthly. This should help analyse surface water and ground water interaction around the lease area as well as for monitor the salinity intrusion into freshwater bodies.
18. River mining from outside shall not affect rivers; no mining shall be permitted in an area up to a width of 25m from the active edge of embankments.
19. A monitoring report should review permitted extraction quantities in light of results of the monitoring program, or as improved estimates of replenishment becomes available. The report should document changes in bed elevation, channel morphology, and aquatic and riparian habitat. The report should also include a record of extraction volumes permitted, and excavation location. Finally, recommendations for reclamation, if needed should be documented.
20. Sand mining has to be monitored as per The Mines Act 1952 and The Mines and Mineral (development and Regulation) Act 1957, Mines Act 1952, Mines rules 1955, Mineral Concession Rule 1960, Mineral Conservation and Development Rules 1988.

9.4. Air quality Monitoring

As per the EIA Notification (2006) and subsequent amendments, Air Environment is one of the pollution sources from mining sector which needs to be categorically addressed. Measuring and understanding air pollution provides a sound scientific basis for its management and control. If concentration of pollutant is higher than threshold limit values are observed, the source of fugitive emissions will be identified and necessary measures will be taken. If the levels are high, suitable measures as detailed in Environment Management Plan will be taken. The criteria for pollutants measured are Particulate Matter 10 (PM_{10}), Particulate Matter 2.5 ($PM_{2.5}$), Sulphur dioxide (SO_2), Oxides of Nitrogen (NOx), and Carbon Monoxide (CO) concentration in downwind direction considering predominant wind direction, at the source and a distance of 500 meters from the following dust generating sources shall be measured. Air pollution has to be monitored as per Air (Prevention and Control of Pollution) Act (and subsequent amendments) 1981. The air pollution impacts from the present baseline activities are of low nature as the sand extraction is from water therefore minimum dust emission. Hence emission from transportation and fugitive emission are to be taken care off using best practices in the industry.

9.5. Water Quality monitoring plan

Enforcing environmental monitoring plan is the responsibility of the assigned team and the major objective is to follow the best practices and legislative provisions for the prevention of environmental degradation. Thus, the main actions would be:

- Pooling and communicate the results of the environmental monitoring.
- Proposing mitigation measures based on the results of the monitoring.
- Introducing environmental education programme among the workers and the villagers.

Mines can affect surface runoff and groundwater quality through contamination with dissolved and suspended materials. Mines can de-water groundwater aquifers some distance from shafts or open pits, which can make nearby wells or groundwater bores run dry or saline. Monitoring should inspect the water against the release of chemically or radiologically contaminated water. The sample collection, procedures for sample preservation and methods of analysis are followed as per Standard Methods. Monitoring of water samples will be done at a frequency of once in each season as per CPCB Guidelines for waste water: and Ground water (BIS-10500:2012). Water quality has to be monitored as per the law of Water (Prevention and Control of Pollution) Act (and subsequent amendments) 1974 and the water (Prevention and Control of Pollution) Rules 1975, Cess Act 1977 & Cess Rules 1978.GSPCB carries out regular monitoring of river water quality, same can be extended to the proposed stretches of the river with added parameters to fulfil the legality.

9.6. Solid waste management

Solid waste management is one of the most acute environment issues. Site clearance and tidiness is very much needed to have less visual impact of mining. Dumping of waste shall be done in earmarked places as approved in Mining Plan. Thus, team/operator can monitor the bin and waste receptacles at the site, storage, segregation and its lawful disposal to a registered vendor. Monitoring has to be carried for each lease area and area of operation follows the Solid Waste Management Rules 2016. Monitoring team should ensure a record/log will be maintained for general and regulated waste disposal. The log shall record the type of waste, and the point and date of disposal.

9.7. Marine Environmental Monitoring

Water quality monitoring is an important aspect which needs to be monitored. A water quality monitoring system is required to signal, control or predict changes or trends of changes in the quality of a particular water body, so that curative or preventive measures can be taken to restore and maintain ecological balance in the water body. Project team should collect water parameters to check the physico-chemical parameters. Along with the parameters, the project team has to collect sediment sample to check the benthic faunal diversity. The monitoring has to be done as per The Environment (Protection) Act, 1986 and EIA Notification (and amendments) 2006.

Water quality is the main cause for the damage to marine environment and can be monitored by conducting training / awareness programs once a year for all the relevant staff/stakeholders.

The project teams also have to identify floral diversity like native and invasive species along the estuarine and riparian region of the estuary. The station locations identified in the baseline are to be monitored every six months (covering pre- and post- monsoon season) as given in Table 9.1.

Table 9.1: Water quality monitoring parameters and schedule

Sr. No	Cluster	Parameters measured	Locations	Operation Phase
1	Sea Water	Temperature, Salinity, DO, BOD, OC, Nutrients	15 locations	Once every six months
2	Sediment	Texture, Grain Size, OC	15 locations	Once every six months
3	Plankton & Benthos	Phytoplankton, Zooplankton, Meio & Macro- fauna	15 locations	Once every six months
4	Flora & Mega fauna	Seaweeds, Marine mammals, reptiles & avifauna	Identified habitats in the study area	Once every six months
5	Sensitive habitats	Mudflats, Mangroves, Sand flats and Rocky shores	Identified habitats in the study area	Once every six months

6	Fisheries	Benthic & Demersal fish species & intertidal shellfish.	One bottom trawl & intertidal survey	Once every Six months

9.8 Embankment management and protection

Embankments are the oldest known forms of flood protection works and have been used extensively for this purpose. They serve to prevent inundation, when the stream spills over its natural section, and safeguard lands, villages and other properties against damages. The embankment needs to be monitored as per the Environment (Protection) Act, 1986, CRZ notification, 2019.

- These embankments should be monitored on monthly basis and care must be taken to ensure the proper condition of the embankments. Damaged during the mining activity may leave many riparian zones vulnerable as they are known to protect from floods and soil erosion.
- Other areas should be monitored where there is no protection and it requires embankment construction.
- Saline intrusion in the adjoining areas should be monitored.
- Any repair work and construction of embankments should be monitored are recorded in site visit reports.

9.9 Monitoring of conservation plans

Conservation of ecosystem is the most neglected aspect of any developmental project or mining activity as such. The present area is rich in biodiversity and requires serious conservation efforts. Otters, crocodiles, turtles play an important role in maintaining riverine ecosystem. As this ecosystem provide promising habitat for these species but it might be a difficult task for their survival because of sand mining, iron ore mining, dynamite fishing etc. Construction along the banks of river like embankments, check dams cause negative impact on their habitat. Cutting and loping of trees along the banks, should be also be monitored. Mass public awareness campaign should be undertaken to educate people, especially fishermen inhabiting closer to estuarine habitats about the ecological role of the important species and their habitats which ultimately provides goods and services to the human society. All the aspects given in the conservation have to monitor to note the status of species, their habitat and actions to be taken for their improvement and enhancement. Conservation of the ecosystem has to be monitored as per Wild Life Protection Act, 1972, Forest (Conservation) Act 1980.

9.10 Monitoring of Plantation Plan

Mining activities will not cause any harm to riparian vegetation cover as the working will not extend beyond the offset left against the banks. Plantation should be followed along the bank of river and along road sides of approach roads. While selecting plant species preference will be given for planting native species of the area and shall have soil binding capacity. The state forest department will supply saplings to surrounding villagers for green belt development in their villages and encourage the plantation by means of social forestry. Green belt development as per the scheduled plan will be reviewed every year plantation records will be maintained for period of plantation, area under plantation, length of avenue plantation, type of species density of planted area and survival rate. Monitoring of Plantation needs to be monitored as per Environment (Protection) Act, 1986.

- The implementation for development of green belt will be of paramount importance as it will not only add up as an aesthetic feature, but also act as a pollution sink.
- The species to be grown in the area should be dust tolerant and fast-growing species so that permanent green belt is created.
- To stabilize the river bank erosion, the plants having good growth will be planted along the river bank.
- Apart from the green belt and aesthetic plantation for elimination fugitive of emission and noise control, all other plantation efforts shall be decided and executed with the assistance and co-operation of the local community.

9.11 Integrated Aquaculture and eco-tourism

The discharge of nutrients, sediment, BOD, bacteria, and pathogens into estuarine waters is one of the problems which impacts the aquaculture and to be covered by existing programs. Land based facilities can be regulated under the existing waste discharge laws and regulations. The impacts are site specific and controllable with any other source of water to estuaries.

- The site of the aquaculture should give more important to the conservation; such importance can be maintained by monitoring the norms to be followed as per national guidelines and best practices in aquaculture.
- Aquaculture farms should not pose a significant threat to the surrounding environment. The potential impact of the aquaculture must be understood and an accurate assessment made to monitor the water quality changes.

- The feed is a primary cause of direct and indirect pollution of water resources used for aquaculture. Therefore, the assessment of feeds should be considered as important practices and monitored frequently.
- Land based facilities can be regulated under the existing waste discharge laws and regulations. The impacts are site specific and controllable with any other source of water to estuaries. Potential problems exist where water quality standards either do not exist for some pollutants (eg: Nitrate or phosphate in estuarine waters).
- The eco-tourism activities planned and carried out should be monitored, for their impacts (negative and positive).
- It should be monitored that the native community gets maximum benefit from the eco-tourism schemes.
- It is to be monitored that the eco-tourism activities should be non-polluting and should be carried out using indigenous material.
- The number of tourist/foot fall should have a cap every season and the activities also should have upper limit considering the carrying capacity of the region/habitat/area.

RECOMMENDATIONS

Sand mining is one of the most sensitive subjects in India as well as other parts of the world. It has been the issue of social conflict, environmental sustainability and administrative issues. 'Sand Mining' has been one of the most revenue generating business as direct extraction of natural resources does not require much investment or skillset or raw material for production. It has to be considered as limited natural resource with a limited ability to be replenished over long duration. But the impacts of sand mining have been deleterious and sustainability of sand mining is always difficult. Being the most important commodity, sand is required for construction and thus the holistic development and urbanization.

The present status of the Zuari river has been detailed out in this report. Considering the on-going activities including sand mining, site sensitivities, national guidelines, international best practices and concerns as well as directions by Hon'ble NGT, following are the recommendations:

- Considering the results of the baseline, Zuari estuary has been influenced by cumulative anthropogenic activities and natural riverine and costal processes.
- Over the years, many pits and deep gorges are formed at many stretches of the river/estuary.
- The lower stretches of the estuary are influenced by higher salinity regime thus the adjacent banks have been protected by traditional embankments. These embankments allow the locals to carry out agriculture- predominantly paddy. These traditional embankments consistently face the problem of saline water intrusion and require continuous repair and maintenance. There are several reasons for the damage of embankments viz; high tidal surges, subsidence of land, removal of sand/sediment from the river bed, non-maintenance of embankments and flooding due to rainfall and upstream water flow.
- The salinity intrusion has also changed the land use, converting many paddy fields and riparian zones and mudflats into unproductive areas or mangrove areas.

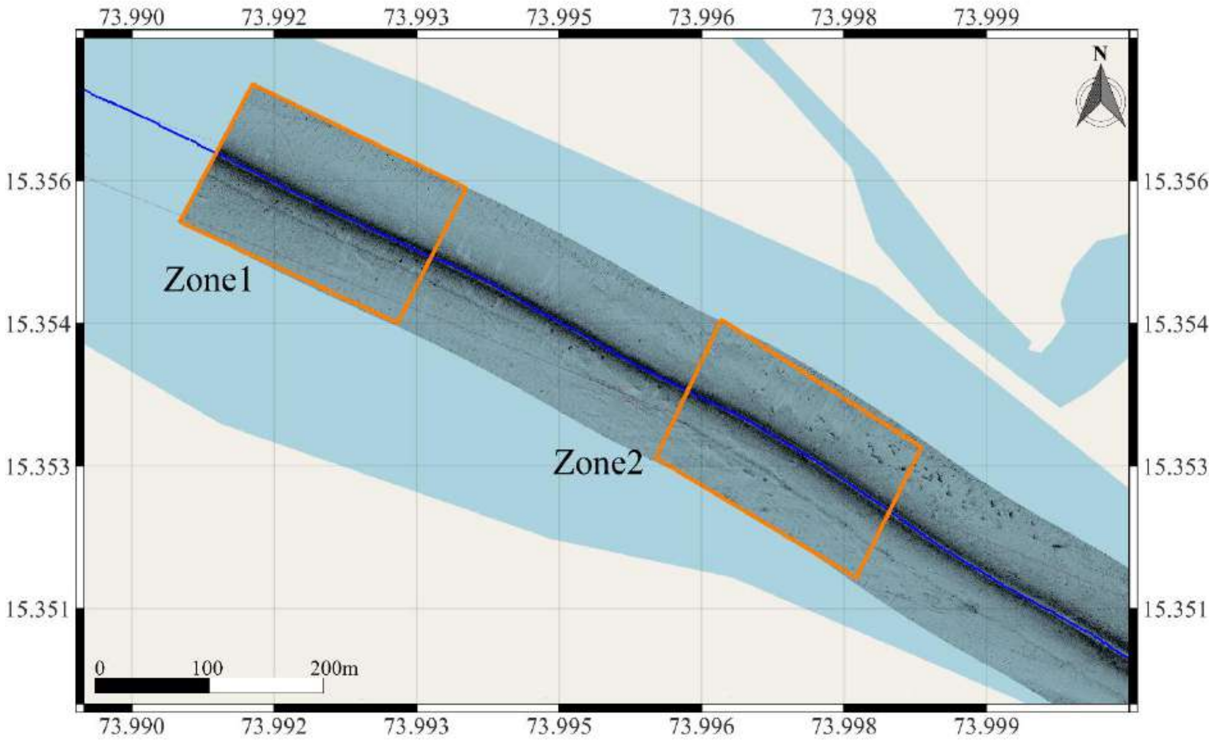
- Based on the baseline data and the prevailing site conditions (cumulative impacts herein) sand extraction at unregulated rates or in the sensitive area will have negative impacts on the environment. Therefore, minimum areas recommended as per SSMG (2016) & Hon'able NGT are to be followed. Accordingly, certain areas in the stretches of the river have been demarcated where sand extraction from the river bed requires restrictions.

- The bed level changes for the post-mining scenario are mostly around -0.2 m to 0.5 m based on the studies covering monsoon (July-November, 2020) and non-monsoon period (November, 2020 - June, 2021). The changes in bed morphology in the post-mining scenario at different sections of the river are highly dynamic and patchy in nature.

- Based on the geomorphology, sensitive zones, numerical modelling, ten zones have been identified as probable sand mining sites and the details are given below.

- The sand extraction has to be conducted by traditional (manual) method only. No mechanized boats or machinery to be operated. The activity shall be restricted to the available areas only and the depth of extraction should not exceed 3m from the existing baseline profiles.
- Once the lease areas are issued, the delineated “Environmental Conservation and Management Plan” needs implementation. The plan also describes the team/committee which should be capable to address, execute and monitor all the aspects of the plan. Furthermore, the team/committee should appoint sub-teams, SHG’s, Village committees on requirement basis as per the plan.

Zone 1–2



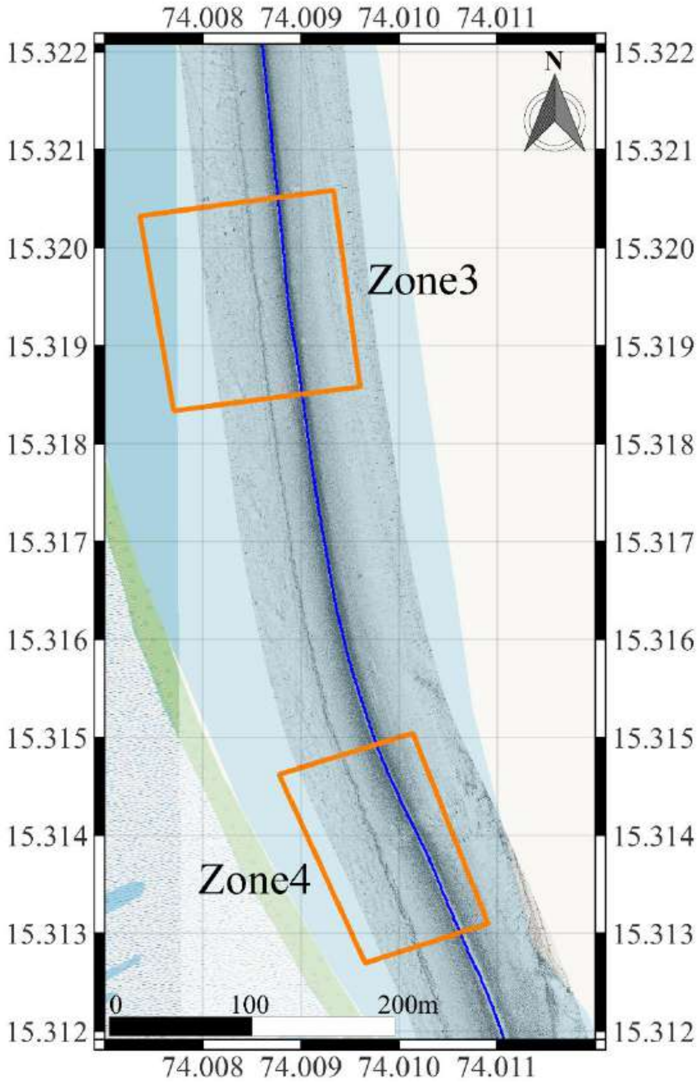
Zone-1 Block Coordinates

S. No.	Longitude (°E)	Latitude (°N)
1	73.99402042	15.35542131
2	73.99329963	15.35400606
3	73.99100455	15.35506826
4	73.99177181	15.3565154

Zone-2 Block Coordinates

S. No.	Longitude (°E)	Latitude (°N)
1	73.998813	15.35269736
2	73.99812745	15.35132459
3	73.9960186	15.35258494
4	73.99670607	15.35403854

Zone 3 – 4



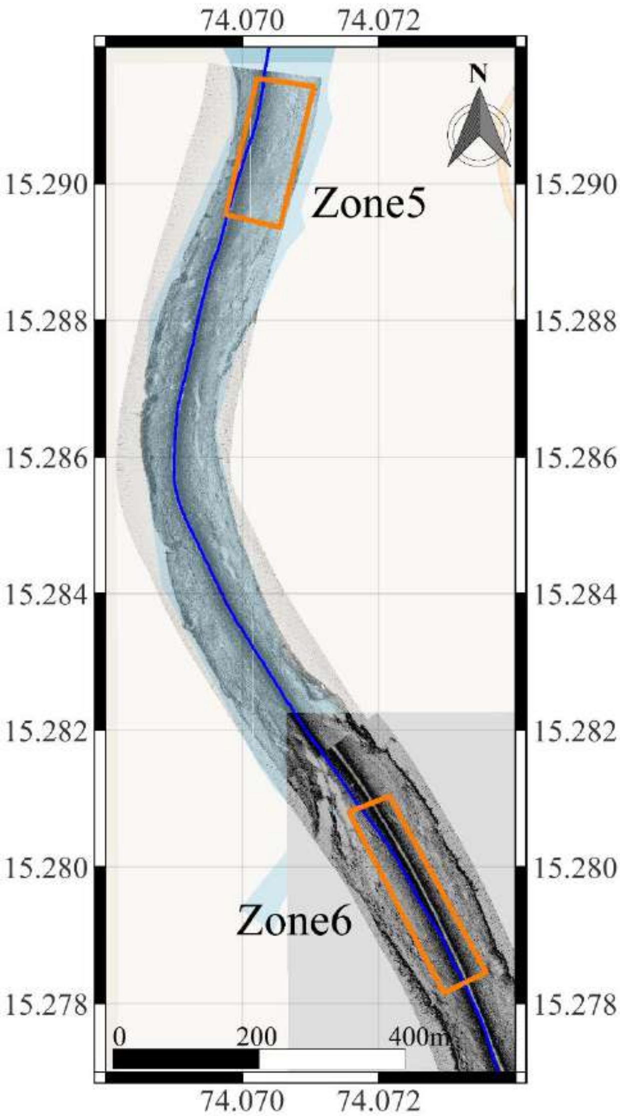
Zone – 3 Block Coordinates

S. No.	Longitude (°E)	Latitude (°N)
1	74.0096	15.31858
2	74.0077	15.31834
3	74.00736	15.32033
4	74.00933	15.32059

Zone – 4 Block Coordinates

S. No.	Longitude (°E)	Latitude (°N)
1	74.01090764	15.31309777
2	74.00965454	15.31269565
3	74.00877549	15.31462207
4	74.01014082	15.31504289

Zone 5 – 6



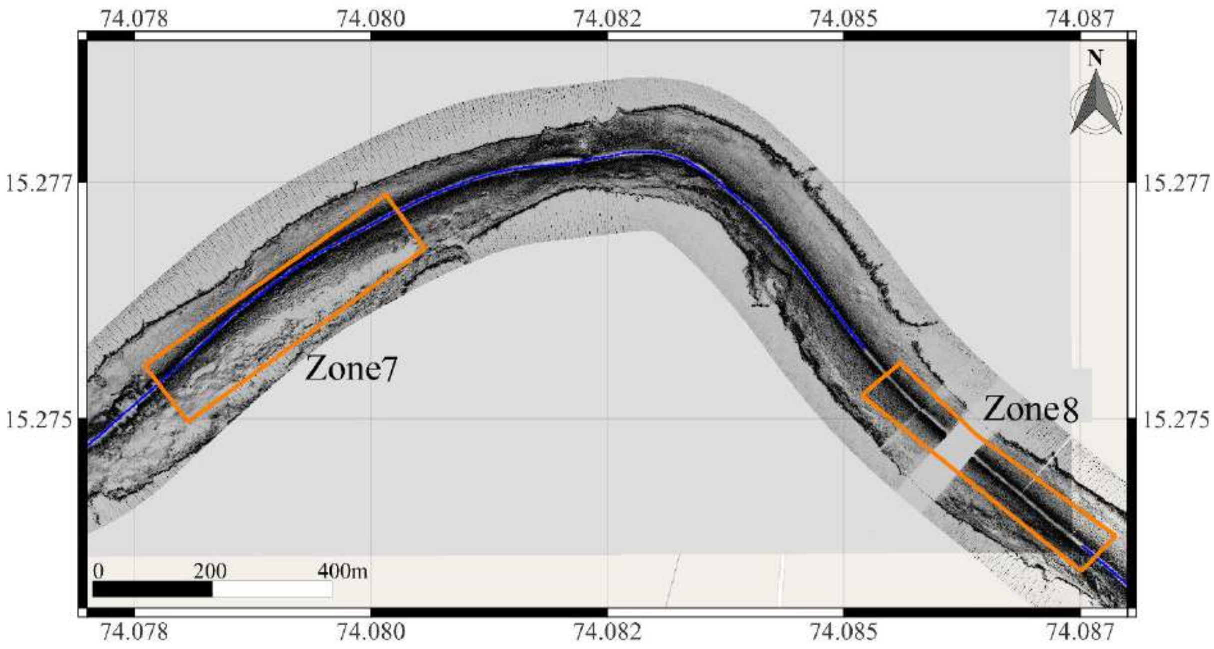
Zone – 5 Block Coordinates

S. No.	Longitude (°E)	Latitude (°N)
1	74.07104978	15.29142089
2	74.07078793	15.29022856
3	74.07010527	15.29035013
4	74.07038114	15.29150505

Zone – 6 Block Coordinates

S. No.	Longitude (°E)	Latitude (°N)
1	74.07356768	15.2784579
2	74.07295048	15.2781586
3	74.0715571	15.2808098
4	74.0721556	15.2810342

Zone 7 – 8



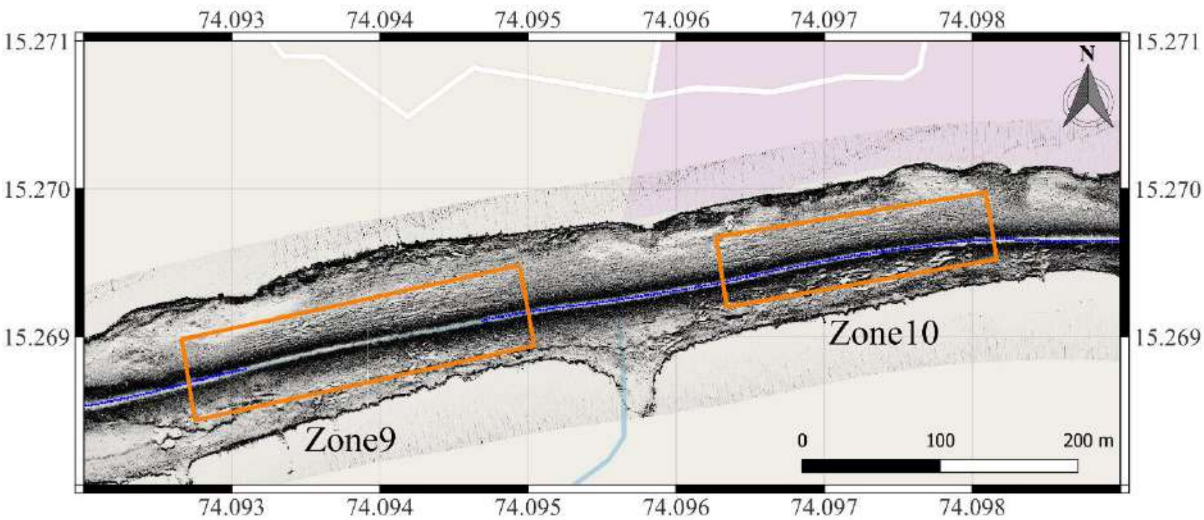
Zone – 7 Block Coordinates

S. No.	Longitude (°E)	Latitude (°N)
1	74.08056965	15.276798
2	74.07806811	15.2749698
3	74.07760521	15.2755636
4	74.08015818	15.2773684

Zone – 8 Block Coordinates

S. No.	Longitude (°E)	Latitude (°N)
1	74.08642606	15.2748108
2	74.08787087	15.2737634
3	74.08751084	15.2733894
4	74.08518931	15.275248
5	74.08559143	15.2755893

Zone 9 – 10



Zone – 9 Block Coordinates

S. No.	Longitude (°E)	Latitude (°N)
1	74.09504117	15.2689404
2	74.09275004	15.2684354
3	74.0926612	15.2689824
4	74.09494298	15.2694827

Zone – 10 Block Coordinates

S. No.	Longitude (°E)	Latitude (°N)
1	74.09816458	15.2695248
2	74.09634103	15.2692022
3	74.0962709	15.2696745
4	74.09808977	15.2699784

Identied Sand Mining Zones with quantity

S. No.	Zones	Area (ha)	Volume (Cubic m)	Weight (Tons)
1	Zone1	4.8	68,614	1,09,700
2	Zone2	4.5	64,360	1,02,240
3	Zone3	4.6	72,036	1,15,258
4	Zone4	3.4	43,221	69,154
5	Zone5	2.04	62,680	1,00,288
6	Zone6	2.32	82,408	1,31,853
7	Zone7	2.69	47,923	76,677
8	Zone8	1.66	28,753	46,006
9	Zone9	1.53	32,648	52,236
10	Zone10	1.02	27,206	43,530

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