



Research Article

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Impact of Mining Activities on Estuarine Hydrological Regime and Benthic Life in Goa, India



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Abstract

The open cast mining in Goa for ferromanganese ore has generated a high amount of waste material rich in metal concentration. The discharge of such a great volume of waste is a potential eco-toxicological risk to the water quality and benthic life in several ways. The main objective of this study was to assess and evaluate the impact caused by large scale dumping of mining rejects on the hydrological condition and benthic community matrices. River Mandovi was considered for this study because of the major mining activities and dumping of waste is found in its upper reaches. For comparison, reference stations in Chapora River were selected, where such mining activities are not noticed. Data for macrobenthos and hydrological parameters were collected seasonally during 2010-2011 from three sites along the salinity gradient of both the estuaries. The hydrological parameters of the two estuaries were similar in range and mean but differed in suspended matter and metal (iron and manganese) concentration. The community parameters of the two estuaries showed clear difference. Total number of species recorded was 48 and 61 in Mandovi and Chapora, respectively. Average faunal density was 542 ± 138 and $733 \pm$ and diversity (H') 2.81 ± 0.87 and 3.55 ± 1.04 in Mandovi and Chapora, respectively. Polychaetes were by far the most dominant group (>50%) in both areas but differ in feeding type. The dominance of scavengers and absence of filter feeding forms in Mandovi was noticeable. Sediment mean size, salinity and metals appeared to have direct influence on the fauna distribution. Effects, attributable to mining apart from seasonal variation, included changes in species composition, reduction in total density, species diversity and other community attributes. The effect was conspicuously noticed in Mandovi as compared to Chapora.

Keywords: Open cast mining; Mine waste; Metal concentration; Hydrological condition, Benthic community matrices

Introduction

Environmental protection is a pre-requisite to a healthy economy and also to a society development. Mining in Goa for iron ore has been the most important economic activity contributing significantly to the state revenue over the years. The open cast mining of iron ore in Goa is an old industry. It has resulted in adverse effect on environment and water quality [1,2]. According to a report, for every one tone of quality ore about three tones of waste is generated in an open cast mining (Anonymous, 1981). The discharge of mine waste and wash off of mining activities on passing through drainages reach downstream rivers and other water bodies and thus pollutes them because of a high concentration of iron in them [3]. Thereby, such water bodies often assume red colour, especially during the monsoon season. The heavy particles in marine suspended matter with high metal load gets settled in the estuarine system. The silt deposition blankets the bottom along the course of the water bodies, thus causes severe damage to benthic life and hydrological regime. The influence of heavy mining discharge and its potential damage to benthic life of the estuarine system of Goa is sparsely addressed.

The mining discharges increase the concentration of total

suspended matter (TSM) in the tributaries and rivulets. According to a report about 3400 tonnes of TSM in Mandovi was recorded during monsoon period [4]. This has resulted in significant increase in the clay minerals and suspended solids in the entire course of the Mandovi estuary [5]. The increased turbidity has multiple disadvantages for the biological productivity in the aquatic environment [6]. The most important ecological concern associated with discharge of mine rejects is the leaching of metal into sediment and water, resulting in metal bioaccumulation in the marine food chain [7]. Thus, investigations on the ecological damages of such anthropogenic activity on environment and benthic assemblage assume great significance in understanding the implications on coastal biodiversity. The present study was undertaken in order to evaluate the extent and magnitude of the impact of the mine discharges on soft bottom macrobenthic community and the hydrological regime in estuarine system of Goa.

Materials and Methods

Study area

Majority of old mines were located along the banks of river Mandovi and hence this river was selected for the present

investigation. Mandovi is connected with Zuari through a canal called Cumbarjua canal. Ore loading platforms are constructed along the bank of the river from where it is loaded on the barges and transported to harbour. Thus, the estuarine bed and associated mangroves located along the Mandovi are exposed to high influx of metal affluent from ferromanganese mining [7]. There is a report of high concentration of suspended solid from the mine tailing going on for several decades in the Mandovi estuary [2]. This discharge of clay and finely divided iron ore subjected the water column to continuous turbidity and the sub-tidal environment to continuous sedimentation by allochthonous particulate material [8]. River Chapora on the other hand does not have any mining activity along its traverse and was selected as a reference area for comparison and also to draw inferences [9].

Field collection

Sampling for benthos and environmental parameters was

carried out in three seasons, post-monsoon (Oct-Nov 2010), pre-monsoon (Mar-Apr 2011) and monsoon (Aug-Sep 2011). On each sampling date, water, sediment and benthic fauna were collected from three locations spread about 5km apart on a salinity gradient, in Mandovi and Chapora river estuary (Figure 1). Replicate samples were collected from each station on each sampling date. Water samples were taken with the help of a Niskin water sampler and sediment was collected with the help of a van Veen grab of 0.04m² area. Macrofauna samples were sieved through a 0.5mm mesh sieve and preserved in formalin Rose Bengal solution. The pH, water temperature and dissolved oxygen were measured in the field using a multi-parameter portable meter (EUTECH PCD 650, Japan). Water sample was also collected from each station for suspended solid (SS) and metal concentration. The water was filtered through a pre weighed 0.4µm Millipore filter paper. The SS retained on the filter paper was dried and weighted again.

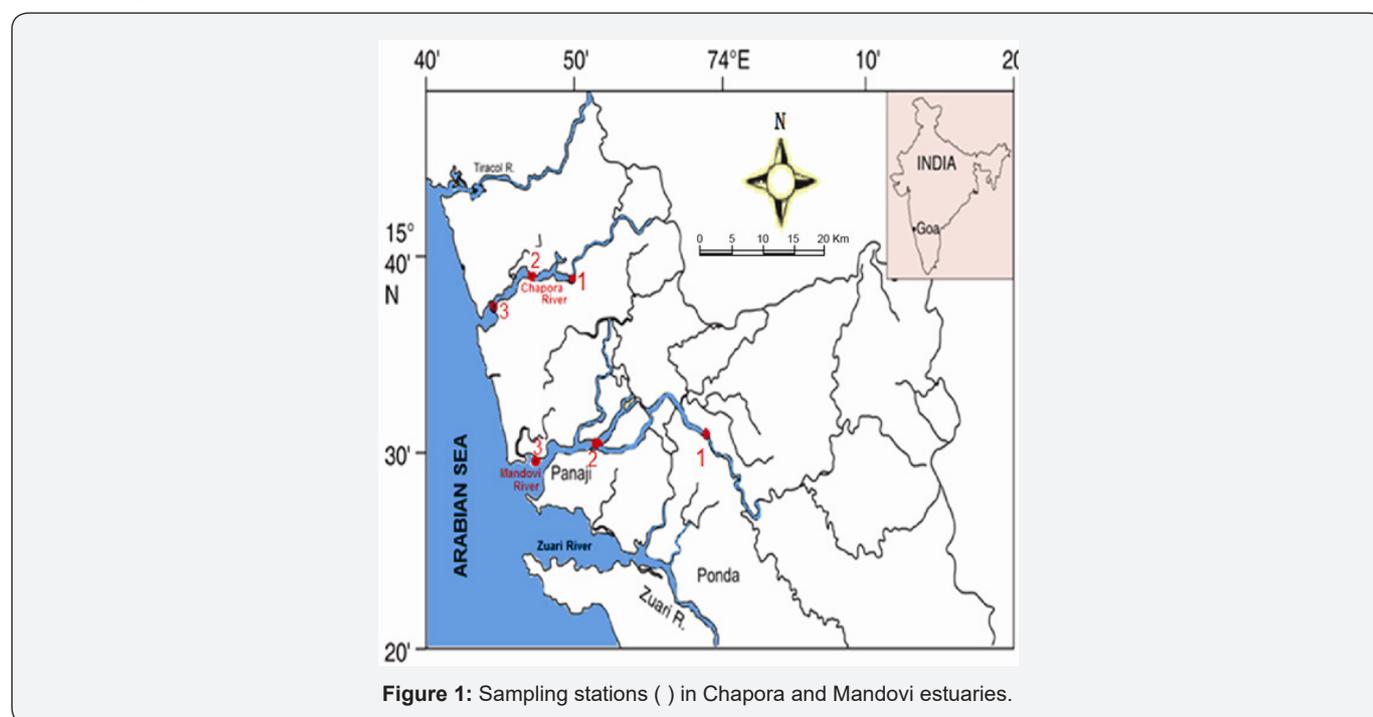


Figure 1: Sampling stations () in Chapora and Mandovi estuaries.

Laboratory analysis

Water and sediment and tissue samples were analyzed for physico-chemical parameters by following the methodology given in APHA [10]. The sediment was analyzed for different fractions (sand, silt, clay) by the method of Buchanan [11]. Macrobenthic animals were sorted, identified to the lowest taxonomic level using literature, counted and weighed. The iron and manganese in water and sediment was analyzed by following the method given in Mesquita and Kaisary. The amount of Mn and Fe was detected using a flame Atomic Absorption Spectrometer (AAS, Perkin-Elmer Model 5000). Sediment organic carbon was estimated using titrimetric wet oxidation method as described by Allen et al. [12].

Data analysis

The numerical density and species richness of each site were analyzed by ANOVA after transformation of data to log₁₀ when necessary. Possibilities (p<0.01) were considered statistically significant. Changes in community attributes such as abundance, species richness, diversity/dominance and structure of the benthic invertebrates assemblage under stress were studied by subjecting the data to univariate analysis for reference and effected sites. Various diversity indices are widely for comparison of community on spatial and temporal scale as well as for the assessment of environmental quality. This included Species richness, Shanon-Wiener diversity and species evenness. The degree of variability present in the macrofaunal

assemblages in the impacted area were compared with that in the reference area following statistical software, PRIMER 6 (Plymouth Routine in Multivariate Ecological Research) [13].

Result

Environmental characteristics of study area

Mandovi and Chapora are monsoonal estuary and their flow of water is regulated by semi-diurnal tide. The hydrographical conditions are significantly influenced by the south-west

monsoon (June-September). The freshwater discharge is highly seasonal in these estuaries, markedly from wet to dry season. The runoff in Mandovi increases two fold at lower down near Panaji due to many tributaries joining the main river unlike in Chapora. The runoff which is responsible for the washing of the mining rejects varies considerably. During the peak season it may be as high as 3400McuM and is negligible after cessation of monsoon. Due to the small catchment area, the hydrographical characteristics of Chapora river differs from that of river Mandovi.

Water quality characteristics of Mandovi

Table 1: Average value of hydrographical parameters in the study area.

Mandovi			
Parameters	Post-monsoon	Pre-monsoon	Monsoon
Temperature (°C)	27.8	29.4	24.2
Salinity (psu)	14.8	24.6	5.8
Dissolved oxygen (mg/l)	3.92	4.45	5.28
pH	7.5	7.4	7.9
Suspended solid (mg/l)	18.9	28.7	92.2
Fe (ppm)	65.2	20.7	118.9
Mn (ppm)	1.8	1.7	2.2
Chapora			
Temperature (C°)	29.2	30.2	24.7
Salinity (psu)	24.8	28.6	4.5
Dissolved oxygen (mg/l)	3.76	3.68	6.82
pH	7.9	7.5	7.4
Suspended solid (mg/l)	0.52	0.45	1.64
Fe (ppm)	0.15	0.12	0.18
Mn (ppm)	0.01	0.06	0.08

The hydrographical feature of the study area of Mandovi estuary which is influenced by the mining activities is presented in Table 1. The surface water temperature of the study stations ranged between 28.2–30.9 °C in pre-monsoon, 23.8-25.6 °C in monsoon and 27.5-28.0 °C in the post monsoon season, respectively. The lowest temperature recorded in monsoon was as expected due to cloudiness and increased intensity of monsoon precipitation normally observed during this part of the season. The warming up of surface water takes place in October when the sky is clear and the annual average temperature along the transect, during post-monsoon varied between 26 and 28 °C. The salinity in the Mandovi estuary varied widely, both seasonally and spatially due to tidal excursion. The observed values were in the range of 20.2 -30.9psu in pre-monsoon, 1.08-9.25psu in monsoon and 8.9-20.5psu in post-monsoon, respectively. Lowest salinity was recorded in monsoon. During dry season the salinity keeps increasing, indicating intrusion of salt. The variation in salinity depends on intrusion during dry season and flushing during wet season. According to Shetye & Murty [14], the estuary is flushed of salt during the wet season by freshwater entering the estuary at the upstream end. The

dissolved oxygen (DO) content of the surface water at the study stations ranged from 4.2-4.7mg/l in pre-monsoon, 4.6-6.5mg/l in monsoon and 3.92 to 4.12mg/l in post-monsoon, respectively. The values suggest that the surface water in the study area is well oxygenated. The maximum values were attained in monsoon when the estuary is almost a freshwater dominated body. The annual average concentration of DO in the transect stations varied between 4.02 -5.6mg/l. The DO showed inverse relation with salinity. The pH values varied with a narrow range in all seasons. The values were in the range of 7.2-7.6 in pre-monsoon, 7.7-8.2 in monsoon and 7.2-7.6 in post-monsoon, respectively. The suspended solid (SS) was in the range of 26.5-32.2mg/l in pre-monsoon, 83.4-110.6mg/l in monsoon and 18.2-20.8mg/l in post-monsoon. Variation in SS in the study transect is an indication of land drainage including discharges from mine tailings. Its magnitude is highest during the monsoon months and the variation in other months is regulated by the addition from land. The suspended solid coming from the mining areas situated along the river bank in the upper reaches is regularly flushed out by strong currents.

Water quality characteristics of chapora

Table 2: Average values of sediment properties in the study area.

Mandovi			
Parameters	Post-monsoon	Pre-monsoon	Monsoon
Sand (%)	44.6	51.3	44
Silt (%)	25.6	21.3	32.4
Clay (%)	29.8	21.4	23.5
TOC (%)	1.67	1.5	2.1
Fe (ppm)	76.3	109.2	108.5
Mn (ppm)	1.4	1.7	0.8
Chapora			
Sand (%)	71.6	51.3	44
Silt (%)	20.5	21.3	32.4
Clay (%)	7.9	21.4	23.5
TOC (%)	1.12	1.09	0.78
Fe (ppm)	15.7	14.2	17.4
Mn (ppm)	0.14	0.19	0.35

The results of the hydrographical parameters of the Chapora river estuary (reference area) are given in Table 2. The water quality appears to follow a definite seasonal pattern. The water temperature during post-monsoon was in the range of 28.5-29.6 °C, in pre-monsoon 29.6-31.8 °C and in monsoon 24.7-25.9 oC. The salinity was high in post- and pre-monsoon and the values ranged from 21.4psu in post-monsoon to 30.2psu in pre monsoon. The monsoon recorded the lowest values of 1.88-8.16psu. The dissolved oxygen (DO) recorded moderate to high values with a range of 3.52-3.98mg/l in post-monsoon and 3.43-4.22mg.l in pre-monsoon. High values (5.25-6.47mg/l) were however, recorded in the monsoon season. The pH was always above 7. The suspended solid remained significantly low even during the monsoon season. The minimum value of SS was 0.22mg/l recorded in pre-monsoon while the maximum of 1.85mg/l was recorded in monsoon season.

Sediment

Table 3: Macrofaunal abundance in the study area- values are range and means (in parenthesis).

Mandovi			
Station	1	2	3
Density (No./m ²)	128-236 (204)	258-1027 (516)	352-1377 (876)
Biomass (g/m ²)	3.74-6.02 (4.16)	8.63-12.29 (9.76)	14.45-29.36 (18.55)
Chapora			
Density (No./m ²)	136-382 (278)	388-1522 (828)	476-1618 (928)
Biomass (g/m ²)	4.28-7.923 (5.38)	10.22-14.62 (11.76)	16.25-30.82 (20.18)

The sediment composition and its seasonal variation are depicted in Table 3 & 4. In the Mandovi estuary, the sediment was admixture of sand silt and clay with varying admixture of cobbles and pebbles particularly in the upper reaches originating from mining activity, however with percentage composition in different season. The sand was 24.6 to 72.4%, silt 15.5-41.6% and clay 8.0-39.6%. Silt was dominant fraction at the upper and lower zone while sand was dominant in the middle zone of Mandovi estuary. Total sediment organic carbon ranged between 0.92 to 2.75%. The values were high in fine silty clay and low in sandy sediment. In contrast the sediment of Chapora estuary was predominantly sand having very low percentage of silt and clay. The sand was 65.4-88.5%, silt 9.0-26.6% and clay 2.1-8.4%. Total organic carbon (TOC) was also low with 0.44 to 1.55%. There was no seasonal variation in the total organic content of both estuaries. However, the TOC of Mandovi was higher than that of Chapora.

Table 4: Average value of community parameters of benthos in the study area.

Parameters	Post-monsoon	Pre-monsoon	Monsoon
Mandovi			
Number of species/m ²	35	36	17
Species richness (D)	4.28	5.02	3.59
Species diversity (H')	3.14	3.42	1.97

Evenness (j)	0.98	0.95	1
Chapora			
Number of species/m ²	38	42	24
Species richness (D)	5.64	5.98	3.67
Species diversity (H')	3.86	3.92	2.04
Evenness (j)	0.98	0.96	0.95

The iron values in water were found to be in the range of 20.7 to 118.9ppm in Mandovi estuary and 0.12 to 0.18ppm in Chapora estuary (Table 5.1). Similarly, the manganese values were in the range of 1.7 to 2.2ppm in Mandovi and 0.01 to 0.05ppm in Chapora estuary. During the pre-monsoon, concentration of Fe in water from Mandovi estuary was found to be 20.7ppm while, water from Chapora had Fe content of 0.12ppm. During the monsoon season, the iron content was 118.9ppm in Mandovi and 0.18ppm in Chapora whereas, during the post-monsoon season; the values recorded were 65.2ppm in Mandovi and 0.15ppm in

Chapora estuary. Thus, a difference of an order of significant magnitude of metal contents were observed, ranging from high to very high concentrations of Fe in water from Mandovi and low concentration of Fe in water from Chapora. Seasonal variation of Mn concentration in waters from Chapora river was from a minimum of 0.02ppm (monsoon season) to maximum of 0.06ppm (pre-monsoon season). Whereas, on the other hand, seasonal Mn values in waters from Mandovi estuary showed a variation from 1.7ppm (pre-monsoon season) to 2.2ppm (monsoon season).

Macrobenthos abundance

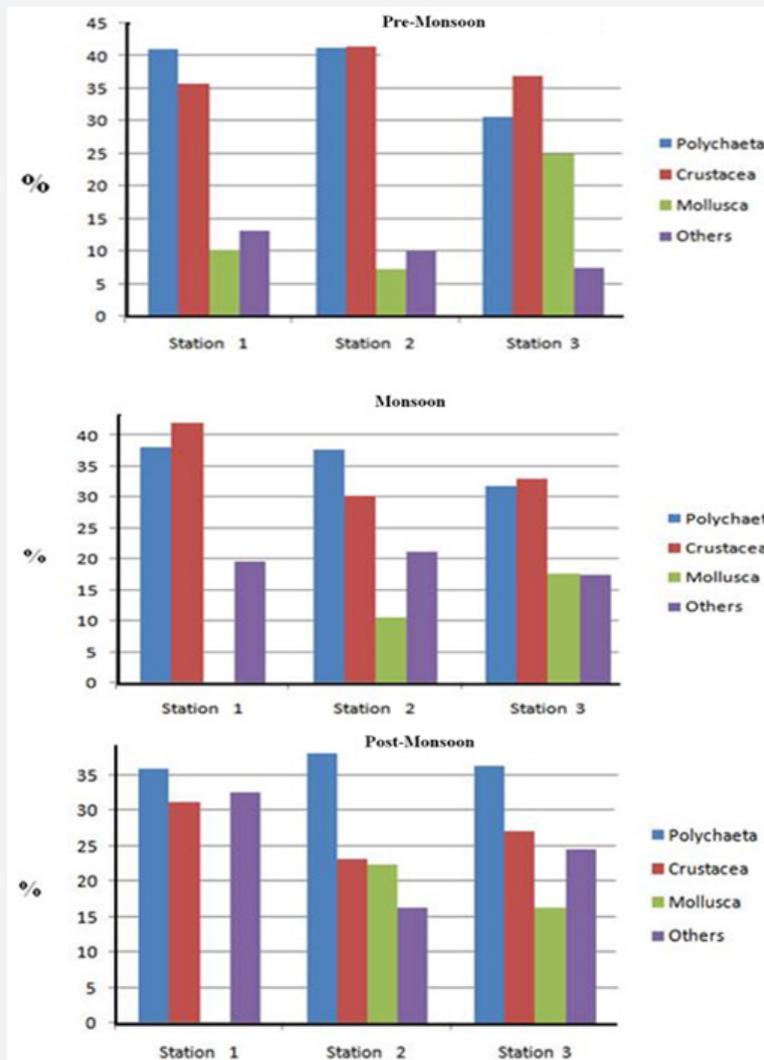


Figure 2: Percentage contribution of major benthic groups in each season in Mandovi.

A total of 4882 animals were collected from three locations in the Mandovi estuary during the study period (Table 3). The lowest density (no/m²) was recorded in the upper mesohaline (5-18psu) area (station #1) and high density in the euhaline (32psu and >) at station #3. Intermediate abundances were also observed in the middle part of the estuary (St. #2) which falls in a polyhaline area. Highest density in the euhaline zone located in the mouth region, several km down from the intense mining activity was recorded. The macrofaunal density ranged from 128 to 236/m² at St. #1, 254 to 1027/m² at St. #2 and 352 to 1377/m² at St. #3 (Table 3). Similarly the biomass ranged between 3.74 to 6.02g/m² at St.#1, 8.63 to 12.29g/m² at St. #2 and 14.45 to 29.36g/m² at St. #3. The average density was lowest at St. #1 and highest at St. #3. The inter-sample differences were also recorded at three sites. The fauna comprised of three main groups, the polychaeta, crustacean and mollusca. Minor phyla

comprised the other groups (Figure 2).

Polychaeta was the dominant group at all three stations and its percentage contribution was in the range of 36.0-41 at St. #1, 37.2-41.2 at St. #2 and 31.8-36.3 at St. #3. The crustaceans were second in the order of abundance and contributed 31.3-42.1% at St. #1, 23.1 -41.5 at St. #2, 27.1 -37.0 at St. #3. In some cases the abundance of crustacean was more than that of polychaeta. Similarly, the mollusca contribution was in the range of 0-10.2% at St. #1, 7.3-22.4 at St. #2 and 12.1-24.9% at St. #3. The seasonal average contribution suggested that polychaeta and crustacean were significant in percentage contribution. The mollusca contribution was insignificant. The other group was formed by minor phyla contributed by sipunculida, Echiurida, nematode and nemertina. The contribution of this group together was higher than that of mollusca.

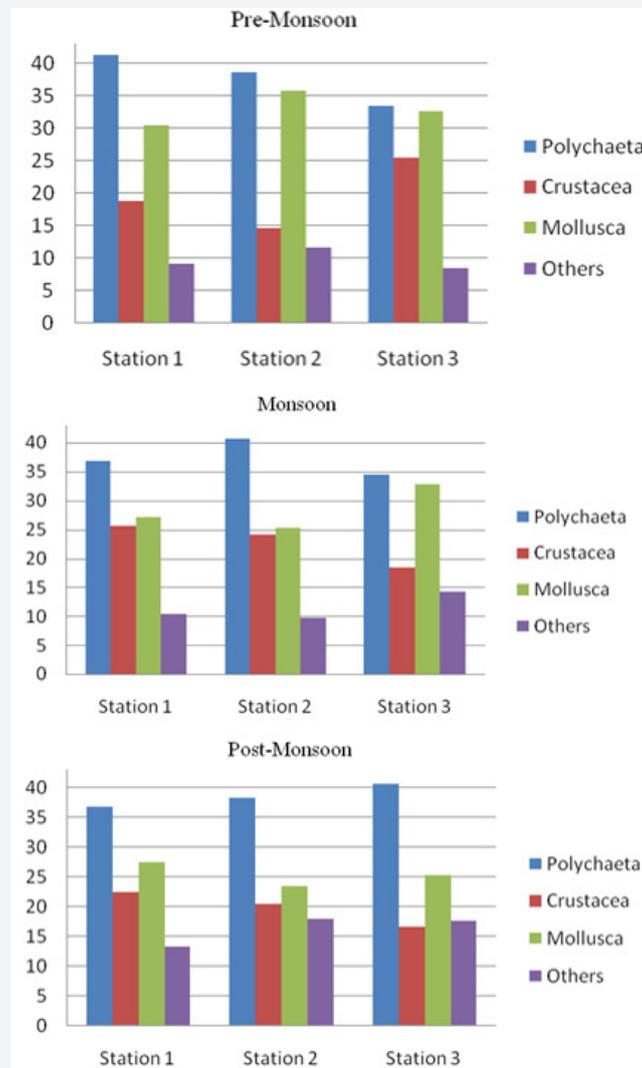


Figure 3: Seasonal changes in percentage composition of major benthic groups in Chapora

The benthic abundance in the reference area of Chapora recorded very high density and strong seasonality in the occurrence (Table 3). A total of 5705 individuals were collected

from three sites. The average density was 278, 828 and 928 at St. #1, St. #2 and St. #3, respectively. The lowest average density of 278/m² was recorded in monsoon at St. #1 and the

highest average density of 928/m² in pre-monsoon season at St. #3. Thus, a variation in distribution was also noticed along the salinity gradient; the low number present at lower salinity while the higher number recorded in the high saline zone. The dominant taxa in the order of abundance were polychaeta (33.4-41.2%), mollusca 30.4-35.8%) followed by crustacean (16.6-22.6%) (Figure 3). The other groups include a number of minor phyla such as anemonia, sipuncula, echiurida, anthopleura and nematoda. The polychaeta and mollusca were similar in distribution while crustacean were significantly lower in abundance as compared these species to found in Mandovi.

Community parameters

The values of community parameters are given in Table 4. The occurrence of species in Mandovi showed clear seasonal variation. During monsoon lowest values were recorded and in pre-monsoon season highest values were observed. The species richness (D) was in the range of 3.59 and 5.02 and species diversity (H') 1.97 and 3.42. The evenness was similar in all season. In the Chapora the number of species recorded ranged between 24-42, the species richness 3.67-5.98 and species diversity (H') 2.04-3.92. The seasonal range of variation in the two areas was similar but the average values in Chapora were higher than in that of Mandovi.

Major species contribution

In the present study, 46 species of macrobenthos were identified in Mandovi. This included 21 species of polychaetes. The macrobenthos of Chapora was characterized by the presence of 56 species belonging to polychaeta, crustacean and mollusca in different seasons. The occurrence of dominant and abundant species in the two areas is given Table 5. There was seasonal variability in the occurrences. There was more dominance of polychaete worms in both estuary. The dominance of opportunistic group such as *Prionospio pinnata*, *dendronereis aestuarina*, *Mediomastus sp.* *Nephtys polibranchiata* and scavenging and seston feeding crustaceans, such as *Ampelisca*

sp., *Corophium sp.* *Cyathura sp.*, *Tanaidacea*, and *Ostracoda* in the Mandovi was the result of condition developed due to mining discharges. This is supported, in parallel, by the absence of many filter feeding forms such as bivalves. On the other hand the Chapora showed normal distribution of macrofauna with more number of polychaeta species such as *Nereis capensis*, *Lumbriconereis sp.*, *Onuphis sp.* *Diopatra neapolitana* and *Polydora ciliate*, *Prionospio cirifera*, and high density of suspension/and filter feeding forms such as *Meretrix casta*, *Paphia textile*, *Tellina sp.*, and *Cyclospis sp.* The order of dominance of major group was polychaeta, crustacean and mollusca in Mandovi while polychaeta, bivalvia and crustacea in Chapora. The estuarine fauna of Mandovi and Chapora follows seasonality in the distribution, with low number in monsoon and high in pre-monsoon (Plate 1).

Physico-chemical and biological parameters inter-relationship

In order to study the inter-association of physico-chemical and biological parameters and their interdependence, the correlation coefficient were analysed for Mandovi and Chapora and the results are presented in Table a & b. The values were tested at p<0.05, p<0.01 and p<0.001 level of significance. In the first case of Mandovi salinity-temperature showed highly significant positive correlation (r=0.94, p<0.001). The suspended solid was positively correlated with dissolved oxygen (r=0.88, p<0.01). Among biotic parameters macrofaunal density showed significant positive correlation with dissolved oxygen (r=0.77, p<0.05), ph (r=0.72, p<0.05) and suspended solid (r=0.73, p<0.05). The density and diversity were negatively correlated with sedimentary Fe (r= -0.78, p<0.05) and Mn (r= -0.84, p<0.01). The diversity showed significant positive relationship with density (r=0.73, p<0.01). The density showed significant positive correlation with DO (r=0.77, p<0.05), ph (r=0.72, p<0.05) and suspended solid (r=0.73, p<0.05). The high negative association between biotic parameters and metal suggest their negative effect on benthos.

Table 5: Dominant species in different season. Numbers in parenthesis indicate percentage composition in each season.

Stations	Premonsoon	Monsoon	Postmonsoon
Mandovi	<i>Dendronereis aestuarine</i> , (20), <i>Glycera alba</i> , (11), <i>Prionospio pinnata</i> , (22), <i>Paraprionospio patiens</i> , (14), <i>Meretrix casta</i> , (6) <i>Ostracoda</i> (8), <i>Tanaidacea</i> (10), <i>Nephtys polibranchiata</i> (6), <i>Cyclaspis sp.</i> (12),	<i>Mysidacea</i> , (12) <i>Corophium sp.</i> , (16) <i>Prionospio pinnata</i> (7) <i>Cosura sp.</i> (9) <i>Paphia malabarica</i> (8) <i>Ampelisca sp.</i> (4) <i>Amphithoe sp</i> (5) <i>Photis sp.</i> (7)	<i>Cossura sp.</i> , (14) <i>Nephtys sp.</i> (19) <i>Cirratulus sp.</i> (5) <i>Magelona cincta</i> (7), <i>Lumbriconereis sp.</i> (5) <i>Glucera alba</i> , (6) <i>Natomastus sp.</i> (5) <i>Ampelisca sp.</i> (8) <i>Cyathura sp.</i> (8)
Chapora	<i>Nereis capensis</i> , (12) <i>Lumbrinereis sp.</i> (18), <i>Onuphis sp.</i> (9), <i>Polidora ciliate</i> (12), <i>Corophium sp</i> (11). <i>Marginella sp</i> (8). <i>Tellina sp</i> (7). <i>Diopatra neapolitana</i> (8). <i>Paphia textile</i> , (7) <i>Meretrix casta</i> , (6) <i>Modiolus metcalfi</i> (6)	<i>Paphia textile</i> , (9), <i>Meretrix casta</i> , (12), <i>Ampithoe sp.</i> (6) <i>Diopatra neapolitana</i> (16) <i>Ampelisca sp.</i> (8) <i>Marginella sp.</i> (8) <i>Cirithedia morus</i> , (10), <i>Eurydice sp</i> (6). <i>Polydora ciliate</i> (10)	<i>Prionospio cirifera</i> , (12) <i>Donax cuneatus</i> , (8), <i>Corophium sp.</i> , (7), <i>Cyathura sp.</i> (6) <i>Diopatra neapolitana</i> (10), <i>Polidora ciliata</i> , (13), <i>Tainadacea</i> (8), <i>Cyclaspis sp.</i> (11)

The correlation coefficient matrix for Chapora suggested highly significant relation between temperature and salinity (r= 0.94, p<0.001). DO showed significant negative relation with temperature (r= -0.79, p<0.05) and salinity (r = -0.88, p<0.01). Suspended Solid demonstrated a significant negative relation (p<0.01) with temperature, salinity and DO. Among

biotic parameters, diversity showed positive significant relation with temperature (r= 0.84, p<0.01), salinity (r=0.85, p<0.01). Diversity was negatively related with suspended solid (r= -0.77, p<0.05) and Fe (r= -0.80, p<0.01). Interestingly, the density was poorly related to other parameters unlike noticed in Mandovi, thus suggesting no adverse effect on benthos.

Discussion

The hydrographical feature of the Mandovi river- estuary has been studied fairly extensively and there is a great deal of information available on water temperature, salinity, DO, SS, chemical properties, water currents and water flow pattern [15-17]. The most important feature emerging from these studies is that the hydrographical features are found to be fairly regular and follow the seasonal cycle. The intense precipitation and land runoff during the monsoon bring about large changes in water quality and sediment regime. During the dry season, the season (post-monsoon) the water in the estuarine region remains well mixed and marine condition develop in the pre-monsoon season [14]. The concentration of dissolved oxygen is influenced by biological and physico-chemical processes. The gross factors controlling its solubility are water temperature, salinity and humidity. High oxygen saturation during monsoon period has also been reported by many researchers. There were no significant differences in the hydrological parameters of the two estuaries.

The high value of Fe and Mn in water and sediment of Mandovi as compared to reference sites in Chapora is attributed to the transport of ferromanganese ore through Mandovi and high precipitation of mining waste discharges. In a recent study, Attri & Kerkar [7] reported high to very high concentration of Fe and Mn in the mangrove sediment of Mandovi and low concentration in Chapora which was related to mining activity. The high concentration could be explained by the strong association of the geo-chemical matrix between the two elements of Fe and Mn. Information biological characteristics of Mandovi estuary particularly on chlorophyll, phytoplankton abundance, zooplankton production [18] and benthos is available [19]. In recent studies, significant changes in benthos feeding type associated with large changes in water quality and sediment granulometry due to anthropogenic activity including mining has been reported [20,21].

The suspended solid (SS) recorded significantly high values in Mandovi as compared to Chapora. This is the result of large mining washing and its discharge in the Mandovi estuary and concentrated mining activity in the upper reaches of the Mandovi [17]. A low SS observed in Chapora could be attributed to no mining activity along its bank. Kessarkar et al. [8] have reported high spatio-temporal variability in suspended solids in Mandovi river which is attributed to mining activities. The settlement of sediment in the river is largely affected by river discharge and settling velocities of sediment. Thus the heavier particles settle faster within the mining zone while the red clay particles, characteristics of mining dust move forward and settle [4].

The sediment in the Chapora estuary is predominantly sandy in all season with little percentage variation of silt and clay. Earlier studies in Chapora have also suggested strong seasonality in hydrological and sediment granulometry changes [9,22]. The benthic fauna also showed seasonal variation and

the fauna was dominated by mollusca and polychaeta. The third group was represented by crustacea but in low percentage. In an ecological study of Chapora bay-estuarine system, Untawale & Dhargalkar [23] have reported high benthic production, dominated by filter feeding bivalves such as *Meretrix casta* and *Perna viridis*. According to them the benthic production of the bay was high due to high organic production and was dominated by filter feeding edible bivalves such as *Meretrix casta*, *Perna viridis* and gastropods. They have also found very low percentage of epibenthic crustaceans as observed in the present study.

The metal values recorded in the water and sediment was within the limit recorded by Attri & Kerkar [7] for the same area. The results of the present study on correlation matrix agrees with Snelgrove & Butman [24] who concluded that with the exception of extreme habitats benthic community in the coastal zone is not controlled by one or a simple combination of parameters. An ideal habitat for benthic animals like worms, bivalves is the soft sediment, a combination of sand silt and clay. Any change in bottom deposit such as red clay, cobbles and pebbles, as observed in Mandovi estuary, will deter the settlement and growth of suspension, deposit feeder and other infaunal benthic invertebrates [20]. The dominance of polychaete filter feeders and scavenging crustaceans is reported for a disturbed area in Zuari estuary of Goa [25]. This in conformity with the observations made in this study.

High degree of impoverishment in macrobenthic community with decrease in abundance and species richness due to shoreline discharge of iron ore mine tailing in Chile was reported by Lancellotti & Stotz [26]. The impoverishment of fauna in particularly in Mandovi is related to anthropogenic disturbances. The benthic larvae settlement on altered deposit is affected due to increase in suspended solid. It will choke the filtration apparatus with possible mortality of the infaunal assemblage. Thus, the present study suggests towards decline and impoverishment in native benthic animals, in particular, reduction in filter feeding bivalves, deposit feeding polychaetes and increase in seston feeding forms and scavengers such as crustacea. In earlier studies, reduction in macro and meiobenthos of Goa estuaries due to mining activity have been reported [20,27,28]. In another study, Panoram et al. [29] observed significant decline in the number and species of foraminiferans of Mandovi estuary which have related to mining pollution. The sand excavation and removal from the river bed has aggravated the situation. High density bed of estuarine clam, *Meretrix casta* (>1000/m²) once existed in the estuary, has reduced to few numbers in the present study. The abatement of the recurrence of such a phenomenon is the only solution which will help in resettlement of the high benthic diversity of the affected Mandovi river-estuary [30-33].

Summary and Conclusion

The anthropogenic interferences along with natural disturbances have yielded varied results globally in the past. Mining was the backbone of economy in Goa; however, illegal

mining in the past decade has caused severe damage to the ecology, hydrology and agriculture. This study was aimed to provide information on effect of mining on hydrology and benthic community in Goa. The impoverished macrofaunal assemblage including filter feeders and dominance of scavengers in the affected Mandovi estuary as compared to high density, diversity, richness and dominance of filter feeding polychaetes and bivalves in reference area of Chapora was noticeable. This is the direct effect of turbidity of water column, sedimentation of the bottom due to discharge of mine tailing which were probably responsible for dissimilarity in faunistic composition in the two areas under consideration. Although the climate induced changes including the temporary ban on mining might have brought reduction in waste discharges, the negative effect on the macro-invertebrate community of Mandovi due to mining discharge is clearly evident in the present study. For a healthier estuarine condition more flushing is required bring the positive effect on estuarine benthic fauna.

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