Pollution Status in Mangrove Ecosystem of Mahi and Dadhar River Estuaries

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Abstract : Mangrove forests are extremely important coastal resources, which are vital to our socioeconomic development. However, they are often considered as uncreative land and used as discharge ground for pollutants. The Gulf of Khambhat and coast of south Gujarat had reasonably good mangrove cover in the past but the ecosystem has degraded due to development activities. The present study was carried out in four mangrove sites located along the Mahi and Dadhar river estuaries; Sarod, Neja, Asarsa and Dahej. Due to estuarine and gulf hydrodynamics and sediment composition mangrove forests have high organic load, both suspended and dissolved. The organic matter in the form of industrial effluent add to the total organic load of the mangrove ecosystem in this region. In present study COD of water ranges from 768 to 18.12 mg/l while sediment COD ranges from 233 to 15 mg/l. Level of phenolic compound ranges from 10.26 to 0 mg/l in water and sediment from 4.7 to 0 mg/l in sediments. Mangrove litter degradation add to natural phenolics in water and sediments, however, in present studies higher phenolic levels were due to pollution discharges in the gulf. Heavy metals like Cu, Zn, Cr, Ni, Pb, Hg, Cd, Co and Mn were recorded from the water and sediment samples of the studied mangrove ecosystems. Heavy metals like Cu, Zn, S, Si, Sr, Ti and Br were recorded from the root, stem and leaves of *Avicennia marina* samples also while, Cu, Zn, K, Fe, Sr and Br were recorded from samples of crab tissue. The status of over all pollution and its effect on crab population is discussed.

***Key words* :** Metal pollution, Mangrove, Brachyuran Crab, Mahi-Dhadhar Estuary

Introduction

Mangrove forests are extremely important coastal resources, which are vital to our socio-economic development. Extraordinary capacity of the mangrove habitat sediments to accumulate large amount of pollutant make them a favorable ground for the effluent disposal by industries. Although mangrove ecosystems can act as sinks for pollutants, they can also become pollution source. Various kinds of the pollutants, from the industries and sewage, are accumulated in the mangrove swamps changing bio-physical environment of the habitat and consequently the floral and the faunal diversity change at the faster rate. Gujarat always had good and flourished mangrove cover along the coast but during past two decades this extensive and diverse ecosystem had degraded due to one or other developmental activities. Mangrove were considered as 'Economically Unproductive Areas' and suffered massive loss (Hirway and Goswami, 2007). Benthic systems are enriched by the deposition of organic matter and the primary production at the water-sediment interface. So importance of COD in sediment is more for mangrove (Wang et al., 2010; Gandaseca et al., 2011; Deshkar et al., 2012). Mangrove water, having low penetration of light, high salinity, high turbidity and high microbial activities, has high concentration of phenolic compound, like tannin, that leaches from mangrove's litter, but the problem arises when artificial phenolic compound are introduced in the water through pollution discharge (Labunska et al., 1999; Sebastian 2002; Deshkar et al., 2012). Mangrove roots often act as barrier, retain most of the heavy metals and reduce the translocation of heavy metals to other plant parts. Heavy metal level can also act as indicator to other pollution in the mangrove ecosystem (Mateu et al., 1996; Labunska et al., 1999, Kathirasen, 2002, Machado et al., 2002; Mermi and Machiwa, 2002; MacFarlane et al., 2003; Agoramoorty et al., 2008; Kumar et al., 2010; Ahemad et al., 2011; Kumar et al., 2011; Kamaruzzaman et al., 2012).

Present study sites are located in Gulf of Khambhat which is trumpet shaped gulf of the Arabian Sea, projecting northward the coast of Gujarat state, western India, between Mumbai and the Saurashtra Peninsula. The Gulf is characterized by a number of large and small estuaries. Many rivers, like Sabarmati, Mahi, Narmada and Tapti, have their river mouth in the Gulf of Khambhat. The Golden Chemical Corridor of Gujarat is located along the Gulf of Khambhat and thus poses environmental hazards. Over the past three decades the Gulf ecosystem has been conspicuously influenced by developmental activities, therefore, this area was selected to evaluate the pollution status of mangrove ecosystem.

Material and Methods

Study Sites: Sarod (22°10'31.12"N & 72°45'18.49"E) and Neja (22° 9'2.00"N & 72°33'3.10"E) are situated in Mahi river estuary while Asarsa (21°53'53.75"N & 72°34'56.43"E) and Dahej (21°43'13.50"N & 72°31'42.90"E) are situated in Dhadhar river estuary. Sarod, Neja and Asarsa falls in Jambusar taluka while Dahej falls in Vaghra taluka of Bharuch district.

Methodology selected and the studies carried out are divided in to field surveys, sampling and data collection and laboratory analysis for abiotic and biotic components. The site entry point was taken as middle point and workable area was extended to 500 meter on both sides. Sediment, water and biotic data were collected in July, December and April for two years to have complete idea of structure and pollution stress in the ecosystem. For heavy metal analysis sediment, water, mangrove and crab samples were collected once in study period. Determination of chemical oxygen demand and phenolic compounds in sediment leachet and water were carried out by APHA (1999) standard methods. Heavy metals in water, sediments, mangrove and associated fauna were measured by Energy Dispersive X-Ray Florescence Spectrometer (EDXRF Spectrometer).

Random quadrate of 5 m^2 were laid in the study area to assess mangrove density while quadrates of 0.25 m^2 size were laid to assess crab burrow density. Statistical analysis was carried out by Spearmen Correlation of Biotic and Pollution Components in Microsoft Office Excel program. One way ANNOVA was carried out to know whether there is any correlation of biotic and pollutant components between sites. Bray-Curtis similarity analysis was carried out to find out similarity of diversity of associated fauna among the sites. This analysis was done in PAST software.

Results and Discussion

The description of study sites is presented in Table 1. An overall analysis suggests that there is a high level of pollution and lowest mangrove density at Sarod as compared to other sites.

Chemical Oxygen Demand (Figs. 1.1, 1.2)**:** The chemical oxygen demand is based on the chemical decomposition of organic and inorganic contaminants, dissolved or suspended in water. Many scientists have worked on the aspects of chemical oxygen demand (COD) of water of mangrove ecosystems. Gandaseca et al. (2011) studied water quality in Sibuti Mangrove (Malaysia) and reported COD ranging from 7.5 to 2.5 mg/L. Wanga et al., (2010) studied water quality of mangrove of Zhangjiang Estuary (China) and reported variation of COD in March (2.0 mg/l), June (1.25 mg/l), September (0.50 mg/l) and December (0.60 mg/l). In present study COD of water ranges from 768 mg/l (Sarod site, July'10) to 18.12 mg/l (Asarsa site, April'12) with cumulative average of 265.55 mg/l of all sites. Mean COD value (Fig.1.1) was observed to be higher at Sarod, 624.74 mg/l, as compared to other sites but the mean variation between the sites was not significant (ANOVA F=132.34 , Fcrit = 3.09 P> 0.5). At the value of COD 768 mg/l average mangrove density and burrow density at Sarod were observed to be 0.33 mangroves/ m^2 and 1.2 burrows/ m^2 respectively. While at the value of COD in water 18.12 mg/l average mangrove density and burrow density at Asarsa were observed 4.20 mangroves/ m^2 and 32.70 burrows/ m^2 respectively. Mangrove density showed significant negative correlation with COD at Sarod (r= 0.75) while non significant negative correlation was observed at Dahej (-0.18). Mangrove density showed non significant positive correlation with COD at different sites like Neja (r= 0.06) and Asarsa (r= 0.12). Average burrow density showed significant negative correlation with COD at sites Sarod (r= 0.83) and Dahej (r= 0.61) while Average burrow density of Neja(r= 0.56) and Asarsa (r= 0.88) showed positive correlation with COD.

Table 1: Description of study sites and their qualitative status

No	Parameter	Sarod	Neja	Asarsa	Dahej
A	**Location**				
1	N	22°10'31.12"	22° 8'52.57"	21°57'10.28"	21°42'51.39"
2	E	72°45'18.49"	72°33'54.19"	72°35'32.55"	72°34'57.98"
3	Estuary	Mahi	Mahi	Dadhar	Dadhar
4	Taluka	Jambusar	Jambusar	Jambusar	Bharuch
B	**Mangrove Patch**				
5	Type	Sparse	Open	Open/Dense	Dense
C	**Mangrove Status**				
6	Avg. Density (m2)	1.94	19.83	25.11	18.00
D	**Associated Faunal Status**				
7	Avg. Burrow Density in LZ (m2)	0.87	22.35	32.77	17.20
8	Avg. Burrow Density in UZ (m2)	0.82	34.57	52.07	32.72
9	Total number of Faunal Species	2	30	40	36

E	**Sediment Pollution Status**				
10	Avg. ChemicalOxygen Demand (mg/l)	207.70	43.20	21.83	2
11	Avg. Phenolic Compounds (mg/l)	3.78	0.48	0.02	0.16
12	Total Heavy Metals (mg/l)	3.69	0.42	0.03	0.34
F	**Water Pollution Status**				
13	ChemicalOxygen Demand (mg/l)	624.74	289.49	28.53	23
14	Phenolic Compounds (mg/l)	7.37	1.31	0.03	0.31
15	TotalHeavy Metals (mg/l)	7.87	1.72	0.2	0.7
G	**Heavy Metal Status in Biotic Components**				
16	Mangrove Root (%)	2.82	1.24	1.72	1.84
17	Mangrove Stem (%)	1.11	2.76	1.64	2.63
18	Mangrove Leaf (%)	4.83	4.08	3.64	3.23
19	Crab (%)	1.44	0.83	0.50	0.83

In present study COD of sediment, ranges from 233 mg/l (Sarod site, December'11) to 15 mg/l (Asarsa site, July'10) with cumulative average of 89.25 mg/l of all sites. Mean COD value of sediement (Fig. 1.2) was observed higher at Sarod, 207.70 mg/l, as compared to other sites but the mean variation between the sites was not significant (ANOVA F=257.30, Fcrit= 3.09 P>3.86). At the value of COD of sediment 233 mg/l, average mangrove density and burrow density at Sarod were observed to be 0.47 mangroves/ m^2 and 1.2 burrows/ m^2 respectively. While the value of COD in water was 15 mg/l, average mangrove density and burrow density at Asarsa were observed to be 4.60 mangroves/ m^2 and 51.55 burrows/ m^2 respectively. Mangrove density showed significant negative correlation with COD at Sarod (r = 0.63) while non significant negative correlation was observed at Asarsa (r = 0.04). Mangrove density showed significant positive correlation with COD at Dahej (r = 0.81) while non significant positive correlation was observed at Neja (r = 0.01). Average burrow density showed non significant negative correlation with COD at Sarod (r = 0.35) and Asarsa (r = 0.03) while Average burrow density showed significant positive correlation with COD at Neja (r = 0.63) and Dahej (r = 0.81).

Phenolic Compounds (Figs. 1.3, 1.4): Mangrove water, which having low penetration of light, high salinity, high turbidity and high microbial activities, has high concentration of phenolic compound that has leached from mangrove's litter. This concentration of natural phenolic compound is good, as scientists suggested but the problem arises when artificial phenolic compounds are introduced in the water through pollution discharge. Labunska et al. (1999) found Alkyl phenol derivatives in samples collected at Sarod. Deshkar et al. (2012) studied three estuaries in Gujarat and found that in Mahi estuary the level of phenolic compound ranges from 2.61 to 6.21ug/l with an average of 3.63 ug/l. Sebastian (2002) studied biogenic compounds in mangroves of Kerela and found that there was pre-monsoon (4.80 to 1.80 mg/g), monsoon (4.50-2.0 mg/g) and post-monsoon (4.0 to 2.0 mg/g), fluctuation in concentration of phenolic compound.

In present study water phenolic compound, ranges from 10.26 mg/l (Sarod site, July'10) to 0 (Asarsa site) with cumulative average of 1.25 mg/l. Mean water phenolic compound value (Fig. 1.3), was observed higher at Sarod, 7.37, as compared to other sites but the mean variation between the sites was not significant (ANOVA F=46.43, Fcrit = 3.09 P> 0.5). At the value of phenolic compound in water 7.37 mg/l, average mangrove density and burrow density at Sarod were observed to be 0.33 mangroves/ m^2 and 1.2 burrows/ m2 respectively. While where the value of COD in water was 0 mg/l, average mangrove density and burrow density at Asarsa were observed to be 5.02 mangroves/ m2 and 40.59 burrows/ m^2 respectively. Mangrove density showed significant negative correlation with concentration of phenolic compound at Sarod (r = 0.60), Neja (r =0.55) while non significant negative correlation was observed at Asarsa (r = 0.01) and Dahej (r = 0.38). Average Burrow density showed non significant negative correlation with phenolic compound at Sarod (r= 0.35) while significant positive correlation observed at Asarsa (r = 0.57) and non significant positive correlation observed at Neja (r = 0.40) and Dahej (r = 0.41).

In present study, sediment phenolic compound ranges from 4.7 mg/l (Sarod site, December'10) to 0 mg/l (Asarsa site) with cumulative average of 1.11 mg/l. Mean sediment phenolic compound value (Fig. 1.4), was observed to be higher at Sarod, 3.78 mg/l, as compared to other sites but the mean variation between the sites was not significant (ANOVA F=127.76, Fcrit= 3.09 P> 0.5). At the value of phenolic compound in sediment 7.37 mg/l, average mangrove density and burrow density at Sarod were observed to be 0.60 mangroves/ m2 and 1.2 burrows/ m2 respectively. At the value of COD in water 0 mg/l, average mangrove density and burrow density at Asarsa were observed to be 5.02 mangroves/m2 and 40.59 burrows/ m2 respectively. Mangrove density showed significant negative correlation with concentration of phenolic compound at Sarod (r = 0.79) while non significant negative correlation was observed at Neja (r = 0.11), Asarsa (r = 0.01) and Dahej (r =0.40). Average Burrow density showed significant negative correlation with phenolic compound in sediment at Sarod (r =0.66). Average Burrow density showed significant positive correlation with phenolic compound in sediment at Neja (r =0.81), Asarsa (r = 0.57) while it has showed non significant positive correlation at Dahej (0.46).

Heavy Metals (Figs. 1.5 to 1.10): Heavy metals, accumulated in primary producer, i.e. mangrove, finds its way to human population through the various primary and secondary consumers like crabs and fishes. Heavy metals not only affect the flora or fauna but ecosystems as a whole. Heavy metal level can also act as indicator to other pollution in the ecosystem (Mateu et al., 1996). Labunska et al. (1999) studied heavy metal, released by Nandesari Industrial Estate, Vadodara and its concentration in Mahi estuary. This estate has more than 300 units out of which 82% are dye manufactures and rest 13% are of pharmacy based industries (CPCB, 1996). Samples collected from Sarod (IT9053) showed presence of Cadmium (Cd), Cromium (Cr) and Cobalt (Co) <10 ug/l, Copper (Cu) 10 ug/l, Lead (Pb) 40 ug/l, Mercury (Hg) <2 μg/l, Nickel (Ni) 60 ug/l and Zinc (Zn) 50 ug/l. Another study conducted by Lotfinasabasl et al. (2013) on metal pollution in water at Alibag (Maharashtra) mangrove showed Cu (0.64 mg/l), Cd (0.67 mg/l), Co (1.53 mg/l) and Cr (BDL) in water samples collected from 18 stations. Kathirasen (2002) has reported heavy metals like Copper (7.85±3.7 ppm), Cobalt (4.84±1.7 ppm), Lead (2.05±0.9 ppm) etc. in the degraded mangrove of Pichavaram. Kumar et al. (2008) also studied the changes in heavy metal concentration in Cochin estuary and found heavy metal like Mn (210.5-315.35μg/g), Zn (101.3-455.68 ìg/g), Cr (53.30- 90.22μg/g), Ni (30.60 69.35 μg/g), Pb (19.5-39.50 μg/g), Cu (23.97- 39.12 ìg/g), Co (12.82-23.08 μg/g) and Cd (0.062-0.223 ìg/g). Agoramoorty et al. (2008) studied heavy metal pollution in Pichavaram mangrove and found Pb (8 μg/l). MacFarlane et al., (2003) have reported concentration of Pb (5 μg/g) in the *Avicennia marina* of Australia. Nirmal Kumar et al., (2011) studied accumulation of heavy metals in various parts of Avicennia marina, at Valmeshwer mangrove (Gujarat) and found mean accumulation of heavy metal in pattern of Root>Leaf>Stem. In present study presence of heavy metals was found in pattern of Leaf>Stem>Root. Shazili et al., (2012) studied bio-accumulation in *Scylla serrata* in Malaysia and reported that heavy metal accumulation in *Scylla serrata* followed Zn > Cu > Pb > Cd order. Ahemad et al., (2011) studied heavy metal accumulation in macro benthic fauna of Sundarban mangrove and found accumulation of heavy metals like Cu (3.66 ± 0.89 to 7.55 ± 1.29 μg/g), Zn (76.8 ± 8.55 to 98.5 ± 6.49 μg/g), Cd (0.46 ± 0.11 to 0.859 ± 0.2 μg/g) and Pb (4.66 ± 1.17 to 6.77 ± 1.1 μg/g).

In present study, heavy metals like Cu, Zn, Cr, Ni, Pb, Hg, Cd, Co and Mn were recorded from the water samples, Copper (Cu), with average of 0.73, recorded highest at Sarod, (1.21 mg/l) and lowest at Asarsa (0.10 mg/l). Zinc (Zn), with average of 0.76, recorded highest at Sarod, (1.19 mg/l) and lowest at Asarsa (0.10 mg/l). Cromium (Cr), with average of 0.45, recorded highest at Sarod, (1.20 mg/l) and lowest at Asarsa and Dahej (0 mg/l). Nickel (Ni), with average of 0.22, recorded highest at Sarod, (0.78 mg/l) and lowest at Asarsa and Dahej (0 mg/l). Lead (Pb), with average of 0.27, recorded highest at Sarod, (0.67 mg/l) and lowest at Asarsa (0 mg/l). Mercury (Hg), with average of 0.15, recorded highest at Sarod, (0.59 mg/l) and lowest at Asarsa and Dahej (0 mg/l). Cadmium (Cd), with average of 0.05, recorded highest at Sarod, (0.20 mg/l) and lowest at Neja, Asarsa and Dahej (0 mg/l). Cobalt (Co), with average of 0.01, recorded highest at Sarod, (0.02 mg/l) and lowest at Neja, Asarsa and Dahej (0 mg/l). Magnesium (Mn) were absent from the sample. Mean heavy metal value (Fig. 1.5) was observed higher at Sarod, 0.87 mg/l, as compared to other sites and the mean variation between the sites was significant (ANOVA F =7.14, Fcrit = 2.90 P< 0.01). At high concentration site, Sarod, average mangrove and burrow density was observed as 0.39 mangroves/ m^2 and 0.84 burrows/ m2 respectively. At the lowest concentration of heavy metal site, Asarsa, average mangrove and burrow density was observed as 5.02 mangroves/ m^2 and 42.42 burrows/ m2 respectively. Mean Mangrove density and mean heavy metal concentration shows significant negative correlation (r = 0.97) at all sites. Mean burrow density and mean heavy metal concentration also shows significant negative correlation (r = 0.93) at all sites.

In present study heavy metals like Cu, Zn, Cr, Ni, Pb, Hg, Cd, Co and Mn were recorded from the sediment samples. Copper (Cu), with average of 0.32 mg/l, recorded highest at Sarod, (1.15 mg/l) and lowest at Dahej (0.01 mg/l). Zinc (Zn), with average of 0.36 mg/l, recorded highest at Sarod, (1.12 mg/l) and lowest at Asarsa (0.01 mg/l). Chromium (Cr), with average of 0.17 mg/l, recorded highest at Sarod (0.57 mg/l) and lowest at Asarsa and Dahej (0 mg/l). Nickel (Ni), with average of 0.12 mg/l, recorded highest at Sarod (0.44 mg/l) and lowest at Asarsa and Dahej (0 mg/l). Lead (Pb), with average of 0.13 mg/l, recorded highest at Sarod (0.31 mg/l) and lowest at Asarsa (0 mg/l). Mercury (Hg), with average of 0.03 mg/l, recorded highest at Sarod (0.10

mg/l) and lowest at Neja, Asarsa and Dahej (0 mg/l). Cadmium (Cd), Cobalt (Co) and Magnesium (Mn) were absent from the sample. Mean heavy metal value (Fig.1.6) was observed higher at Sarod, 0.41 mg/l, as compared to other sites and the mean variation between the sites was significant (ANOVA F=5.98, Fcrit = 2.90 P<0.01). At high concentration site, Sarod, average mangrove and burrow density was observed as 0.39mangroves/ m^2 and 0.84 burrows/ m^2 respectively. At the lowest concentration of heavy metal site, Asarsa, average mangrove and burrow density was observed as 5.02 mangroves/ m^2 and 42.42 burrows/ m^2 respectively. Mean Mangrove density and mean heavy metal concentration showed significant negative correlation (r = 0.97) at all sites. Mean burrow density and mean heavy metal concentration also shows significant negative correlation (r = 0.93) at all sites.

In present study, heavy metals like Cu, Zn, S, Si, Sr, Ti and Br were recorded from the root, stem and leaves of *Avicennia marina* samples. Mean heavy metal value(Fig. 1.7) in root was observed higher at Sarod, 2.82 %, as compared to other sites and the mean variation between the sites was significant (ANOVA F=0.30, Fcrit = 3.00 P< 0.5). In roots, Copper (Cu), with average of 0.31 %, was recorded highest at Sarod (1.23 %) and lowest at Neja, Asarsa and Dahej (0.00 %). In roots, Zinc (Zn), with average of 0.18 %, was recorded highest at Sarod, (0.32 %) and lowest at Neja, Asarsa and Dahej (0.00 %). Mean heavy metal value (Fig. 1.8) in stem was observed to be higher at Dahej, 2.63 %, as compared to other sites and the mean variation between the sites was significant (ANOVA F=0.23, Fcrit = 3.00 P< 0.5). In stem, Copper (Cu), with average of 0.18 %, was recorded highest at Sarod, (0.70 %) and lowest at Neja, Asarsa and Dahej (0.00 %). In stem, Zinc (Zn), with average of 0.05 %, was recorded highest at Sarod, (0.21 %) and lowest at Neja, Asarsa and Dahej (0.00 %). Mean heavy metal value (Fig 1.9) in leaves was observed to be higher at Dahej, 4.83 %, as compared to other sites and the mean variation between the sites was not significant (ANOVA F=0.09, Fcrit = 3.00 P>0.5). In leaves, Copper (Cu), with average of 0.11 %, was recorded highest at Sarod, (0.45 %) and lowest at Neja, Asarsa and Dahej (0.00 %). In leaves, Zinc (Zn), with average of 0.04 %, was recorded to be highest at Sarod, (0.16 %) and lowest at Neja, Asarsa and Dahej (0.00 %).

In present study, heavy metals like Cu, Zn, K, Fe, Sr and Br were recorded from tissue of crab samples, Mean heavy metal value (Fig. 1.10) in crab was observed higher at Sarod, 1.44 %, as compared to other sites and the mean variation between the sites was significant (ANOVA F=0.67, Fcrit = 3.09 P<0.5). Copper (Cu), with average of 0.04 %, recorded highest at Sarod (0.16 %) and lowest at Neja, Asarsa and Dahej (0 %). Zinc (Zn), with average of 0.06 %, recorded highest at Sarod (0.14 %) and lowest at Asarsa and Dahej (0 %).

Mangrove Density (Figs. 1.11): Mangrove is the primary producer in the mangrove ecosystem and by evaluating its density one can have a fair idea about healthiness of the ecosystem. Many scientists have worked on mangrove ecosystem and produced valuable information on the forest structure of mangrove. But there are only few studies focusing on the density of mangrove. Kairo et al., (2002) studied mangrove of Watamu Marine National Reserve (Kenya) and reported relative density of A. marina 11.59 to11.57 mangroves/m^2.

In present study, maximum mangrove density was observed 32.67 mangroves/m^2 (Asarsa site, December'10) while lowest density was observed 1.0 mangroves/ m^2 (Sarod site, April'11) with overall average of 16.22 mangrove/m2. Mean mangrove density (Fig. 1.11), was observed higher at Asarsa, 25.11 mangrove/m2, as compared to other sites but the mean variation between the sites was not significant (ANOVA F =20.69, Fcrit = 3.09 P>0.5). Asarsa with highest mangrove density 5.02 mangroves/ m^2 showed burrow densirty of 44.55 burrows while with the lowest density of mangrove of 0.39 mangroves/ m^2 Sarod showed burrow density of 0.60 burrow/m^2. Average mangrove density showed non significant postive correlation with burrow density at different sites like Sarod (r = 0.34), Neja (r = 0.46), Asarsa (r = 0.49) and Dahej (r = 0.46).

Crab Density (Figs. 1.12, 1.13)

Associated macro benthic fauna plays an important role in mangrove ecosystem. They act as primary consumer (crabs), secondary consumer (fish) and decomposer (gastropods) in healthy mangrove ecosystem.
Prosser (2004) studied burrow density in mangrove of Moreton Bay (Australia) and reported mean density of 294 ± 29 burrows/ m^2.

In present study highest average burrow density in lower zone was observed as 44 burrow/m^2 (Asarsa Site, July'11) and lowest average burrow density in lower zone was observed as 0.50 burrows/ m^2 (Sarod, April'12) with overall average burrow density in lower zone of 18.30 burrows/ m^2. Mean burrow density (Fig. 1.12) in lower zone (32.77 burrows/ m^2) was observed higher at Asarsa, as compared to other sites and the mean variation between the sites was not significant (ANOVA F = 27.02, Fcrit = 3.09 P>0.5). Highest burrow density (44 burrows/ m2) in the lower zone was observed Asarsa with average mangrove density of 25 mangroves while lowest burrow density (0.55 burrows/ m2) in the lower zone was observed at Sarod with average mangrove density of 1.67 mangroves/ m^2. Average burrow density in lower zone showed significant positive correlation with mangrove density at sites like Neja (r = 0.57), Asarsa (r = 0.55) and Dahej (r = 0.58) while non significant positive correlation was observed at Sarod (r = 0.13).

In present study, highest average burrow density in upper zone was observed as 59.10 burrow/m2 (Asarsa Site, July'11) and lowest average burrow density in upper zone was observed as 0.40 burrows/ m2 (Sarod, April'11) with an overall average burrow density in uper zone of 30.04 burrows/m2. Mean burrow density (Fig.1.13) in upper zone (52.07 burrows/ m2) was observed to be higher at Asarsa, as compared to other sites and the mean variation between the sites was not significant (ANOVA F=293.36 , Fcrit= 3.09 P>0.5). Maximum burrow density (59.10 burrows/ m2) in upper zone was observed at Asarsa with an average mangrove density was 5.02 mangroves/ m2 while lowest burrow density (0.40 burrows/ m2) in upper zone was observed at Sarod with an average mangrove density was 0.39 mangroves/ m2. Average burrow density in upper zone showed non significant positive correlation with mangrove density at different sites like Sarod (r= 0.49), Neja (r= 0.19), Asarsa (r= 0.26) and Dahej (r= 0.20). Significant positive correlation was observed between lower zone and upper zone burrow density at different sites like Sarod (r= 0.66), Neja (r= 0.69), Asarsa (r= 0.92) and Dahej (r= 0.60).

Associated Fauna (Figs. 1.14): Health of mangrove ecosystem is reflected by the presence of associated fauna that are primary and secondary consumer and decomposers. It has been observed that diversity of associated fauna is more where the mangrove patch is relatively undisturbed then the mangrove patch which is disturbed, either by local population or by pollution. Many scientists studied mangrove associated fauna. Rao (1997) has reported different faunal groups like fishes (397 sp), crab (259 sp.), mollusca (256 sp), insect (450 sp.) and mammals (250 sp.) dwell the in mangrove ecosystem of the world. In present study, total 51 species belonging different groups like mollusca (7 sp.), arthopoda (13 sp) and cordata (31 sp.) were recorded.

Sarod has its own kind of diversity and didn't show any kind of similarity with other group. Neja has 60% similarity in species composition with the group of Asarsa and Dahej (Fig. 1.14). Asarsa and Dahej have 80% similarity in species composition. Maximum mangrove associated faunal diversity was observed at Asarsa (40 species) followed by Dahej (36 species) Neja (30 species) and Sarod (2 species). Amongst the mangrove associated species observed in the area, maximum species were reported form class Aves (25 species,11 families) followed by class Malacostraca (9 species,7 families),class Gastropoda (6 species, 6 families), class Insecta (4 species, 2 families), class pisces (3 species, 2 families), class Reptila (2 species,1 family) and Class Bivalve (1 species,1 family).

Conclusion

Though Chemical Oxygen Demand is good up to certain level, GPCB limits of COD in water is >4.0 mg/l (Deshkar et al., 2012). All the sites showed high COD in the water and sediments. As predicted Sarod had the highest COD of water and very low mangrove and burrow density per meter square. Although naturally occurring phenolic compound are good for mangrove, as they act as an antioxidant but artificial phenolic compound found in the water and sediments are cause of worry. As revealed in the results that although they didn't have significant effect of the associated fauna, further study is needed on the effect of phenolic compound on the density of crab and mangrove along with other factor. Heavy Metal recorded from the study showed that anthropogenic activities have considerable pressure on the mangrove ecosystem of the study site. Heavy metal in water and sediment shows negative correlation with mangrove and burrow density. The most striking results have been observed at Sarod where average mangrove and burrow density were 0.39 mangrove/ m^2 and 0.84 burrows/ m^2 respectively. This shows that the ecosystem is under tremendous pressure. Presence of heavy metal in mangrove also shows that there are defiantly chances of heavy metals to pass to human as mangroves of this area are utilized for fodder and also the seed consumption in form of food. Associated fauna also found contaminated with heavy metal which creates high risk of bio-accumulation in human as these fauna is an important part of the diet of the local people. Present status of mangrove, density, height and diameter, suggested that there are possibility that Sarod had relatively good patch of mangrove in past as Sarod has highest diameter of mangrove. But due to increasing pressure from the various anthropogenic activities that patch is now reduced to almost zero in case of mangrove density. As stated earlier burrow density can be an indicator of healthy mangrove ecosystem, Sarod being most polluted site had very low burrow density in both zone as compare to other site. Composition of associated fauna clearly reflects the fact that status of physiochemical parameters and degree of pollutant affect the diversity of associated fauna in the mangrove forest. Sarod being most pollutant site had very less diversity of associated fauna while on other hand Asarsa, relatively free from pollution, had high diversity. But the high diversity of associated fauna at Asarasa, Neja and Dahej is facing pressure anthropogenic activity, i.e. fishing.

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Map 1: Location of study sites

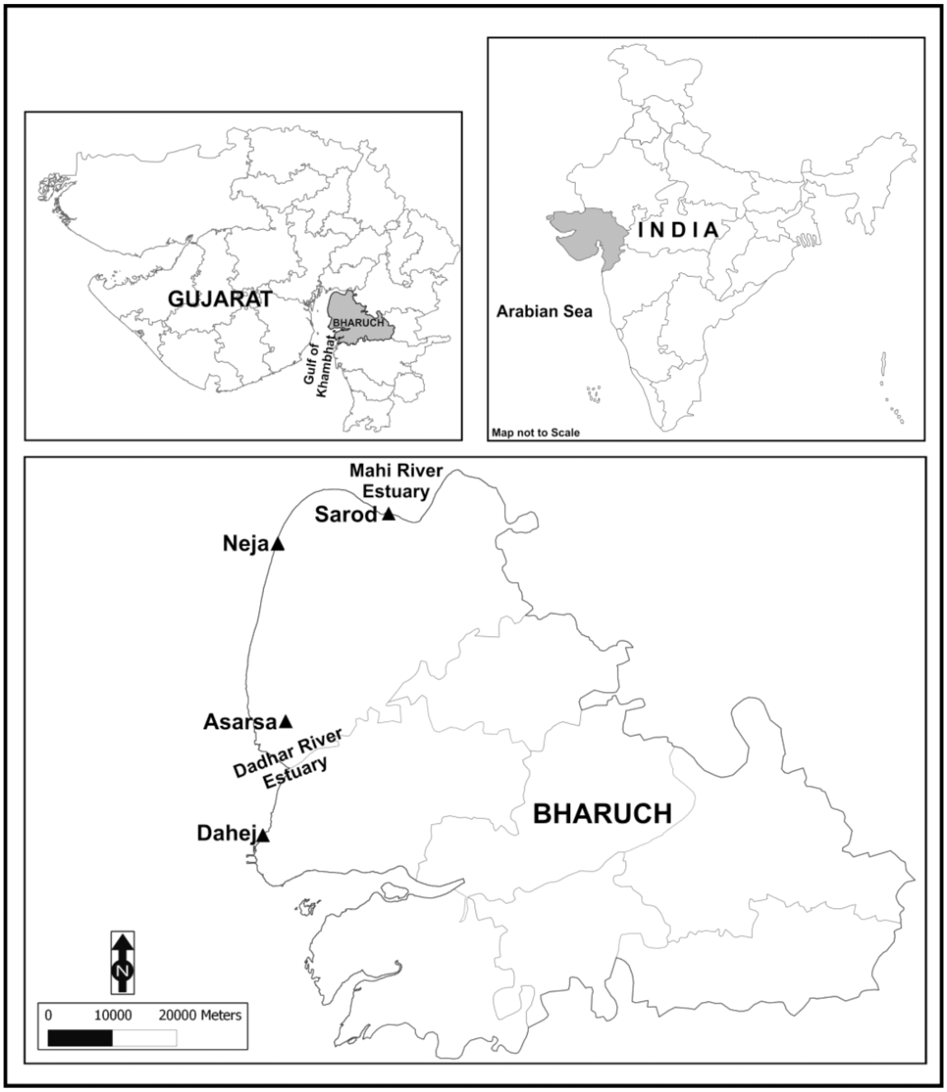

Fig. 1.1: Analysis of COD (mg/l) of Water at all Sites

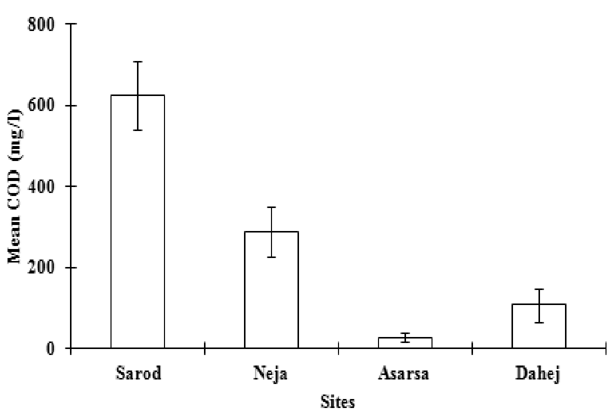

Fig. 1.2: Analysis of COD (mg/l) of Sediment at all Sites

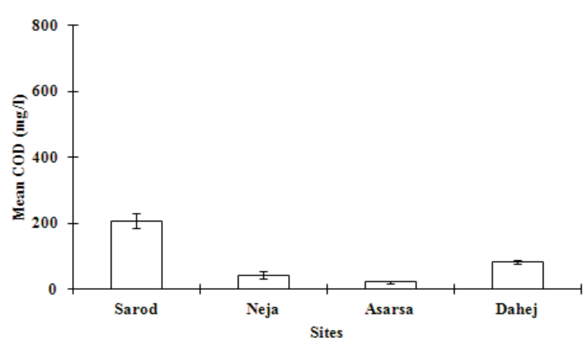

Fig. 1.3: Analysis of Phenolic Compounds (mg/l) of Water at all Sites

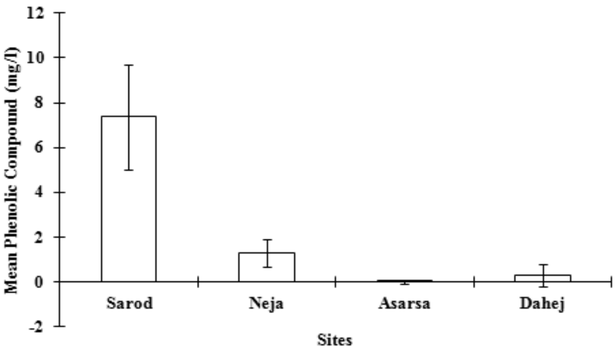

Fig. 1.4: Analysis of Phenolic Compounds (mg/l) of Sediment at all Sites

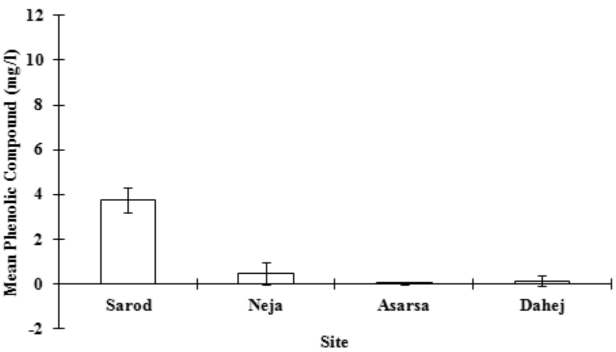

Fig. 1.5: Analysis of Heavy Metal (mg/l) of Water at all Sites

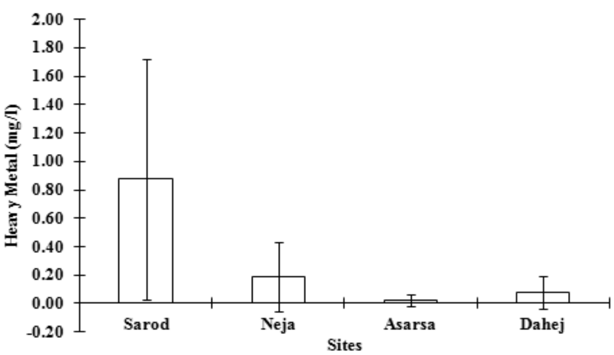

Fig. 1.6: Analysis of Heavy Metal (mg/l) of Sediment at all Sites

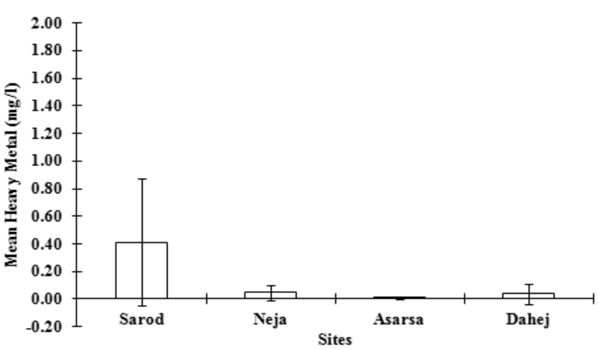

Fig. 1.7: Analysis of Heavy Metal (%) presence in *A. marina* Root at all Sites

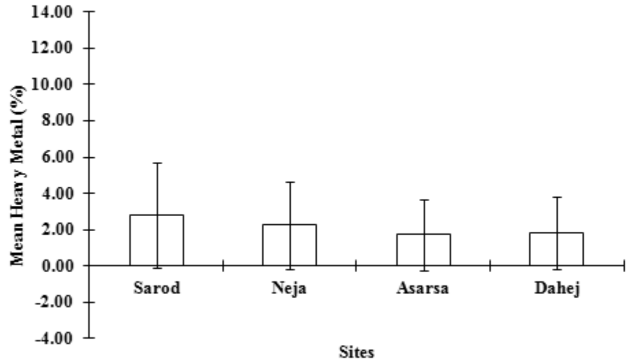

Fig. 1.8: Analysis of Heavy Metal (%) presence in *A. marina* Stem at all Sites

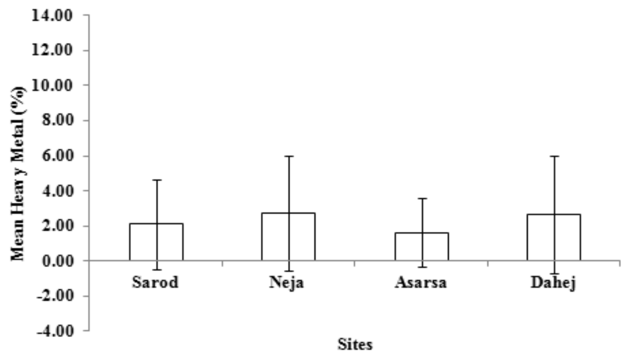

Fig. 1.9: Analysis of Heavy Metal (%) presence in *A. marina* Leaves at all Sites

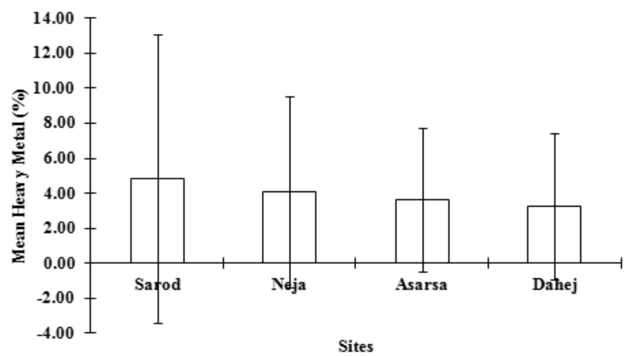

Fig. 1.10: Analysis of Heavy Metal (%) presence in Crab at all Sites

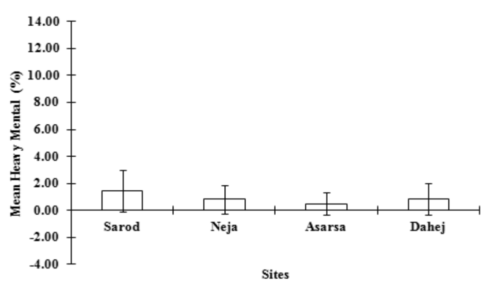

Fig. 1.11: Analysis of Mangrove Density (m2) at all Sites

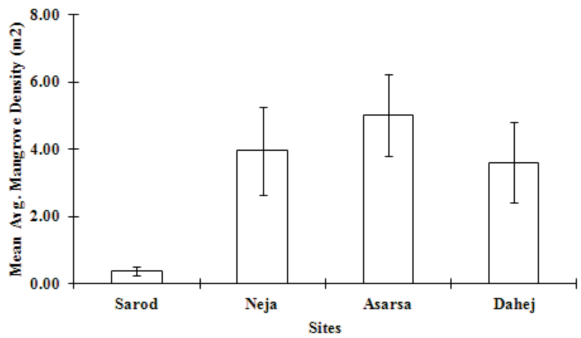

Fig. 1.13: Analysis of Upper Zone Burrow Density (m2) at all Sites

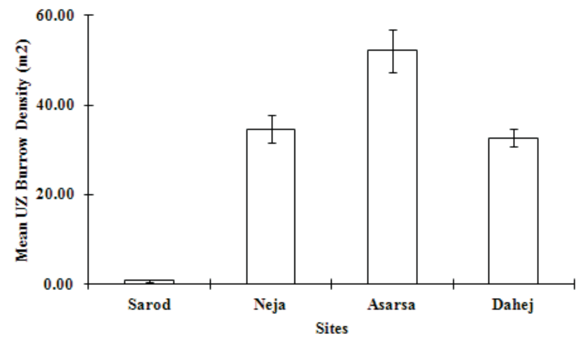

Fig. 1.12: Analysis of Lower Zone Burrow Density (m2) at all Sites

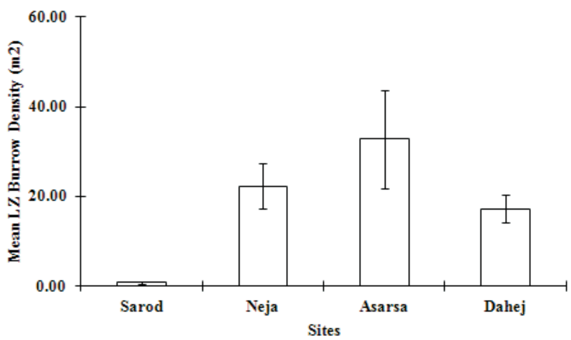

Fig. 1.14: Bray-Curtis Analysis of presence of associated fauna at all Sites