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Ecological Assessment for Water Quality of Bhavanapadu (Mangrove) Swamps of North Coastal Andhra Pradesh, East Coast of India

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Abstract: This paper examined nutrient dissolved metal concentration in Bhavanapadu mangrove ecosystem at North Coastal Andhra Pradesh in the east coast of India—the area studied. Surface water samples were collected from the different regions of mangrove-creek complex during the post-monsoon season. There was distinct variation in chemical constituents of water among the creek, mangrove and bay region. Physicochemical parameters like pH, EC and TDS and nutrients like NO_3 and PO_4 varied significantly among three sectors. The cations like K^+, Ca^{2+} and NH_4 and anions like SO_4^{2-}, HCO_3^- and SiO_2 didn't showed any significant variation. There is high concentration of dissolved metal in this mangrove system. The above fact will reveal that mangrove is facing severe threat due to industrial pollution. The metals, Cu, Zn and Co showed higher affinity, while Pb and Cr also result in strong coupling with each other.

Key words: Water quality, heavy metals (water, sediment), estuary, mangrove, India, geochemistry, stratification, coastal area, pollution, surface sediment.

Introduction

The cycling of heavy metals, because of their toxicity, bio-accumulation capacity and persistence, is a serious question recently addressed by many studies on mangrove environments (Harbison, 1986; Clark et al., 1998). In contrast with organic pollutants, heavy metals cannot be biologically or chemically degraded and thus may either accumulate locally or be transported over long distances. In natural environments, the associations of metals and their distributions depend on various parameters including redox conditions (Guo, 1997) and organic contents (Nissenbaum et al., 1976; Mounier, 2001). These parameters may influence the toxicity of metals through processes like mercury methylation and by controlling their availability for living organisms (Mason et al., 1994). In addition, metals can be adsorbed onto the surface of minerals, like clay minerals, Fe and/or Mn oxy-hydroxides (Dong et al., 2000; Quemerais, 1998). Consequently, high concentrations of heavy metals can accumulate in sediments and especially in fine-grained oozes, which present high mineral specific surfaces. Mangrove ecosystems, developing in the intertidal zone of most tropical and subtropical regions, are characterized by major contrasts in redox conditions and high rates of organic carbon accumulations (Krishna Mohan, 2008). They may act as a sink or a source of heavy metals in coastal environments because of their variable physical and chemical properties (Kathiresan, 2007). The present study was undertaken to understand the prevailing situation of the water quality and the impact of the anthropogenic input on this mangrove dominated creek ecosystem.

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Materials and Methods

Site Description and Characteristics

Geographically Bhavanapadu (18° 32′ N and 84° 17′ E) is a panchayat village of Santhabommali Mandal of Srikakulam district, Andhra Pradesh and a coastal village where marine and estuarine fishing is the main occupation of the inhabitants. The area (Figure 1) is covered in the survey of India toposheet 74B. The village is on the Indian East Coast, at the northern borders of the Orissa state. The village has a natural creek in its southern borders, the mouth of which has a width of >100 m. It is a tide-dominated mangrove with areas of high tidal range of semidiurnal; with mean tide level 1.5 to 3.4 M. These area exhibit bidirectional tidal fluxes and thus forms extensive, low gradient inter-tidal zones available for mangrove colonization. It supports a rich floral diversity with about 14 species of mangroves.

The average annual rainfall is about 1670 mm of which ~70% is received during August and September. In summer, the temperature ranges from 30°C to 20°C (day and night respectively) whereas during winter it is 20°C to 15°C (Meteorological Department, 2006). The relative humidity remains between 75 and 80% throughout the year. The sediments are divided into two categories, "older alluvium" (GSI, 1974). The recent sediments are presented by sand, silt and clay with assorted boulders and pebbles, which are dark and loosely compacted with high moisture content. The Pleistocene deposits comprise clay, sand, silt and "Kankar", with locally cemented pebbles and gravels. These are reddish brown due to high degree of oxidation (Banerjee et al., 1990).

Sampling Techniques

The samples were collected during the post-monsoon period of year 2005 from three zones—creek, mangrove region and bay region. Fifteen samples were collected. Water samples were collected at low tide so as to minimize the tidal fluctuations. The average of the measurements was considered for data interpretation. Thermo-Orion water analysis kit (Model Beverly, MA, 01915) was utilized to examine pH, electrical conductivity (EC), and total dissolved solids (TDS). Bicarbonate (HCO^{3-}) was measured by titration at the time of sampling. Samples were collected in pre-washed polypropylene bottles separately for nutrient and heavy metal analysis. Samples for metal analysis were filtered through 0.45 µ glass fibre Whatmann filter paper and acidified to preserve dissolved metals. The collected samples were stored in ice-chest during sampling and were transferred to the laboratory and stored at 4ºC until further analysis. Analysis of water samples was carried out as per the standard procedures mentioned (APHA, 1998). Dissolved metal was measured by using an

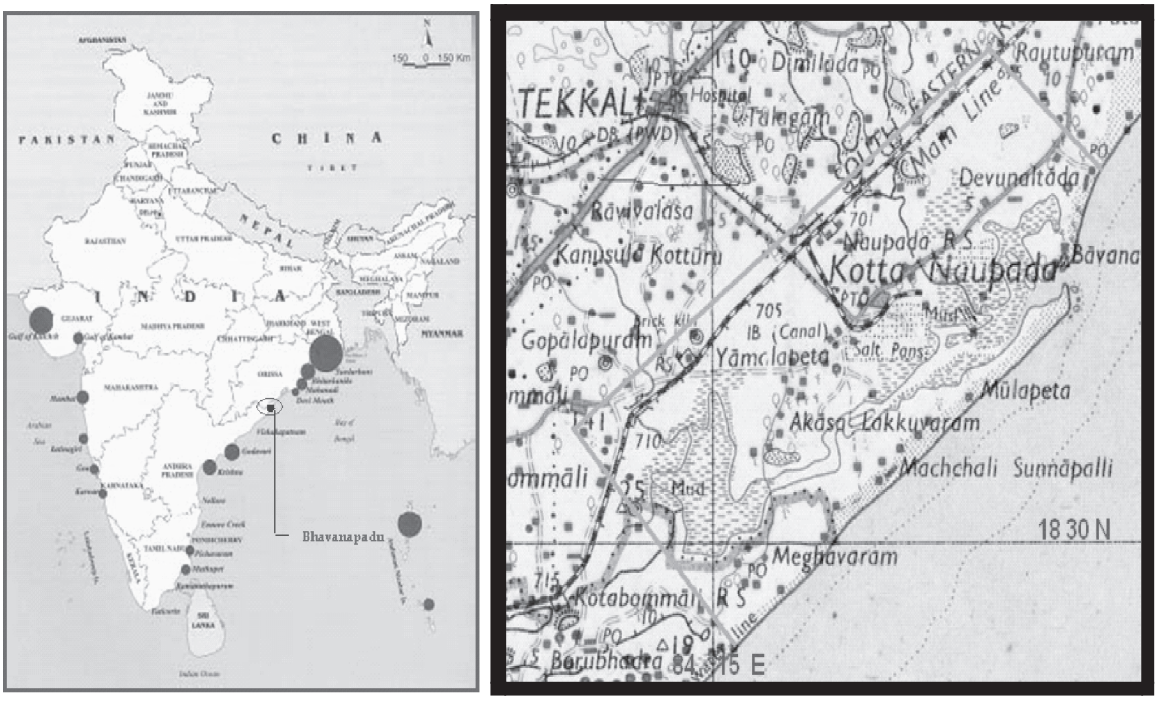


Figure 1: Topo map of the Bhavanapadu study area.
(GSI Sheet 74 B, 2nd Edition, 1978).

(Shimadzu-AA-6800) Atomic Absorption Spectroscope. The instrument was standardized using multi-elemental standard MESS 2 (Merck). The percentage error for all samples examined was within 5%. Statistical calculation was done using MS Excel ver. 2003 and Statistica 5.5.

Results and Discussion

Water Quality Analysis

The Bhavanapadu Creek system is tide nominated. The environmental parameters showed wide variations as per the topography and geomorphic setting of the ecosystem. The three regions viz. creek, mangrove and bay are well marked in the system. Creek region is the region with entry point of Bhavanapadu Creek to mangrove area and is area of intermixing of freshwater with the tidal area. Mangrove area represents the area dominated by dense mangrove vegetation. The Bay region represents the area close to Bay of Bengal i.e., the entry point of tidal water (Figure 2).

A large variability in all parameters was observed within all the three regions as depicted by Table 1. The pH of water was highest as 8.0 in bay regions, which represents the pH of typical seawater, while the pH of creek area is next in line, as represents the mixing of freshwater with sea water (Table 1). The physicochemical parameters of water such as pH, EC, TDS differ significantly among three regions (Table 2). The EC showed a large range of 3200-33,750 $\mu S.cm^{-1}$, along the gradient from creek area to bay region, which is primarily due to mixing of seawater with river water. The creek and mangrove region represent a similar average chloride (Cl^-) concentration (5870 mg l^{-1}), while it was gradually increased to 12,200 mg l^{-1} for the bay region. Bicarbonate (HCO_3) concentration showed a decreasing tendency along the creek to bay region. The bicarbonate and calcium (Ca) values are indicative of intense chemical weathering in the Indian subcontinent. The high sulfate (SO_4^{-2}), chloride and sodium (Na) values are largely due to the proximity of the sea (Subramanian, 1987) (Table 1).

The present data also reveals that potassium (K) was lower in concentration than Na. This may be due to preferential absorption and incorporation into silicate minerals (Ramanadham, 1993). Ca and K concentration is highest in creek region, due to the more influx of riverine source. Bhavanapadu Creek catchments are characterized by recambrian granites, gneisses and schist's of the Eastern Ghats. There is local basic intrusive and volcanic lithologies; limestone, sandstones and shale

1 to 6: Creek region Water Quality Monitoring Stations
A to D: Freshwater drains
* Mangroves region
Δ Bay region

Figure 2: Location map (a satellite view) of study area representing various sampling locations of three regions – mangrove, creek and bay sites.

of the Gondwanas; and recent deltaic alluvium deposits at the river mouths on the Bay of Bengal (Ray et al., 1984). However, no distinct variation was observed for K, Ca and SO_4^{-2} among the three regions (Table 2).

Generally, creek mangrove waters have relatively low content of dissolved inorganic phosphorus and nitrogen (Alongi et al., 1990). In some cases, the degree of human impact seems to control nutrient (Nedwell, 1975; Nixon et al., 1984), while in others the degree of upland influence and the hydrology of the ecosystem appear to be of greater importance (Ovalle et al., 1990). The entire mangrove system of the study area had shown significant variation in nitrate and phosphate (Table 2). Higher nitrate and phosphate concentration in creek water is mainly due to intense agricultural activities. The agricultural activity involves extensive usage of urea and diammonium phosphate fertilizers. In mangrove region, the rich microbial community utilizes nitrate and phosphate for their metabolism (Dittmar et al., 2001). In bay region, nitrate and phosphate content is higher. This is due to intense Bhavanapadu port activity as well as agricultural runoff from nearby villages (Table 1). The

Table 1: Physicochemical constituents of water in different sectors of Bhavanapadu mangrove average concentration of heavy metals for all sampling sites

	Creek		*Mangrove*		*Bay region*	
*Concentration***	*Mean**	*SD*	*Mean**	*SD*	*Mean**	*SD*
pH	7.6	0.2	7.5	0.3	8.0	0.3
EC ($\mu S.cm^{-1}$)	3200	337	13438	4419	33750	14820
Na	393	83	575	102	739	215
K	147	35	133	39	131	35
Ca	166	95	110	45	0.1	70
SO_4	346	58	370	73	475	220
PO_4	0.3	0.1	0.2	0.1	0.4	0.2
NO_3	1.2	0.3	1.0	0.2	1.6	0.6
Cl	5870	119	5900	278	12200	626
HCO_3	74	14	69	26	56	16
SiO_2	25	12	27	3	32	17
NH_4	0.22	0.13	0.16	0.17	0.17	0.19

* Mean of five replicates.

**All concentrations are in mg/l except EC, where it is $\mu S.cm^{-1}$.

Table 2: Analysis of variance (ANOVA) table for Bhavanapadu mangrove three regions—creek, mangrove and bay region

Parameters	*F*	F_{crit}	*Significance at 0.05*
pH	5.64	3.46	√
EC	23.3	3.46	√
TDS	5.39	3.46	√
Na	4.22	3.46	√
K	0.37	3.46	X
Ca	1.74	3.46	X
SO_4	1.86	3.46	X
PO_4	5.56	3.46	√
NO_3	5.29	3.46	√
Cl	5.85	3.46	√
HCO_3	1.19	3.46	X
SiO_2	0.8	3.46	X
NH_4	0.46	3.46	X

√ – Significant

X – Non-significant

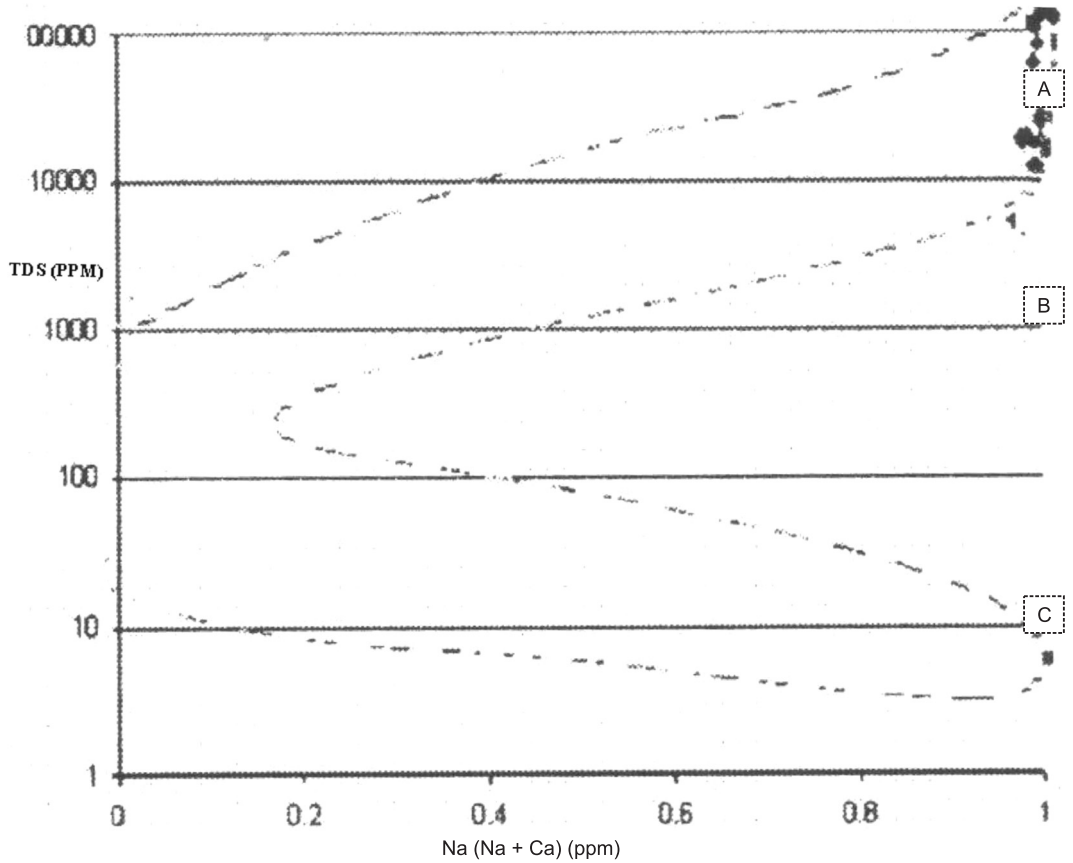
Gibbs diagram of the source of total dissolved material in the mangrove water gives the impression of salinity dominance. This is essentially due to tidal influence from nearby Bay of Bengal (Figure 3.).

Heavy Metal in Bhavanapadu Mangrove

A large variability was observed in the concentration of heavy metals in water from all three sectors. The creek region represents the highest concentration for all the selected heavy metals, which is confluence/entry point of Bhavanapadu Creek with mangrove area. The heavy metal concentration was lowest in the bay regions (Table 3). This is due to pioneer function of mangrove i.e. mangrove forest act as filter for the ecosystem. The coastal region receiving water from mangrove is almost devoid of heavy metal (Lacerda et al., 1998). Major source of heavy metal pollution in the mangrove system are the Bhavanapadu creeks. These creeks were shown to have extremely variable trace element concentrations, which is consistently higher than the world river average (Konhauser et al., 1997). The impact on pollution on river chemistry is most evident in the Bhavanapadu Creek, where high elemental concentrations correspond to the presence of heavily industrialized areas (GSI, 1974).

Bhavanapadu Creek receives aqueous effluent discharged by fertilizer industries and agricultural, thermal power stations. These industries utilize coal and are active source of fluorides, nitrogen compounds, cyanide, chromium, fly ash and other suspended solids. The end result of all industries is a collective discharge of effluent, in which the concentrations of most elements are enriched over 10 times the upstream values (Konhauser et al., 1997). Correlation analysis depicted a positive and significant (p<0.05) correlation of Fe and Mn (0.7). The Zn also observed positive correlation with Co (0.94) and Cd (0.94). Pb and Cr also revealed positive and significant correlation which shows the strong affinity for each other (Table 4).

Table 5 will ascribe the factor analysis that had been carried out to delineate the sources and interrelationships



A: Evaporation/crystallization dominance; B: Weathering dominance and C: Precipitation dominance.

Figure 3: Gibbs diagram showing the dominance of salinization process by means of evaporation/crystallization dominance.

Table 3: Average concentration of heavy metals for all Bhavanapadu mangrove sampling sites

	Creek region		*Mangrove region*		*Bay region*	
Conc. (mg/l)	*Mean**	*SD*	*Mean**	*SD*	*Mean**	*SD*
Fe	4.10	2.13	7.19	4.43	6.72	4.12
Mn	0.03	0.02	0.15	0.25	0.12	0.26
Ni	0.04	0.03	0.04	0.04	0.03	0.05
Zn	0.59	0.74	0.14	0.09	0.09	0.10
Cr	0.38	0.11	0.35	0.17	0.35	0.09
Co	0.47	0.27	0.14	0.09	0.09	0.10
Cd	0.47	0.17	0.14	0.09	0.10	0.11
Pb	0.40	0.14	0.41	0.23	0.37	0.12

* Mean of five replicates.

Table 4: Spearman coefficient of correlation matrix for all heavy metals

	Fe	*Mn*	*Ni*	*Zn*	*Cr*	*Co*	*Cd*
Mn	0.71						
Ni	0.09	0.31					
Zn	0.03	-0.12	0.18				
Cr	0.12	0.07	0.35	-0.17			
Co	0.05	-0.14	0.13	0.94	-0.06		
Cd	0.05	-0.12	0.15	0.94	-0.05		
Pb	0.07	0.00	0.37	-0.16	0.91	-0.07	-0.06

Table 5: Principal component analysis (factor) of heavy metal component

Conc. (mg/l)	*1*	*2*	*3*
Fe	-	-	.890
Mn	-.118	-	.937
Ni	.212	.573	.294
Zn	.975	-	-
Cr	-	.944	-
Co	.988	-	-
Cd	.990	-	-
Pb	-	.954	-

Variance
Extraction Method: Principal Component Analysis
Extraction Method: Varimax with Kaiser Normalization

between the heavy metals. Factor 1 is statistically dominant and accounts for 37 percent of variance.

This factor is characterized by strong loading of Zn, Co and Cd, due to industrial pollution in the upstream of Bhavanapadu Creek. Factor 2 accounts for 26 percent of variance with positive loadings of chromium and lead, which is derived from port activities. Factor 3 accounts for 22 percent of variance and depict the strong biogeochemical affinity of iron and manganese. In the deep reducing part of the sediment iron and manganese hydrous oxides are dissolved and migrate upward through the sediment column and are subsequently precipitated in the oxidizing sediment surface or lost to the overlying water and thus added to water column (Olausson et al., 1980).

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