

GEOCHEMICAL AND SEDIMENTARY PROCESSES IN THE MANGROVE SWAMPS OF GODAVARI DELTA: IMPLICATIONS ON COASTAL AND ESTUARINE BIOLOGICAL ECOSYSTEM

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ABSTRACT

Mangrove swamps along the coastal tracts act as buffer zone between land and sea and provide habitats and sustenance to many fauna and flora. As could be observed elsewhere, the mangrove swamps of Gautami sector of Godavari delta forms vital link of food chain to diversified fauna and flora and for the same reason, the area has been declared as wildlife sanctuary. Statistical analyses of granulometric and geochemical data of sediment samples from these mangrove swamps revealed that the swamps act as repositories of organic carbon and associated heavy metals through adsorption and complexation processes. Integration of these results with data on land use and shoreline changes, deltaic coast evolution and the nature of mangrove colonization suggests that the wildlife sanctuary is under ecological threat and needs nourishment.

Key Words: Mangrove, sedimentation, geochemistry, ecosystem, statistics.

INTRODUCTION

The coastal zone in India is important in view of its productive ecosystems, concentration of population and for exploitation of renewable and non-renewable natural resources (Nayak et al. 1996). The coastal vegetation plays an important role in the deltaic environment by enhancing the sedimentation and stabilization of the seashore and sea bottom. It provides habitat and nursery areas for many commercially important fish and crustaceans (Robertson and Duke, 1987) and play important role in chemical buffering, water quality maintenance and storage of genetic materials (Saenger et al. 1983) besides contributing considerable amount of organic matter (Odum and Heald, 1972; Day et al. 1973; Prakash et al 1973; Boto, 1982; Untawale and Jagtap, 1991) thereby increasing the productivity of the coastal waters. The deltaic regions have allochthonous coasts wherein the freshwater discharge along with terrestrial sediments, due to flocculation effect, leads to the rapid deposition of terrigenous sediments. The detritus and litter in these sediments help colonization of flora thereby aiding in land growth and stabilization. The establishment of mangroves and associated species on the

newly stabilized land causes rapid deposition and firmament of mangrove swamp occurs within 50-100 years (Untawale and Jagtap, 1991). The rising sea level and indiscriminate felling of mangroves for fuel and aquaculture ponds drastically affects these natural geological processes and lead to rapid retreat of shoreline landwards; as a consequence of which, the existing equilibrium in the ecosystem gets disturbed which may be, sometimes, irreversible (Saenger et al. 1983). Owing to their importance, many workers have recorded the sedimentary characteristics of the mangrove swamps (for example, Cauvery delta – Ramanathan, 1997; Periyakali et al. 2000; Krishna and Godavari deltas – Rao and Swamy, 1987, 1991, 1995; Mahanadi and Pennar deltas – Swamy et al. 1990).

The Godavari delta, third largest after those of Ganges and Mahanadi, hosts vast tracts of mangrove swamps. Ramkumar et al. (1999, 2000a) have recorded the ongoing shoreline shift due to sea level rise (1.2mm/year – Bird, 1985) and land subsidence (1.34m since Flondrian? – Ramkumar et al. 2000b) that destructs coastal mangroves which are protected as Coringa Wildlife Sanctuary (CWS). Added to these, there has been a spurt in destruction of mangrove swamps around the CWS for the development of aquaculture ponds, which can pose a serious threat to the ecosystem. This paper attempts to understand the environmental factors that influence sedimentary and geochemical processes on the mangrove swamps in and around CWS and draw implications on the preservation of ecology of the CWS.

METHODS AND MATERIALS

The study area (Fig.1) has been systematically mapped in the scale of 1:25,000. The geomorphic landforms vis-à-vis sedimentary environments were delineated and their boundaries were fixed with the help of GPS. The information collected from the field were compiled to produce sedimentary environmental map of the study area (Fig.2). From the field, 10 uncontaminated surface samples of mangrove swamp were collected. They were analyzed for organic carbon (OC) and CaCO₃ following the procedures of Jockson (1973) and are expressed in Wt%. Bulk sediment samples were analyzed for trace elemental concentrations namely, Cu, Ni, Pb, Zn, Cr and Co with the help of Atomic Absorption Spectrophotometer and are expressed in ppm. Na and K were analyzed with Flame Photometer and are expressed in ppm. The sediment samples were subjected to sieve and pipette analyses following the standard procedures and are detailed

in Ramkumar et al. (2000c). The granulometric data were used for calculating sand-silt-clay ratio and statistical parameters of the sediments in terms of mean size (M_z), sorting (S_d), skewness (S_K) and Kurtosis (K_G). Standard laboratory procedures were followed for generating geochemical and granulometric data on these sediments and are detailed in Ramkumar et al. (2000b). The statistical parameters of granulometric and geochemical characteristics of mangrove swamp sediments are presented in the table 1. In this paper, comparison of the data with other deltaic regimes and statistical analyses of the data were performed to draw inferences on status of sedimentological and geochemical processes in mangrove swamp.

RESULTS AND INTERPRETATIONS

The sediments are of fine silt to clay with poorly to very poorly sorted nature, implying widely varying, yet low energy conditions of deposition. They are very coarse to very fine skewed and very platykurtic to extremely leptokurtic, signifying prevalent low energy conditions and deposition under the influence of tidal asymmetry. The organic carbon content is comparatively high (mean 0.739%; minimum 0.106%; maximum 2.778%). Occurrence and preservation of organic carbon in sediments depend on the rates of accumulation of organic matter content, its decomposition, dilution by clastics and burial. The CaCO_3 content of these sediments are higher (mean 6.9%; minimum 2%; maximum 15%). The amount of CaCO_3 in sediments is dependent on the source, dilution by clastic influx and the physicochemical factors acting upon them (Stewart, 1958). Among trace elements, Zn shows very low variability (standard deviation 16.462) while that of K is very high (standard deviation 991.031). Data after Deurer et al. (1978) imply that the co-precipitation with carbonates may be an important mechanism for metals viz., Zn, Cd, etc. It has been observed that the heavy metal cations sorbed onto the surface of carbonate become part of the crystal lattice (Forstner and Wittmann, 1983). As will be explained latter, the affinity of heavy metals to organic matter and its decomposition products also govern the behavior and distribution of heavy metals in the sediments.

Correlation analysis was performed to understand relationships between the sedimentological and geochemical parameters and the results are presented in table 2. For statistical analyses of the data, the procedures presented by Ramkumar et al. (2000b) have

been followed. For interpretations, only the correlations that have more than 95% significance level, identified by STASTICA software were taken for consideration.

Mz is positively correlated with clay, Cu and Co implying that these elements were sorbed onto and or accumulated along with, finer fraction of the sediments. The negative correlation of Mz with Sd indicates poor or lack of sorting in the finer fraction of sediments. This interpretation is supported by negative correlation of Mz with S_K. Negative correlations of Mz with sand, Pb and Na could be interpreted as either or all of the factors listed herein.

- a. Periodic prevalence of higher energy conditions in the mangrove swamps. When energy conditions are high, finer fractions of sediments are swept away, leaving behind the coarser fractions in the sedimentary record.
- b. The elements Pb and Na are associated exclusively with coarser fraction of the sediments. Since Pb is an industrial element (increased accumulation of it in natural sedimentary environments after the advent of industrial era earned this name to Pb – Grant, 1990) and the fact that Na is available abundantly in seawater, non-correlation of Pb and Na in CaCO₃ and absence of negative correlation (Pb and Na may occupy the lattice positions of Ca in shell carbonates because of more or less similar atomic size and chemical properties) force to interpret that the industries and urban settlements located along the Kakinada bay could have contributed Pb to the mangrove sediments. The proximity of these industrial and urban settlements to the mangroves and prevailing circulatory currents in the Kakinada bay (Fig.2) may also have been influenced sorbtion of heavy metals onto suspended particulate materials and organic mater and deposited them in mangrove swamps give rise to preferential accumulation of heavy metals. As these heavy metals have lesser mobility and residence time in aquatic medium, they might have been deposited in nearby mangrove in view of favorable conditions namely proximity to source and depocenter and flocculation effect, etc.
- c. It is also to be noted that in view of rising sea level and reducing discharge, the river Godavari is not debauching fresh water directly to the Bay of Bengal via its confluences; rather it takes a circuitous route via comparatively low energy regimes such as Kakinada bay and adjacent mangrove swamps (Ramkumar, 1999). During its

course, the river crosses many industrial establishments and aquaculture ponds (Fig.3) that release their effluents directly to the Godavari estuary. These factors contribute directly towards the enrichment of Pb and Na in mangrove swamp sediments. These interpretations are supported by the existence of positively correlated nature of sand with Ni and Pb as higher energy conditions bring in coarser sediments, which in turn have higher concentrations of Ni and Pb.

The standard deviation is negatively correlated with Cu that may be interpreted as association of Cu only with finer fractions of the sediments and its preferential accumulation/sorption onto finer sediments owing to higher surface-volume ratio. It could also be established in accordance with Ramkumar et al. (2000b) that such sorption takes place in lower energy conditions, which facilitates prolonged sediment-water interaction. S_K is positively correlated with sand and Na and negatively correlated with Clay, Cu and Co, which support the interpretations presented in preceding sections.

Sand is positively correlated with OC. Generally, organic matter is enriched with finer fractions of the sediments (Kukul, 1971; Al-Ghadban, 1990) as reported by Nedwell et al. (1994), Hedges and Keil, (1995), de Haas et al. (1997), Rao and Swamy (1995), Ramkumar et al. (2000c) and Periyakali et al. (2000) who have reasoned such behavior of OC as a result of similarity in the settling pattern of organic carbon and finer fraction. However, presence of positive correlation between sand and OC is also observed in many cases such as Anton et al. (1993) and could be attributed to deposition from suspension cloud in depocenters at or near standing water body. Occurrence of unsorted nature in mangrove sediments supports this assertion. Ramkumar et al. (2000a) reported erosion of coastal lagoons (that contain repetitive sequences of peat bogs) and mangrove swamps (naturally enriched with organic carbon) and transport of eroded sediments towards estuary and offshore (depending on tide and discharge conditions). In such a case, the materials transported towards inland should settle at or near the erosional regimes. This inference is being supported by the proximity of these mangrove swamps to the eroded regimes. Periyakali et al. (2000) also observed the occurrence of association of organic matter with that of coarse fraction and sought to explain it by the occurrence of coarse vegetal organic debris and also partly to the induced adsorption of organic matter onto the mineral grain surface. They have drawn support from the statement of Tipping (1981)

that adsorption of organic material onto mineral grains was increased by the formation of complexes with Ca^{2+} and Mg^{2+} which is a result of adsorption of Ca-organic complexes, where the calcium ion bonds to the surface. Anton et al. (1993), based on their observation of positive correlation of organic carbon with coarse fractions, concluded that it must have been resulted by terrestrial contaminants. It is to be noted that, in order to maintain required pH levels in aquaculture ponds in and around the study area, lime powder (CaCO_3) is being added at periodical intervals. Draining of water from aquaculture ponds directly to the crisscrossing tidal channel and Godavari estuary without any treatment has been a regular practice in this region. This effluent is hypersaline and contains exotic concentrations of Ca and nutrients; which should have increasing influence over the natural complexation processes of organic matter with heavy metals. Tipping (1981) also pointed out that Ca^{2+} and Mg^{2+} might reduce the electrostatic repulsion between the molecules at the surface. Thus, increase in Ca^{2+} and Mg^{2+} concentrations due to the mixing of hypersaline water with fresh water might have increased the interaction between organic matter and mineral grains, generating positive correlation between coarser fractions of sediments and OC.

Silt is positively correlated with CaCO_3 , and is in accordance with the observations of Al-Ghadban (1990) implying occurrence of silt sized shell materials and microorganisms in the sediments (Periyakali et al. 2000). Occurrence of perfect negative correlation of clay with CaCO_3 supports this interpretation. Organic carbon is positively correlated with Pb (and also has less significant correlation with Na) which, along with positively correlated sand may serve as a pointer to that organic matter in these sediments must have been brought from erosional sources. The organic matter, in view of its higher reactivity, sorbs the industrial toxic pollutants such as Pb. This inference has serious implication, as the mangrove swamps supply nutrients to the coastal waters through resuspension process and majority of coastal and estuarine biological cycles depend on these nutrients. On resuspension and intake of OC by the biological components of the system, lead toxication would severely cripple the food chain and life cycle of coastal and estuarine organisms. Together, negative correlation of OC and Pb with Cu and positive correlation of Cu with finer fractions, could be viewed as that the trace metals Cu and Pb have entirely different sources and also accumulate/sorbed onto/complexed with different

size fractions of sediments. The Ni and Cr are positively correlated implying similarity of behavior during accumulation in sediments. Pb is negatively correlated with Co and positively correlated with Na.

Studies of possible contamination of sediments often generate data on concentrations of those elements which may be anthropogenically enriched (such as Pb, Cr, Zn, Cu, etc. – Grant, 1990). Several studies have sought to identify areas of particularly high anthropogenic contamination by using multivariate statistical analyses of such data sets (Samhan et al. 1987; Hamilton, 1989; Krumgalz, 1989; Simenov and Andreev, 1989). Factor analysis has been used extensively for extracting natural (Periyakali et al. 2000) and anthropogenic (Grant, 1990) imprints on the sediments and thus it was attempted with varimax rotation in the present study. It has given rise to three factors explaining 83.31% (Table 3). Cumulatively, the variables Mz, clay and Pb have contributed towards the three factors than any other variables implying two dominant factors namely, energy condition and accumulation of Pb that take place in the mangrove swamps of CWS.

The first factor explains 48.42% of variance and accounts for 58.12% of the total variance explained by all the three factors. This factor is positively loaded with Sd-S_K-Sand-OC-Pb-Na, which means that higher energy conditions prevalent in the mangrove swamps brought in coarser fractions; or, selectively removed finer fractions leaving behind only the coarser fractions. However, the observed poor sorting in these sediments suggests that the sediments are brought to the depocenter by suspension clouds and when the critical velocity of currents decreased, settling took place, which has resulted in unsorted nature. The coarser fractions of sediments possess high content of OC, Pb and Na. Higher content of organic matter in association with toxic heavy metals has been considered as an index of severe pollution by Mohammed and Shamlan (1977). Occurrence of association between finer fractions (Clay), Cu and Co is explained by the negative loading of Mz-Cu-Co-clay in this factor. The second factor explains 20.64% variance and accounts for 24.78% of total variance explained. This factor is positively loaded with clay and negatively loaded with silt-CaCO₃ implying preferential occurrence of CaCO₃ in silt sized fractions in the form of microorganisms and shell material. It could also be interpreted as exclusive terrestrial source for clay, which thwarts deposition of

CaCO₃ as the latter could get deposited/precipitated only in areas where clastic deposition did not take place. The third factor is negatively loaded with Ni and Cr. This factor explains 14.25% variance and accounts for 17.10% of total variance explained. This factor, together with positive correlations of Ni and Cr with Sd, sand, OC and negative correlation with Cu and clay (although few correlations are not significant to 95% confidence level) could be interpreted such that they were drawn from terrestrial sources and followed the sedimentation pattern of coarse fractions.

DISCUSSION

The 17th and 18th century hydrographic charts of the study area indicate that far down south of present day bayline, the palaeo Godavari had its confluence where it debauched at “Coringah” bay along Coringah port. In view of rapid deposition, the Godavari channel and Coringah port have been abandoned. From 1851 onwards, present day Kakinada spit and bay started developing. The main reason for rapid deposition in Coringah bay was influx of excessive sediments during floods (Prakash and Agarwal, 1979) that could not be flushed out during periods of normal flow and as a result, along with other forces that were operative, the main flow of Godavari changed to southerly distributaries (Ramkumar, 2003). By the year 1890, the Coringah bay turned into mudflats and mangrove swamps interspersed with tidal creeks resulting in shift of bayline further north (Prakash and Agarwal, 1979). Analysis of Survey of India toposheets of the years 1937 and 1975 coupled with present observations shows that the bay gets filled up but in a slow pace compared to the past. Currently, the principal locus of deposition is along southern part of the bay (Fig.4) paving way for mudflat (Reddy and Rao, 1996) followed by marsh and mangrove development and land stabilization. The whole process (shift of locales of debauching of Godavari river, growth of spit, formation of bay and subsequent filling up of it to form mangrove swamps) took place over a span of <130 years (Ramkumar, 2000).

A delta grows if the sediment introduced on the periphery of sea faster than it gets removed by coastal processes (Rao, 1991). During recent past, the progradational phase of the Godavari delta is reversed and it can be stated that excepting southern sides of Nilarevu and Gautami mouths, only erosional phases are witnessed (Fig.5). Even the prevalent depositional sites as shown by the occurrence of vast chenier plains are

undergoing erosion indicating advancement of coastline over land. Occurrence of eroded beaches and chenier plains indicate rising sea level and resultant erosion (Bird, 1985). The coastal mangroves, which require longer colonization and stabilization time, are under threat by the ongoing erosion. Added to these, indiscriminate felling of mangrove flora for fuel and establishment of aquaculture ponds lead to complete destruction of these invaluable flora. The mangroves receive their sediments from freshwater discharge as well as eroded sediments from coastal regions. The area under study is so situated that, it acts as interface between freshwater discharge from the Godavari river and saline water from Bay of Bengal. In view of location of major industries and urban settlements along Kakinada bay and the course of Godavari river (Fig.3), besides the circulatory currents (Fig.2) prevailing in the Kakinada bay, the mangrove swamp accumulates sediments and pollutants from both of these sources. Urban and industrial establishments around tidal water bodies are reported to affect seriously the water quality, sediment and nutrient cycles (Valdes and Real, 1998). There had been many studies such as Brush (1991) that documented clear linkage between landuse pattern and coastal sedimentary characteristics. Table 4 clearly indicates the recent accelerated changes of landuse pattern surrounding the mangrove swamps of CWS (Fig.2), particularly the urban and industrial lands and aquaculture ponds, which show multifold increase in areal extent. As the mangrove regions supply nutrients to the coastal and estuarine biological system, the periods of higher resuspension of mangrove swamp sediments disperse the pollutants as well, which has been established by the correlation relationships and factor analysis beyond any reasonable doubt. Macko et al. (1990) have also stated that there is some irrefutable relationship between living organisms and the compounds preserved in the sediment's organic materials. In view of the nature of these heavy metals that once they are introduced to the metabolic systems of organisms of coastal and estuarine regions, they may pose irreversible adverse effects (Marcovecchio et al. 1990) including extinction (Brush, 1991).

The mangrove swamp region under study is protected as wildlife sanctuary and supports around 70 plant species belonging over 24 families. The sanctuary is known for its endangered mammals like dolphins and guggongs and the highly endangered species of estuarine crocodiles and the soft textured Indian otters. This sanctuary also hosts a large

number of avian fauna (around 120 species), mollusks, fish, crabs and mudskippers that have commercial, ecologic and aesthetic value. This information clearly projects the study area as ecologically sensitive and important. The existence of many major industries and aquaculture ponds around this wildlife sanctuary (Fig.3) that release untreated effluents into the tidal channels that crisscross this region makes the entire system vulnerable to endemics. The observed accumulation of toxic heavy metals such as Pb, Cr and Ni in the mangrove sediments, their resuspension and dependence of coastal and estuarine biological community on these sediments for their nutrient requirement (Jennett et al. 1983), largely enhances the scope for these pollutants to get accumulated in the biological system which will cripple the food and life cycles and eventually, would devastate the CWS and its biota.

CONCLUSION

Analysis of sedimentological and geochemical processes of mangrove sediments of CWS through correlation and factor analysis and integrating the interpretations with the data on shoreline changes and landuse dynamics revealed the following.

- a.** The coastal zone of the Godavari delta undergoes severe erosion as a result of which previously prograded areas are under destruction. While it took around 130 years for the mangrove and associated flora to colonize and stabilize the area prograded by the river, the onset of sea level rise and coastal subsidence fast destructs the fragile coastal ecosystem.
- b.** The mangrove swamp sediments act as sink for offshore and terrestrial sediments and associated heavy metals and organic carbon. The rising tidal energy redistributes the settled sediments that forms source of nutrients to the estuarine and coastal fauna and flora.
- c.** The admixture of industrial toxic metals and their complexation with organic matter in mangrove sediments is recorded with this study. As the organic matter in mangrove sediments form prime source of food for many fauna and flora, chances are very high for those toxic metals to poison the metabolic system of organisms of CWS that may lead to adverse effects.
- d.** Since the mangrove swamp region acts as homeland for a wide variety of fauna and flora and also the fact that it is housing endangered species, based on the

interpretations made, it could be concluded that the area under study (CWS) is under ecological threat. To ascertain these generalized interpretations, detailed studies on pathways of toxic heavy metals in terms of source, mode of accumulation and distribution and dispersal in the biological system are required that are underway.

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Table 1 SEDIMENT CHARACTERISTICS OF THE MANGROVE SWAMP

	'n'	Mean	Minimum	Maximum	Std.Dev.
Mz	10	8.376	5.650	9.530	1.182
Sd	10	2.456	1.660	3.350	0.499
S_K	10	-0.542	-0.810	0.630	0.521
K_G	10	1.349	0.480	3.930	1.365
Sand	10	9.570	0.000	52.830	16.018
Silt	10	27.012	0.000	65.960	20.413
Clay	10	45.023	7.869	76.630	23.907
CaCO₃	10	6.900	2.000	15.000	3.872
OC	10	0.739	0.106	2.778	0.829
Cu	10	86.667	51.000	111.000	17.664
Ni	10	136.889	79.000	179.000	30.596
Pb	10	34.222	0.000	114.000	51.722
Zn	10	69.667	40.000	99.00	16.462
Cr	10	214.111	91.000	449.000	124.387
Co	10	182.778	0.000	344.000	121.817
Na	10	3556.250	2500.000	5000.000	739.419
K	10	3125.000	2000.000	5000.000	991.031

Mz, Sd, S_K and K_G are in phi scale; Sand, Silt and Clay are in relative percentages; OC and CaCO₃ are in Wt.%; others are expressed in ppm.

Table 2 Correlation coefficients of granulometric and geochemical data

	Mz	Sd	S _K	K _G	Sand	Silt	Clay	CaCO ₃	OC	Cu	Ni	Pb	Zn	Cr	Co	Na	K
Mz	1.00																
Sd	<u>-83</u>	1.00															
S_K	<u>-94</u>	0.60	1.00														
K_G	0.53	-72	-33	1.00													
Sand	<u>-93</u>	<u>0.87</u>	<u>0.81</u>	-38	1.00												
Silt	0.19	<u>-35</u>	<u>-06</u>	-24	-54	1.00											
Clay	<u>0.76</u>	-54	<u>-78</u>	0.65	-47	-49	1.00										

CaCO ₃	-0.15	0.02	0.22	-0.60	-0.21	<u>0.89</u>	-0.72	1.00										
OC	-0.70	0.50	0.71	0.12	<u>0.85</u>	-0.71	-0.14	-0.53	1.00									
Cu	<u>0.89</u>	<u>-0.79</u>	<u>-0.81</u>	0.25	<u>-0.95</u>	0.49	0.47	0.26	<u>-0.87</u>	1.00								
Ni	-0.52	<u>0.74</u>	0.29	-0.55	0.68	-0.65	-0.03	-0.26	0.49	-0.51	1.00							
Pb	<u>-0.89</u>	<u>0.74</u>	<u>0.83</u>	-0.25	<u>0.97</u>	-0.58	-0.39	-0.26	<u>0.93</u>	<u>-0.93</u>	0.67	1.00						
Zn	0.05	-0.36	0.10	0.06	-0.20	0.22	-0.02	0.22	0.02	0.15	-0.02	0.00	1.00					
Cr	-0.14	0.29	0.01	-0.43	0.24	-0.39	0.15	0.05	0.13	0.01	<u>0.81</u>	0.30	0.25	1.00				
Co	<u>0.80</u>	-0.61	<u>-0.77</u>	0.50	<u>-0.76</u>	0.29	0.49	-0.12	-0.64	0.61	-0.72	<u>-0.83</u>	-0.32	-0.64	1.00			
Na	<u>-0.88</u>	0.56	<u>0.93</u>	-0.20	<u>0.77</u>	-0.08	-0.72	0.09	0.72	<u>-0.87</u>	0.16	<u>0.78</u>	0.10	-0.25	-0.57	1.00		
K	-0.11	0.27	-0.05	-0.19	0.24	-0.48	0.26	-0.35	0.30	-0.26	0.64	0.32	0.49	0.50	-0.35	0.06	1.00	

Underlined correlations are significant at or above 95% confidence level

Table 3. Varimax rotated factor loadings

Variables	Factor 1	Factor 2	Factor 3	Communality
Mz	0.953	0.176	-0.140	0.958
Sd	-0.759	-0.072	0.376	0.723
S _K	-0.918	-0.214	-0.049	0.890
K _G	0.334	0.634	-0.547	0.813
Sand	-0.926	0.172	0.223	0.938
Silt	0.298	-0.863	-0.333	0.945
Clay	0.650	0.725	0.117	0.962
CaCO ₃	0.022	-0.980	-0.013	0.961
OC	-0.796	0.518	0.057	0.905
Cu	0.936	-0.220	-0.030	0.924
Ni	-0.435	0.220	0.828	0.923
Pb	-0.905	0.245	0.251	0.942
Zn	0.112	-0.186	0.303	0.139
Cr	-0.010	0.050	0.920	0.850
Co	0.702	0.119	-0.558	0.819
Na	-0.905	-0.100	-0.210	0.873
K	-0.078	0.322	0.698	0.597
Eigen Value	8.232	3.509	2.422	
Explained % of Variance	48.42	20.64	14.25	
Cumulative % of Variance	48.42	69.06	83.31	

Table 4. Statistics on landuse change over the years since 1937 in the study area

Landuse types and sub-types (After Ramkumar et al. 1999)	Area in Km ²			% Area			% Change			Rate of Change (%)		
	1937	1975	1998	1937	1975	1998	1937- 1975	1975- 1998	1937- 1998	1937- 1975	1975- 1998	1937- 1998
I Built-up land	13.0	33.6	71.8	1.35	3.5	7.73	158.46	113.69	452.30	4.17	4.94	7.42
I ₁ Urban, rural and Industrial land	13.0	33.6	71.8	1.35	3.5	7.73	158.46	113.69	452.30	4.17	4.94	7.42
II Agricultural land	536.8	517.1	449.1	55.7	53.82	48.35	-3.67	-13.15	-16.34	-0.97	-0.57	-0.27
II ₁ River/Canal irrigated	443.3	421.2	359.8	46.0	43.84	38.74	-4.99	-14.58	-18.84	-0.13	-0.63	-0.31
II ₂ Tank/Well irrigated	93.5	95.9	89.3	9.7	9.98	9.61	2.57	-6.88	-4.49	0.07	-0.30	-0.07
III Forest	5.3	16.8	33.9	0.55	1.75	3.65	216.98	101.79	539.62	5.71	4.43	8.85
III ₁ Forest plantation	5.3	16.8	29.5	0.55	1.75	3.18	216.98	75.60	456.60	5.71	3.29	7.49
III ₂ Degraded forest	0.0	0.0	4.4	0.0	0.0	0.47	--	--	--	--	--	--
IV Wasteland	339.1	325.9	261.5	35.19	33.93	28.14	-3.89	-19.76	-22.88	-0.10	-0.86	-0.38
IV ₁ Swamp/Waterlogged areas	269.5	275.3	206.9	27.96	28.66	22.27	2.15	-24.85	-23.23	0.06	-1.08	-0.38
IV ₂ Land with or without scrub	44.2	14.9	27.9	4.59	1.55	3.0	-66.29	87.25	-36.88	-1.75	3.79	-0.61
IV ₃ Sandy area	25.4	35.7	26.7	2.64	3.72	2.87	40.55	-25.21	5.12	1.07	-1.1	0.08
V Water bodies	63.4	52.5	61.8	6.58	5.46	6.65	-17.19	17.71	-2.52	-0.45	0.77	0.04
V ₁ River/Channel/Canal	59.9	49.5	57.3	6.22	5.15	6.17	-17.36	15.76	-4.34	-0.46	0.69	-0.07
V ₂ Tank/Pond/Lagoon	3.5	3.0	4.5	0.36	0.31	0.48	-14.29	50.0	28.57	-0.38	2.17	0.47
VI Others	6.1	14.8	50.9	0.63	1.54	5.48	142.62	243.92	734.43	3.75	10.61	12.04
VI ₁ Salt pan	6.1	14.8	5.3	0.63	1.54	0.57	142.62	-64.19	-13.11	3.75	-2.79	-0.22
VI ₂ Aquaculture ponds	0.0	0.0	45.6	0.0	0.0	4.91	--	--	--	--	--	--
TOTAL AREA	963.7	960.7	929.0				-0.31	-3.30	-3.60	-0.01	-0.14	-0.06