CHAPTER V
SUMMARY AND CONCLUSIONS

The river Chaliyar, which is the third major river of Kerala, forms an estuary at Beypore and joins the Arabian Sea. Like the other rivers of Kerala, the Chaliyar is also swift flowing and exhibits stream like characteristics. This river within its 169 km course crosses varied physiographical units and forms a high flux and dynamic estuary. Major industrial houses such as Gwalior Rayons Factory, ship breaking yard etc. flush their effluent into this estuary. Even a casual visitor to this part of the river can witness the scars of pollution caused to the estuarine biosphere. Situated in a hydrographically and physiographically unique locale, pollution monitoring in this area provides ample scope to generate a base-line threshold database. The present study focuses attention on the trace metals distribution in the Beypore estuary. The investigation was planned and carried out to achieve the objectives of studying the sources of trace metals, their transporting pathways and various physical and chemical parameters which control their distribution within the estuary. Hydrological parameters were monitored and their inter-relationship assessed. Based on the results of investigation, the quality of the estuary is derived. The physical parameters monitored include tidal forcing, water temperature, currents, salinity and dissolved oxygen. Suspended sediment load, particulate and dissolved trace metals were estimated for the water column. In addition to the concentration of trace metals in surficial sediments and core sample, their dependence on sediment texture is established. Organic carbon content and the concentration of major elements in the sediments are also dealt in detail. Nature of metal incorporation was deduced through step-wise chemical extraction procedure. The rare earth elements in the upper and the lower estuarine sediment samples are analysed and reported for the first time.

The salient features of the investigation are summarised below:

The water temperature in the Beypore estuary was found to be dependent mainly on solar radiation. River discharge also sometimes influenced the temperature distribution. Temperature regime showed a seasonal cyclicity with increase in temperature during pre- and
post-monsoon periods. Relatively lower temperatures were observed in the sub-surface layer near the mouth of the estuary during monsoon months attributable to the influx of upwelled water into the estuary. Pre- and post-monsoon months depicted negligible difference between surface and bottom layers.

Salinity varied widely in space and time. Main factors controlling the salinity distribution are the tidal pumping and the fresh water discharge from the river. Diurnal variations in salinity were found to be in tune with tides. During peak monsoon, the estuary becomes fresh water dominated. Saline water intrusion by tidal forcing was noticed up to 5 km upstream during monsoon months. Clear stratification was observed with well defined salinity gradients during monsoon. During post- and pre-monsoon periods the estuary transforms to a partially mixed and then to a well mixed one.Saline water intrusion was observed up to 22.5 km upstream during summer months when fresh water discharge was considerably low.

Dissolved oxygen content was higher when river discharge was maximum. The effect of upwelled water was manifested during August and September resulting in depletion of dissolved oxygen concentration especially in the bottom layers. Turbidity in water column due to disturbance by anthropogenic activities results in low photosynthesis at the lower portion of the estuary. This has resulted in low D.O content which could affect the biota adversely. Inverse relationship between D.O and salinity is established in the lower reaches of the estuary. The lower D.O. content noticed during pre- and post-monsoon months can also be attributed to the reduction in oxygen rich fresh water supply and to the oxygen consumption by various biodegradation processes.

Maximum surface current speed was observed during peak monsoon period. The strongest currents observed were found to coincide with the flood and ebb in respective directions. Irrespective of the seasons, sub-surface currents were less stronger than surface currents. Certain local effects, such as, bank orientation, bottom profile, bridges and islands were found to control the flow regime at different locations.
Land derived materials brought in by the rivers contribute maximum to the suspended sediment load in the Beypore estuary and Chaliyar river. Maximum concentration of suspended sediments was observed during monsoon period. Abnormal concentration of suspended sediments observed occasionally at the barmouth region and fisheries harbour area could be due to resuspension of bottom mud caused by the fishing activities using mechanised boats. Increased wave action coupled with shallowness of the estuary has resulted in the higher concentration of suspended sediments in the lower reaches. Resuspension of bottom mud due to scouring action of tidal forcing seem to contribute to high suspended sediment concentrations in the bottom layers.

Spatial distribution of trace metals in the particulates of surface waters were devoid any specific pattern. The metal concentration are comparable with those reported for Cochin estuary. Higher concentration of Cu and Cd in the sub-surface layers could be due to bottom entrainment. Particulate metal concentrations were found to be many fold higher than that of the bottom mud confirming the role of suspended particulates as carriers of lethal toxicants. During the lean period, enrichment of Cr and Zn in the particulate phase were noticed. Higher concentration of heavy metals associated with the suspended matter was either derived from industrial effluent or due to the activity in the harbour area.

Among the dissolved trace metals studied, Pb and Zn recorded higher concentration, probably due to the release of these metals from sediments already contaminated with industrial effluent. Dissolved copper content in the estuary was much lower than the tolerance limit reported for fresh water.

Almost all stations exhibited significant season-wise fluctuation in textural characteristics, indirectly indicating the discharge dependency. Considerable internixing was noticed between different textural grades. A gradual downstream decrease in sand content indicates textural maturity of the sediments as observed in other alluvial streams. This is attributed to dominant unidirectional differential transport of sediment by fluvial dynamics.
Sand, which was the most dominant of the textural grades, seem to be diluted with fines during the post-monsoon season. Though the tidal effect was felt upto 22.5 km upstream, the bottom sediment distribution appears to be controlled by the tidal regime only upto 7 km. *In situ* sorting processes are observed in Beypore estuary due to the scouring effect of tides as the sediments get resuspended and flushed out during ebb flow to the open sea.

Bottom sediments of Chaliyar river and Beypore estuary have an average level of organic carbon comparable to other tropical estuaries. During periods when discharge was minimal, an enhanced level of organic carbon was noticed in the lower reaches of the estuary. Correlation studies indicate definite control of textural grades on organic content in sediments. Silt and clay fraction contained maximum organic carbon than sand. One of the important reasons attributed for the occurrence of higher organic carbon content in fines is their larger surface area that accommodate more dispersed organic particles.

Major elemental chemistry of the bulk sediments is found to be mainly dependent on the detrital and non-detrital fractions. MgO and CaO content were high in the lower estuarine sediments. The range of chemical composition are dominantly influenced by different proportions of major minerals in the sediments except for CaO and MgO. Dominant relationship existed between the major elements and textural composition. The fines contained higher concentration of $\text{Al}_2\text{O}_3$, $\text{Fe}_2\text{O}_3$ and Mn and hence indicate affinity to organic carbon as well. Lack of textural control exhibited by CaO could be attributed to the selective partitioning with the higher proportions of carbonate than non-carbonate phase of the sediments.

Tidal mixing appear to control the temporal and spatial variability of trace metals concentration in the estuarine sediments. Cu, Ni, Zn, Rb, Li, Cr and Co showed uniform distribution in the upper part of the estuary, whereas in the lower reaches their concentration found to be fluctuating considerably. This phenomenon seems to have a direct bearing on the sediment textural distribution and local hydrography. The average abundance of trace metals
are in order of Ba > Sr > Cr > Mo > Bi > Zn > Ni > Co > Rb > Li > Cd > Cu > Be. Total trace metal concentration is found to have a combined influence of mineralogy, organic carbon content and texture. Cu, Ni, Zn, Rb, Li, Cr and Co affinity for finer fractions and organic carbon could be attributed to their higher cation exchange capacity. The clay minerals, especially montmorillonite in sediments is found to facilitate concentration of these metals. Thus, apart from land derived contribution from natural processes, trace metals enrichment by anthropogenic input is also found to be significant in the sediments of Beypore estuary. Cluster analysis indicated four distinctive groups consist of (1) silt, clay, Organic Carbon, Al₂O₃, Fe₂O₃, Co, Mn, Cu, Ni, Rb, Li, Zn, Cr and Ti, (2) Cu, Be and Bi, (3) CaO, MgO and Sr, and (4) Ba and Mo. Respective controlling factors for such groupings are inferred.

Among the four trace metals analysed by sequential extraction method, Pb was found to be mostly associated with lithogenous fraction (lattice-held) followed by Zn, Ni and Cd. In NLF (labile fraction) toxic elements were found to be concentrated more in (i) organic and sulphide phase and (ii) moderately reducible phase. Higher concentration of Ni and Cd in these two phases together could pose a threat to aquatic organisms.

The core sample showed predominance of clay throughout the length. A slight depletion of organic carbon towards the lower layer of the core could be due to its consumption during diagenetic processes. Considerable variation in trace metal content in the sediment column was noticed and only in the case of some elements a base line data could be generated. Higher metal concentration observed in the core sample is mainly due to the fineness of the sediments.

The concentration of rare earth elements (REE) in the upper estuarine sediments are found to be marginally higher than that in the lower reaches of the estuary. Chondrite normalised pattern indicated dominance of LREE over HREE. NASC normalised values signify one tenth reduction of lanthanide concentration in the estuarine sediments of Beypore compared to the shales.
With the exception of a few elements in the particulate and bottom sediments, the observed concentration of most of the trace metals were much below tolerance level. This does not necessarily indicate that the Beypore estuary is pollution-free. During the investigation period, one of the major sources of industrial pollution especially in the lower reaches of the estuary viz., The Mavoor Gwalior Rayons factory was under lock out. During the reconnaissance survey conducted prior to the field investigation in the estuary, information from the local populace indicated the very high pollution levels in the estuary, which had hampered river sand mining and exploitation of benthic bivalves used both for food and lime. Moreover, lignin coating on bottom sand near the effluent discharge point of the Mavoor Gwalior Rayons factory was observed even during the field survey.

The presence of higher concentration of some of the heavy metals could be due to the residuals of the earlier pollution load and indicates a high residence nature of these pollutants in the bottom sediments. Since 1990, the factory is back in operation discharging industrial effluent into the estuary. The Beypore estuary falls well within an area dominated by the monsoon, and is hence unique. Since, similar studies are meagre along the southwest coast of India, the present study provides ideal data set for the assessment and comparison of estuarine pollution derived from industrial sources. With the factory re-opened, a time series monitoring of various pollutant load in this estuarine system is imperative for its better understanding and sustainable use.