CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 INTRODUCTION

Coastal lakes have national as well as global importance as they constitute a unique fragile ecosystem. Although lakes constitute about 0.01% of the total water at the earth’s surface, they have received proportionately greater attention because of their importance to humans (Berner and Berner 1987). India has three large brackish water lakes – Chilka lake in Orissa along the Coromandel coast, Pulicat lake extending between Tamil Nadu and Andhra Pradesh along the east coast of India and the Vemband lake in Kerala along the Arabian sea coast. The Chilka lake has undergone a considerable reduction in surface area due to inputs from natural processes but mostly due to human activities (Panda et al 1995). India is losing its wetlands rapidly because of population pressure and lack of government control over land speculators who are reclaiming them - for example the Kolleru Lake in Andhra Pradesh is choking to death from greed and over development (Ramesh 2000).

Several works have been carried out on the Pulicat lake for its biodiversity (Sanjeeva Raj 1993 and Reddy et al 1994) and the geochemistry of its waters (Nagaraju et al 1994 and Padma and Periakali 1999). However there has been no detailed study on the environmental impact of the geochemistry of the lake waters and the sediments. In this study the core sediments have been
analysed for the excess $^{210}$Pb activities and the rate of sedimentation has been calculated. The depositional rate of the metals accumulated in the core sediments has been computed. The Pulicat lake is subject to pollution from the Buckingham canal which discharges into it, sewage and industrial effluents from Ennore in the south. The Ennore satellite port project, the North-Chennai thermal power station and the proposed Petro-chemical park could cause serious environmental hazards to the ecosystem of Pulicat lake and its neighbourhood. This study aims to understand the biogeochemical processes of the lake ecosystem in order to preserve the ecological and environmental characteristics of this fragile ecosystems.

8.2 SIGNIFICANT RESULTS

This study is a comparison of the past history and present status of the metal accumulation in the Pulicat lake and also the changing quality of water and sediments. The study helps to understand the cause and rate of sedimentation in the Pulicat lake. A geographical information system has been used to relate sediment distribution to heavy metal concentrations. The biogeochemical nutrient budgeting for the Pulicat lake ecosystem was made to quantify the fluxes of nutrients from rivers to the lake and to the Bay of Bengal. The water and salt budgets for the lake ecosystem was computed and the average residence time (water exchange time) was determined.

8.2.1 Seasonal and temporal variations in water chemistry

- The average surface water of the Pulicat lake remained relatively alkaline, with pH range 6.8 during monsoon to 8.8 in summer. Electrical conductivity (EC) shows variations both seasonally (9.5 mS
during the monsoon and 16.3 mS during the summer season) and spatially, with much higher EC values in zone I as compared to the rest of the lake. The zone I, which is the mixing zone is under the direct influence of the sea. The increase in EC reflects an increase in the ionic strength of the water, which in turn indicates an increase in concentration of major ions. There is an expected increase in EC with increasing salinity because of the chemical complexity of lake waters.

- The dominant cations and anions of the surface waters for Pulicat lake are in the order of Cl>Na>SO$_4$>K>Mg>HCO$_3$>Ca.

- The chemical composition of major ions such as Cl, Na and K in the Pulicat lake is greater than the average sea water composition indicating that the lake is influenced by sea water than the fresh water input and the evaporation rate is higher within the lake. These elements showed seasonal variations, with very low concentrations during the monsoon season as compared to the summer season. The concentrations of Cl varied between 12155 to 18501 mg l$^{-1}$, Na showed variation between 56 to 2921 mg l$^{-1}$ and that of K from 36 to 974 mg l$^{-1}$, which are attributable to the freshwater discharge from the seasonal rivers into the lake during monsoon and the strong seawater influence during the summer.

- The HCO$_3$ concentration ranges from 90 mg l$^{-1}$ during the post-monsoon season to 112 mg l$^{-1}$ during the pre-monsoon season. The possible source of HCO$_3$ to the lake ecosystem is partly attributed to the river runoff brought down by the Kalangi and Arani rivers and the other from tidal influences. Localised enhancement of HCO$_3$
concentration during post-monsoon can be attributed to chemical weathering following monsoon.

- Mg is more abundant than Ca throughout the lake. The Mg concentration range was 102 mg l$^{-1}$ to 877 mg l$^{-1}$ as compared to Ca concentration range of 67 mg l$^{-1}$ to 103 mg l$^{-1}$, indicating that Mg-rich seawater periodically enters the lake through tidal influence.

- The sulphate concentration accounts for nearly 4% of the total dissolved solids in the Pulicat lake water. The concentration of SO$_4$ in this study ranged from 880 mg l$^{-1}$ during summer and 509 mg l$^{-1}$ during post-monsoon. The enhancement in SO$_4$ content in the lake waters during summer is basically due to the influence of seawater into the lake. The Pulicat lake also receives fertilizer runoff through the Arani river, where intense agricultural activities take place in addition to receiving effluent discharges from the aquaculture farms nearby.

- Ammonium nitrogen NH$_3$-N (598 µg l$^{-1}$) dominates nitrogeneous nutrients in the lake ecosystem, followed by NO$_3$-N (27 µg l$^{-1}$) and NO$_2$-N (24 µg l$^{-1}$) indicating that ammonification was a dominant process in the lake ecosystem. The seasonal rivers bring in a higher load of nutrients from anthropogenic sources such as effluent discharges from the adjoining industrial as well as agricultural areas.

- The average phosphate (PO$_4$) concentration ranges from 28 µg l$^{-1}$ during the monsoon season, to 67 µg l$^{-1}$ during the post-monsoon season with an increase to 158 µg l$^{-1}$ during summer and much higher concentration during the pre-monsoon season (294 µg l$^{-1}$). The drop in
PO$_4$ concentration during the monsoon season could be, due to the dilution effects of the fresh water discharged by the seasonal rivers. Seasonal variation is an important factor influencing the dissolved PO$_4$ level in the Pulicat lake ecosystem.

- The average N:P ratio for surface water is 9N:1P in comparison to the Redfield ratio of 16N:1P, suggesting higher utilization of N over P by the primary producers. This further indicates additional nutrient loading through agricultural runoff and other industrial discharges through the Buckingham canal.

- Nutrient type trace metals are present in significant quantities in the Pulicat lake ecosystem. Cu concentration ranges from 1 to 493 µg l$^{-1}$ with an average value of 239 µg l$^{-1}$ which is higher than that of Bay of Bengal (4.9 µg l$^{-1}$) [Analia and Sujata 1980] and Arabian Sea (4.9 µg l$^{-1}$) [Sengupta et al 1978]. The increase in Cu concentration from the Bar mouth (1µg l$^{-1}$) to the inner part of the lake (493 µg l$^{-1}$) has been observed. This is mainly due to the lack of water exchange between the lake and the Bay, particularly during summer and due to bacterially mediated decomposition of organic matter.

- Nickel concentration in the Pulicat lake ranges from 1 to 267 µg l$^{-1}$. The distribution of Ni varies spatially throughout the lake. Being a nutrient type element it is taken up in significant quantities before being discharged into the Bay of Bengal. Major anthropogenic sources of Ni, include effluents from metal processing industries and domestic waste water which is brought down by the Buckingham canal into the lake.
• The average concentration of Zn (61 μg l⁻¹) in the Pulicat lake was observed to be nearly 12 times more than seawater (5 μg l⁻¹) [Slowey 1966] indicating the principal anthropogenic sources of Zn could be due to the discharge of domestic wastewater, agricultural and industrial effluents entering the lake.

• The concentrations of the pollutant type of trace metals Co, Pb, Cr and As are significantly high in the Pulicat lake water. The average concentration of Cr in the surface water was 132 μg l⁻¹. Chromium chemicals are used in large volumes by tanning and chemical industries, refractory and metallurgy. The concentration of Cr is found to be much higher in zone III than in the rest of the lake. In this zone the seasonal river Kalangi, discharge sediments and flushes a large volume of water during the monsoon season, which results in high Cr concentration.

• The inter-elemental correlation matrix for trace elements in water shows a negative correlation of Fe with some of the trace elements (Mn, Ba and Cu) due to flocculation of these trace elements in the freshwater – seawater interface. A strong positive correlation between element pairs Cr – Cu (0.59), B – V (0.99), As – V (0.93) and As – B (0.93) was noticed in the surface waters, probably due to common anthropogenic sources.

8.2.2 Grain size and trace metal distribution in bed and suspended sediments

• The grain size distribution of the bed sediments, shows that the percentage composition of fine sand sediments (39%) dominates the lake's bulk sediments.
Strongly fine skewed sediments are present in most part of the lake but zone I & III shows a range of very negatively skewed to very positively skewed sediments. The positive skewness obtained for the central region of the lake (zone II) indicates deposition. This area is the low energy zone in the lake as compared to zone I, which is constantly under the influence of the Bay of Bengal.

The Pulicat lake sediments show values of 0.51 i.e. very platykurtic to value of 1.75 (very leptokurtic). The values of $K_g$ in the Pulicat lake are highly variable, suggesting fluctuations in the deposition of the bed sediments in the lake environment due to influence of the Bay of Bengal (zone I) as well as the two seasonal rivers Arani and Kalangi in zone I and III respectively.

Si is the most dominant element present in the bed sediment samples with an average value of 37.7%, and 3.73% is the mean Al content. Al showed a reverse pattern of distribution as compared to Si % concentration. Al concentration is enriched in zone III and zone II as compared to zone I. Similarly the silt and clay percentage is high in zone III as compared to the other two zones. Al tends to concentrate in finer clay fractions, as it is a major component in forming the clay minerals. A high Si/Al ratio at locations 1, 2 and 3 in zone I (where the lake opens into the Bay of Bengal) suggest addition of silica from detrital quartz.

The concentration of Cu in the bed sediments averages to 27 mg kg$^{-1}$ and that of Ni was observed to be 216 mg kg$^{-1}$. The observed concentration of Cu and Ni is much higher in the clay fractions. The distribution pattern of Zn remains closely similar to that of Cu and
similarly Zn also has a tendency to accumulate more in the clay size fractions of the sediments.

- Statistical relationship of grain size parameter and concentration gradient of different elements discerned that finer particles contain more quantities of trace elements than their coarser counterparts. This shows that adsorption onto the surface act as the key factor for elemental association in the surfacial sediments.

- The trace metal concentration was higher in the suspended sediments in comparison to the bed sediments. The concentration of Fe (%) was five times more than that in the bed sediments. The higher concentration is basically due to the larger surface area in suspended sediments, which binds the trace elements to a greater extent than the bed sediments.

- The annual discharge from the river Arani into the lake is estimated to be 125 mm\(^3\) during monsoon. The sediment and dissolved load carried into the lake depends on the seasonal rivers discharging into the system. The river discharge is reported to occur only during the monsoon season. The average annual TDS and TSM in the lake were estimated to be 19272 mg l\(^{-1}\) and 90 mg l\(^{-1}\) respectively. The observations in the present study indicate that average chemical flux into the lake was estimated to be 2.409 million tons yr\(^{-1}\) and the sediment flux to be 0.01125 million tons yr\(^{-1}\).

8.2.3 Sedimentation rate

- The best fit lines through the data points yield sediment accumulation rates in the range 6.06 mm yr\(^{-1}\) to 15 mm yr\(^{-1}\) with an average
accumulation rate for Pulicat lake at 10.05 mm yr\(^{-1}\) (approximately one meter per 100 years). The sedimentation rates in Pulicat lake were higher towards the southern part of the lake in comparison to the central or the northern region. Particularly, at the discharge locations of the rivers Arani (13.6 mm yr\(^{-1}\)) and Kalangi (10.5 mm yr\(^{-1}\)) and the Buckingham canal (15 mm yr\(^{-1}\)), a sharp increase in the accumulation rates has been observed indicating that sediments are delivered from these rivers to the lake environment at their confluence. Moreover, rapid sedimentation could have also resulted from flocculation under saline conditions in comparison to the northern part of the lake. These results highlight the fact that the lake is subjected to high rate of sedimentation and rapid siltation. An earlier work carried out by studying the fossil pollen grains preserved in the sediments for a single core reported similar results of one meter per 100 years (Ramesh 2000).

- Depth profiles of the trace element concentration in sediment cores display a constant decrease with depth. The relatively high concentration in the top few centimetres is a result of recent industrialization surrounding the lake area. The depositional rates of the measured elements in the Pulicat lake core show high when compared with the depositions rates of Bay of Bengal, Deep-sea clay and Arabian Sea.

8.2.4 Environmental Impact Assessment

- A geographical information system has been used to relate sediment distributions to heavy metal concentrations in the bed sediments. The essential question addressed in this study is whether the spreading of
trace metals are simply dependent on sediment size due to the physical adsorption on the muddy sediment surfaces or are they mainly affected by discharge from industrial outfalls and sewage effluent discharge. A direct spatial correspondence between concentrations of trace metals (like Ni and Cr) and bottom muddy sediments of the lake has been established in the present study. This indicates the effectiveness of industrial sources for the presences of the trace metals which helps in assessing the impact on the lake environment.

- Salt-Water and Biogeochemical nutrient budgeting for the Pulicat lake ecosystem was made to quantify the fluxes of nutrients from the rivers to the lake to the Bay of Bengal. The average residence time (water exchange time) was determined to be 36 days. The stoichimetric calculation of net ecosystem metabolism has been carried out and the results indicate that there is a net dinitrification process occurring in the system and the Pulicat lake ecosystem is strongly heterotrophic.

8.3 CONCLUSIONS

- The Pulicat lake is being increasingly subjected to different types of pollution and anthropogenic disturbance.
- The Buckingham canal is also a pathway for the discharge of sewage-contaminated waters from Ennore in the south.
- The trace elements in the surface waters of the Pulicat lake were remarkably high in all the study areas, when compared to average river or seawater, suggesting that the lake is severely affected by human activities such as pollution, urbanization and agriculture.
The low content of bicarbonate, potassium and calcium, and high content of chloride, sodium, magnesium point out the close similarity of the lake waters with the sea. Near Kalangi estuary in the northern part of the lake, the salinity varies due to the influence of tides and seasonal discharges from the Kalangi River.

Coastal lakes are very rich natural ecosystems but, at the same time it is very fragile and hence integrated approaches are necessary to evolve a suitable management strategy.

The results obtained will serve as a baseline data giving details of pollution history of the sediments for the past 100–200 years.

This study indicates that there is a serious problem of siltation (about 1.05 m per 100 years) resulting in the continuous filling up of the lake, which needs to be reversed by appropriate solutions.

Several workers have carried out studies on the biological aspects of the lake, hence it is essential to acquire an adequate knowledge on the geochemistry of the lake. This will help to formulate integrated management action plan to ensure sustainable utilisation of the lake ecosystem.

In view of the rapid ecological changes over the past decade, the Pulicat lake demands greater attention in management strategies and programs to preserve the natural ecosystem.