CHAPTER 1
INTRODUCTION

Coastal waters form a multi-dimensional system where the dynamic processes are rarely in equilibrium. Compared to the open ocean systems, the coastal region exhibits environmental gradients occurring spatially and temporally on micro or macro-scale. The study of the chemical and physical aspects of the nearshore environment provides background information necessary for the understanding of the coastal oceanographic processes. There is a greater potential in applying the tools of modern oceanography and chemistry to unravel the geological, biological and anthropogenic coastal processes.

Bigelow, (1930) initiated studies in this direction by observing temperature cycle on the continental shelf, Cape Cod to Chesapeake Bay. Ketchum (1955) examined the interaction of freshwater and seawater in coastal regions, which was treated as a “gigantic estuary”. This approach must be considered as one of the major advancements in the study of the coastal ocean environment. Currently the coastal water body is receiving close attention especially with respect to hydrography, biological production and fertility. The structure of the physical and chemical environment is commonly expressed in terms of water quality parameters such as temperature, salinity, dissolved oxygen, nutrients, metal concentration, pigments etc. Hydrogeochemical factors can influence the colour, odour, taste, temperature and degree of mineralisation of water derived from surface runoff, underground springs etc. (Clark and Snyder, 1970). Studies on the distributional and biogeochemical characterisitics of nutrients in coastal waters can provide satisfactory assessment on the bioavailability of various nutrients.

The coastal areas of the tropics are productive except turbid near river mouths, where light penetration is poor. In shallow areas, the high productivity is accounted by the increased regeneration rate of nutrients due
to high temperatures accelerating all bacterial processes at the bottom (Nair et al., 1973). One of the major findings of the International Indian Ocean Expedition during 1962-65 was the extremely high rates of primary production and large standing crops of phytoplankton and zooplankton along the western regions of the Arabian Sea (IIIOE, 1972). The values of primary production and standing crops in the central Arabian Sea are higher than the average values encountered in the world oceans (Wooster et al., 1967). The maximum production was reported nearer to the coasts, within 50 m depths and gradually decreasing seaward (Nair et al., 1973). High rate of production was also noted in the shallow waters of the coastal regions of Laccadive and Minicoy islands (Prasad and Nair, 1960).

The west coast of India experiences a time dependent wind stress due to monsoons (Pankajakshan and Rama Raju, 1987); so also the phenomenon of upwelling (Sastry and D’souza, 1972; Ramamritham and Rao, 1973; Basil, 1983). Charney (1955) showed that in presence of stratification and thermocline displacements, due to upwelling or downwelling, affect only a strip of a few kilometers adjacent to the shore. Upwelling may be coupled with undercurrents, which move the mud deposits from deeper areas to shallow regions (Gopinathan and Qasim, 1974). One effect of upwelling is to force fish and prawns to move closer to the shore to avoid the oxygen deficient waters (Sankaranarayanan and Qasim, 1969). The width of the continental shelf along the southwest coast of India is found to vary from place to place. It is narrower on the southern side and wider on the northern side (Gopinathan and Qasim, 1974). In upwelling region the downward transport of nutrient elements is reversed seasonally and the surface waters get replenished with nutrients (Spencer, 1975).

Man-made changes of the marine transitional systems like coastal marine areas and estuaries have increased rapidly worldwide over the last decades affecting the natural dynamic equilibria and the biotic composition of the respective ecosystems. The main causes for such changes are introduction
of untreated and partly treated sewage rich in organic substances and plant nutrients from human settlements, urban areas and certain industries, leaching of nutrients from soils and agricultural fields and animal husbandry.

In global terms, the quality of coastal water is declining, particularly in estuary, with estimated stocks of species decreasing and vitally important habitats being destroyed or being degraded. It is estimated that the world’s fleet of 35,000 commercial ships release several thousands m$^3$ of water every hour, which have been taken on board at a distant port, thus introducing thousands of new species to another port on the globe (Gilbert Barnabe and Regine Barnabe, 2000). It is also estimated that 600,000 tonnes of hydrocarbons are released into the sea each year, although oil pollution from ships decreased by 60% between 1981-89. In addition to these impacts, marine coastal waters receive fresh water from rivers and urban waste, either treated or untreated. These inputs often upset the coastal water ecology.

The west coast of India is environmentally more sensitive than the east coast primarily because it is bordering one of the most sensitive ecosystems in the world, the Arabian Sea. The environmental property of the northern Arabian Sea is unique which manifests in rich biological production throughout the year through different processes and thus, explain for the Arabian Sea ‘paradox’ (Madhupratap et al., 1996). The mid-depth oxygen deficiency in the Arabian Sea is perhaps the most severely observed anywhere in oceans, as the concentration within $\sim$ 150 – 1000 m are less than 0.1 ml/l within a large part of central and northeastern Arabian Sea (Naqvi and Jayakumar, 2000). This zone is characterised by intense denitrification, which is observed only in 3 regions among world oceans, the other two being observed in the Pacific. With such a delicate biogeochemical balance that exists in the oceanic oxygen-deficient zones, the Arabian Sea will perhaps be among the first to react to potential anthropogenic perturbations such as increased nutrient/organic loading (Naqvi et al., 2000). Any alterations in the rate of mid-depth water renewal or in sub surface oxygen demand may bring
about large changes in chemical fluxes. Similarly, an expansion of the oxygen minimum zone, particularly towards the coastal zone, may also have deleterious effects on biological resources as evident from mass mortality of fish reported off Cochin during southwest monsoon, 1998 (Naqvi et al., 1998). It is still not clear as to how the suboxic ecosystem in the Arabian Sea will respond to changes induced by man.

There is an apprehension that environmental deterioration of coastal and estuarine waters will inevitably have consequences for the Arabia Sea’s ecosystem. The symptoms are on as there is the impact of deterioration of estuarine waters on the coastal ecosystem (Nair et al., 1992; Naqvi et al., 2000; Jayakumar et al., 2001). The emerging big cities associated with industrial establishments and human settlements situated along the west coast of India, thus necessitates a critical evaluation of the nature and quantum of inputs to the Arabian Sea as well as their regional assimilative capacities. If there is a possible threat to the well being of the living resources of EEZ of India, then the coastal waters of southwest coast of India, and in particular, Cochin is one of the prime locations prone to trigger it. Being the second largest city along the West Coast, the coastal circulation of this region is critical because, as compared to the Mumbai coast where the mean tidal height is > 3 m, the southwest coast has only one meter. Because of the low tidal amplitudes, these coastal regions have small inter-tidal expanses, perhaps the smallest among the Indian coasts. This results in incomplete flushing, leaving behind parcels of perennially undulating water. Any substance released in such a waterbody will always have a fraction of it left behind, however small that might be whose residence time will continuously increase with increasing number of oscillations (Sen Gupta et al., 1989). Therefore, to estimate the carrying capacity or assimilative capacity of any coastal waters, it is imperative to critically examine the residual tidal effect of any eventual pollutant in their waters (Sen Gupta and Geetanjali Deshmukhe, 2000).
Cochin, the biggest city along the west coast of India after Mumbai, is one of the finest natural harbours of India and provides safe anchorage even during the roughest monsoon months. The booming city of Cochin has population of nearly 1.5 million (Anon, 1998) and 60% of the chemical industries of Kerala are situated in this area (Table 1.1). Cochin backwaters are the largest of its kind on the west coast of India, occupying 256 km$^2$. The backwaters play a significant role in the socio-economic and cultural history of the State besides constituting an invaluable aesthetic resource (Anon, 1998). In recent years, great concern has been expressed with regard to deterioration of Cochin backwaters and consequent loss of supportive functions of this wetland system, especially due to urbanization, industrialization and agricultural activities in the downstream zones of the rivers. The 16 major and several minor industries situated in the upstream region of the backwaters discharge nearly 0.104 Mm$^3$.d$^{-1}$ of effluents (Anon, 1996), causing large-scale environmental pollution. Apart from this, the backwaters also receive organic wastes (~ 260 td$^{-1}$, Anon, 1998) from domestic sewage, coconut-husk retting yards, fish processing plants etc. The main factors affecting the coastal waters apart from sewage are fish processing, navigational dredging and dumping of dredge spoil and sand mining for filling and construction. In addition, the annual dredge spoil from the harbour area alone come to the tune of $10^7$m$^3$, which are dumped in the coastal seas. To summarize all, as the system has been subjected to irrational economic exploitation during the past five decades, the environmental deterioration has ultimately resulted in ecological degradation. All these factors indicate that the coastal waters of Cochin are prone to receive a significant portion of the wastes arising from the increased developments finding their way to the backwaters.

1.1. Scope and Objectives

The basic requirement to characterise a coastal water body is to have systematic chemical oceanographic (environmental) data at close grids of the
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<tr>
<td><strong>Backwater area</strong></td>
<td>256 km$^2$</td>
</tr>
<tr>
<td><strong>Barmouth</strong></td>
<td>450 m x 12 m</td>
</tr>
<tr>
<td><strong>Population</strong></td>
<td>1.5 million</td>
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<tr>
<td><strong>Population density (Cochin Corpn.)</strong></td>
<td>5500 persons/km$^2$</td>
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<td><strong>Reclaimed backwaters (upto 1985)</strong></td>
<td>700 ha</td>
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<td><strong>No. of major Industries (Cochin)</strong></td>
<td>16 (Kerala 26)</td>
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<td><strong>Industrial effluents</strong></td>
<td>0.104 Mm$^3$.d$^{-1}$</td>
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<td><strong>% of effluents from Kerala</strong></td>
<td>69</td>
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<td><strong>Domestic sewage</strong></td>
<td>~ 260 t.d$^{-1}$</td>
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<td><strong>Dredging</strong></td>
<td>$10^7$ m$^3$.y$^{-1}$</td>
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<td><strong>Fertilizer used (in Kuttanad)</strong></td>
<td>20,000 t.y$^{-1}$</td>
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<td><strong>River discharge</strong></td>
<td>~ 19,000 Mm$^3$.y$^{-1}$</td>
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region covering seasonal signals and evaluate the results with the existing oceanographic processes along the coast. An integrated study of this dimension has not been carried out so far along these regions, which lead to take up this study. Eventhough information is available along the southwest coast of India, regional importance are missing and spatial intervals not less than one degree and regions of less than 30 meters are not studied intensively. With a view to delineate environmental changes of such a vulnerable region, detailed chemical oceanographic studies have been undertaken to monitor water quality and sediment characteristics of coastal waters of Cochin (Fig. 1.1). The survey provides important background information necessary for the study of the coastal processes.

The objective of this study is to evaluate the chemical oceanographic parameters of the coastal waters off Cochin during different seasons and also that of the adjoining backwaters and to make a comparative study of the water quality of these two different compartments to understand the probable changes that may arise in the coastal waters based on the behavior of some of the major environmental tracers like phosphate and nitrate.

1.2. Coastal waters

The Arabian Sea, which forms the western boundary of India, is under the influence of changing wind patterns associated with the summer and winter monsoons. Along the west coast of India, the surface currents are south to southeasterly from April to September and northwesterly from November to January. The Indian Ocean manifests the largest seasonal surface wind variation of the three major ocean basins. The southwest monsoon may persist from May to October and is characterized by a low-level jet (Findlater, 1977) directed from southwest to northeast over the Arabian Sea. During the northeast monsoon (variable between November and March) the winds reverse direction but do not approach the strength of the summer monsoon flow (David Young and John Kindle, 1994).
Fig. 1.1 Satellite imagery of Cochin region

(Source: IRS - IC /L - III of 18-01-2000, NRSA, Hyderabad)
According to Shankar (2000), coastal currents around India change direction with season. From November to January, the current off the Indian east coast, the East India Coastal Current (EICC), is equatorward all along the coast. It bends around Sri Lanka to flow along the Indian west coast as a poleward West India Coastal Current (WICC). The EICC reverses in February, and flows poleward during March-May, forming the western boundary current of a basin-wide anticyclonic gyre. The anticyclonic high off southwest India persists through March-April, weakening thereafter and giving way to a cyclonic low during the southwest monsoon (June-September); during this period, the WICC flows equatorward along much of the Indian west coast; it is poleward in the south, but is equatorward in the north.

The coastal zone of western India experiences upwelling from June to October (Banse, 1959; 1968; Ramasastry 1959; Ramasastry and Myrland, 1959; Naqvi et al., 2000). The studies by Shetye et al., (1990; 1994) led them to conclude that upwelling was largely forced by local winds. However, unlike the other two better-known centers located in the Arabian Sea of Somalia and Oman, upwelling off India is not entirely forced by local winds; instead a remote forcing from Bay of Bengal involving a coastally-trapped Kelvin wave appears to be equally, if not more, important causative mechanism (Shankar, 2000). The weaker wind forcing makes the vertical and cross-shelf advection somewhat sluggish. Moreover, the cold, saline upwelled water is usually capped by a 5 to 10 m thick warm, low-salinity layer formed due to a combination of large land runoff and local precipitation, causing strong stratification and poor ventilation of sub- pycnocline waters.

The upwelled water is derived from a poleward undercurrent, located just off the shelf break (Shetye et al., 1987), which has oxygen content of about 0.5 ml/l at 15°N. Over the shelf, the oxygen content is quickly depleted to near-zero levels owing to excessive consumption fuelled by high primary production mainly within the pycnocline (> 500 mg.C.m⁻³.d⁻¹, Jayakumar et
As the season progresses, severely hypoxic (dissolved oxygen $< 0.5 \text{ ml/l}$) waters are found over almost the entire western shelf (Naqvi et al., 2000).

The sub-pycnocline oxygen depletion over the western Indian shelf, as in other similar environments off Namibia (Calvert and Price, 1971) and Peru (Codispoti and Packard, 1980), has been attributed primarily of natural origin because the nutrient enrichment occurs mainly through upwelling. These conditions start developing in June, reach peak intensity by September-October and dissipate by December. Thus, this shallow, seasonal suboxic zone is distinct from the deeper, perennial suboxic layer of the central Arabian Sea (Naqvi, 1987). The seasonal hypoxic zone on the Indian shelf is separated from the perennial suboxic zone of the central Arabian Sea by an undercurrent that transport waters with higher oxygen contents northward off the continental slope (Naqvi, 1987). The oxygen deficiency off western India was first noticed in 1950's (Banse, 1959; 1968; Carruthers, 1959) based on limited measurements in the inner shelf.

From May through September, during the southwest monsoon period, the mean flow continues southward in the upper layer. Upwelling of the Arabian Sea Water of salinity higher than 35 psu, is the dominant process during this period (Johannessen et al., 1987). This is evidenced by the lifting of the isotherms, with a shoaling and sharpening of the thermocline, and the penetration of the low oxygen water ($< 0.5 \text{ ml/l}$) over the entire shelf. Another feature is the lowering of the surface salinity in the near shore region associated with the runoff due to south-west monsoon rains.

During the northeast monsoon period (November to February) the current reverses, advecting less saline Equatorial Surface Water from the equatorial region and Bay of Bengal northward, causing a sinking or retreat of the Arabian Sea Water (Johannessen et al., 1987; Pankajakshan Thadathil and Aravind Gosh, 1992; Muraleedharan et al., 1995; Hareesh Kumar and Basil
Mathew, 1997). Diminishing of the anticyclonic basin gyre and its slight contraction to the south and west evince the relaxation of southwest monsoon forcing. Associated with this westward propagation, the southward flow along the west coast of India propagates offshore (David Young and John Kindle, 1994).

The five-year study along the Kerala coast by Johannessen et al., (1987) showed a more repetitive pattern of the seasonal variation from year to year than could be demonstrated by the two-year studies by Darbyshire (1967), who concluded that the two-year study showed very different conditions and no conclusions was able to draw. They observed the upwelling to intensify in August-September, causing penetration of low-oxygen water over the entire shelf north of Quilon (~9°N), while south of Quilon it is less significant. The influence of land runoff was traced upto 60 nautical miles offshore. They have also observed changes in biological events: a peak in the plankton production associated with upwelling and pelagic fish concentrating in the surface layer due to the oxygen deficiency below the oxycline, and some species disappearing from the northern part of the shelf during the southwest monsoon months. Withdrawal of demersal fishes from bottom waters having oxygen saturation < 10 % have been reported by Banse (1959). Ramasastry (1959) observed that during southwest monsoon upwelling along Kerala Coast, the Arabian Sea surface water is displaced by the upper subsurface water, resulting a complete overturning in the entire water over the continental shelf.

International Indian Ocean Expedition (1962-65) recorded the nutrient data along with other parameters in the Arabian Sea and Bay of Bengal (Wooster et al., 1967; Rao and Jayaraman, 1968; Sankaranarayanan and Reddy, 1968; Varadachari et al., 1968). The earlier reports on the nutrient characteristics of Bay of Bengal were made by Jayaraman (1951); La Fond (1957); Ganapati and Sarma (1958); Sen Gupta et al., (1977); Rajendran et al., (1980); De souza et al., (1981) and Rao and Satyanarayana (1982).
Satyanarayana et al., (1987) reported the nutrient distribution of Bay of Bengal waters. Distribution of phosphates and silicates in the central western north Indian Ocean was reported by Reddy and Sankaranarayanan (1968). Sen Gupta et al., (1976a) studied the relationship between dissolved oxygen and nutrients in the north-western Indian Ocean. The nutrient fractionation and stoichiometric relationship in the northern and eastern basin were reported by Sen Gupta et al., (1976b). De Souza and Singbal (1986) presented the relationship of phosphorus and nitrogen compounds with the dissolved oxygen in the water masses of central Arabian Sea.

The chemical oceanographic features of Arabian Sea have been exhaustively studied by Banse (1959; 1968); Reddy and Sankaranarayanan (1968; Sankaranarayanan and Reddy (1970); Sen Gupta et al., (1979; 1980); Qasim (1982); Naqvi et al., (1982; 1993; 2000); Naqvi and Qasim (1983); Sen Gupta and Naqvi, (1984); Naqvi (1987; 1991; 1994); Naqvi and (1991) and Naqvi and Jayakumar, (2000).

During summer monsoon period, the nutrient values of the coastal waters shoot up, surface salinity and water temperature come down, detrital load increases and consequently light penetration diminishes. These rapid changes often lead to very high production at primary and secondary levels (Devassy, 1983; Madhupratap et al., 1990). Red tide caused by Noctiluca is a regular feature along the coastal waters and estuaries, especially during August, April and November, thus, exhibiting annual feature (Venugopal et al., 1979; Devassy and Nair, 1987). Even after the upwelling event tapers off, the effects are observed to last for a good part of the ensuing season (October-January) also. In Cochin backwater, the standing crops of phytoplankton reaches peak by the end of October (Devassy, 1983). Surface warming and increase in salinity are identified as preconditions for the onset of Trichodesmium blooms during February-April (Qasim, 1970; Ramamurthy et al., 1972; Devassy et al., 1978). Trichodesmium filaments are known to fix nitrogen and release it into the environment on its decay.
Incidences of blooms of phytoplankton, discolouration of coastal and estuarine waters and swarms of zooplankton have been reported as regular features along the west coast of India (Nair et al., 1992). They have also found that this area is subjected to episodic introduction of nutrients during the summer monsoon through river run-off and coastal upwelling. Responses of phyto- and zooplankton to such inputs are often predictable and have been observed to form persistent patterns in numerous investigations. Spectacular bloom formations of *Trichodesmium* is a regular phenomenon during the later part of the NE monsoon season. At times, these blooms cover hundreds of kilometers.

Qasim et al., (1978) has exclusively studied the biological productivity of coastal waters of India. Compared to Cochin backwaters, the coastal waters are found to be less productive in zooplankton standing stock (Haridas et al., 1980). However, sudden increase of zooplankton swarms as a result of upwelling could occur in coastal waters (Madhupratap et al., 1977; 1980). Despite the high zooplankton productivity, the transfer coefficient from primary to secondary level was only 7% in Cochin backwaters. This excess production in the backwaters might be contributing to the productivity of coastal waters, sustaining rich benthic biomass reported from this region. The species diversity progressively increased from 3.7 in the estuary to 5.9 in the coastal environment (Madhupratap, 1980). Benthic studies of Cochin coastal region by Harkantra and Parulekar (1987) revealed decrease in population density with depth and mainly constituted of polychaetes.

The studies by Hashmi et al., (1981) revealed deposition of clay-sized sediments in the nearshore regions by the process of flocculation, which resulted in trapping of coarse particles in the Cochin-Quilon coast. Higher degree of alteration is observed in the sediments of Central Kerala Coast suggesting its origin during Holocene period and the relict sands subsequently got mixed with the modern clay sediments supplied by coastal processes to form the present type of mixed sediments (Prithviraj, 1991). Compared to
cross shelf transport, along shelf transport appear to be the more dominant mechanism for sediment transport on the western continental shelf of India (Ramaswamy, 1987). Ramaswamy and Nair (1989) have reported that the anthropogenically-derived pollutants, associated with clay particles discharged from the coast, would tend to remain within the narrow confines of the inner continental shelf.

The shoreline along Cochin has been classified under barrier beaches and the changes in morphology in response to different seasons are studied by Prasannakumar and Murthy (1987). They have observed differential wave activity together with static mud suspension at places in the nearshore region. Similar studies by Shenoi et al., (1987) have found an offshore mud bank that protects Narakkal region during southwest monsoon, as this region experienced the least shoreline variability. These observations are confirmed by wave refraction studies of Sajeev et al., (1997), in addition, they reported that Vypeen region experiences convergence of wave energy almost throughout the year.

1.3. Mudbanks of Kerala

The description mentioned above are the general oceanographic features observed in the Arabian Sea and along the southwest coast of India. This discussion, however, will not be complete unless a brief history about a unique feature appearing only along the southwest coast of India – the mudbanks- is given, which occupy the present study region. Mudbanks, locally called Chakara or zones of biorythm (Balchand et al., 1987) are those areas of sea adjoining the coast, which have a special property of dampening the waves resulting in clearly demarcated areas of calm turbid waters during the roughest monsoon period. Along the continental shelf between Mangalore and Quilon, the nature of bottom about 3.5 to 18 m depth is largely muddy. During monsoon, because of the wave actions and rip currents, the fine mud particles get churned up into a thick suspension (Udaya Varma and
Kurup, 1969) in which the wave energy gets consistently absorbed. This annually occurring feature has a semi-circular shape and is unique in many ways. There are several theories of formations of mud banks and their characteristics as put forward by Gopinathan and Qazim (1974); Jacob and Qasim (1974); Kurup and Varadachari (1975); Kurup (1977); Balchand et al., (1987); Nair (1990); Nair et al., (1992; 1993); Nambisan et al., (1987) etc. Mudbanks, as they appear and disappear in the sea, have been considered as unique formations experienced only along Kerala coast. Mudbanks are well known for their fishery during the monsoon months.

1.4. Estuarine studies

An estuary may be defined in several ways. One of the most suitable and widely adopted definitions is that offered by Cameroon and Pritchard (1963). “An estuary is a semi-enclosed coastal body of water which has free connection with the open ocean and within which seawater is measurably diluted with freshwater derived from land drainage”. An alternative suggestion has been provided by Hedgpeth (1967), as “The estuarine system is a mixing region between sea and inland waters of such shape and depth that the net residence time of suspended matter exceeds the flushing time”.

It is within the estuaries that seawater and land derived freshwaters are mixed, producing wide range of brackish waters of intermediate salinities. In this process, both fresh water and saline water interact physically and chemically. Secondly, the estuaries are aquatic environments within which there are interactions of the suspended matter, with the soluble constituents of a succession of fresh, brackish and marine waters. On global basis estuaries are quantitatively very important to the supply of dissolved and solid material to the oceans.

The chemical processes in estuaries are also influenced by fluctuations in estuarine conditions resulting from the variability of run off due to meteorological variations produce considerable changes in the amount of
fresh water input from the catchments area and tidal conditions. These fluctuations often occur in an erratic manner in the supply of dissolved and suspended particulate matter thereby affecting the estuarine processes. The erratic fluctuations in river run off and rhythmic tidal cycle give rise to major difficulties in the sampling of the estuaries, modeling of estuarine processes and the comparison of individual estuaries with each other.

Although estuaries dominate the transport of natural weathering products to the oceans, they are also involved in the transport of pollutants. Pollution in estuaries occurs by the direct introduction of sewage and industrial wastes into them and also by the downstream transport of pollutants already present in rivers. Estuarine pollution is particularly relevant because of the fact that estuaries and their hinterlands are often sites of human settlement, commercial enterprise and recreation.

The Cochin backwaters from Cochin to Alleppey, the largest of its kind along the west coast of India form a bar built estuary with a channel forming the entrance to the Cochin harbour at Cochin and another opening further north at Azhikode. The backwater receives fresh water from six rivers namely Achen kovil, Pampa, Manimala, Meenachil and Muvattupuzha in the south and a branch of the Periyar in the north. Climatological mean of the rivers debouching into the Cochin estuary show that the river discharge varies drastically with the change in season. 33% of the river discharge into the Cochin backwater is from Periyar. Percentage contribution from Muvattupuzha, Achenkovil, Pampa, Meenachil and Manimala were 24.2, 5.8, 19.70, 8.30 and 8.8 respectively (Srinivas, 2000). During the lean period January to May, Muvattupuzha river maintains a constant flow probably due to tailrace water from the Idukki hydroelectric power station.

The tides in the backwaters are of a mixed type, predominantly semi-diurnal with a maximum range of about 1 m and the tidal influence is felt approximately 25 km upstream. The backwaters, as the term implies, include
a chain of brackish water lagoons, hundreds of miles long. These backwaters, in association with the adjoining low-lying lands, paddy fields and a network of canals form an extensive source of prawn and fish cultivation.

The backwaters adjacent to the Cochin harbour which form a part of investigation has a permanent connection to the Arabian Sea about 450 m wide, which forms the main entrance to Cochin harbour. This region is subjected to tidal influence and has all the characteristics of an estuary.

Cochin harbour, situated as it is on one of the islands (Willingdon Island) is surrounded on all sides by channels, which are being constantly dredged to permit the passage to shipping. Because of the influence of the harbour and land the entire area around Willingdon Island becomes polluted. The depth of the backwater varies considerably from place to place. Along the main channel it is maintained at about 10 to 12 m for navigational purposes while at other places it ranges from 2 to 6 m. The condition of the substrata is predominantly muddy.

The rainy season in the Cochin area extends from June to September, when there is a strong southwest monsoon and from November to January, which is the period of northeast monsoon. The annual rainfall at Cochin, based on the average of 10 years, is about 3200 mm of which nearly 75% occurs from late May to September. The prevailing winds are southwesterly from June to September and northeasterly from October to January. For the rest of the year, the direction of the wind keeps changing. The mean wind velocity is approximately 10 to 12 km.

The industries situated at the upstream region of the backwaters are causing large-scale environmental pollution by way of industrial discharge (Table 1.1). The industrial typology includes fertilizer, pesticides, radioactive mineral processing, chemicals and allied industries, petroleum refining and heavy metal processing and fish processing. The fertilizer consumption in Kuttanad region (the main agricultural field draining to Cochin backwaters)
alone is reported to be 20,239 ty\(^{-1}\) (Anon, 1998). The main factors affecting the coastal waters apart from sewage are fish processing, navigational dredging and dumping of dredge spoil and sand mining for filling and construction.

A number of multidisciplinary studies have been undertaken in the estuary during past five decades. The imbalance in the ecosystem by way of reduction in the carrying capacity of the backwaters, disruption in the life cycle of organisms, destruction of natural habitats, accumulation of pollutants, symptoms of eutrophication, tendency for over exploitation and dwindling of resources has stressed the need for the conservation of the ecosystem. Some of the important works worth mentioning in this context are Ramamritham and Jayaraman, 1963; Damodaran and Hridayanathan, 1966; Qasim and Reddy, 1967; Qasim and Gopinathan, 1969; Sankaranarayanan and Qasim, 1969; Murthy and Veerayya, 1972; Wyatt and Qasim, 1973; Manikoth and Salih, 1974; Joseph, 1974; Rajagopal, 1974; Anzari, 1974; Kurian et al., 1975; Unnithan et al., 1975; Vijayan et al., 1976; Qasim and Madhupratap; 1979, Saraladevi et al., 1979, 1991; Venugopal et al., 1980; Lakshmanan et al., 1982, 1987; Remani et al., 1983; Sankaranarayanan et al., 1984, 1986; Saraladevi, 1986; Baby and Menon, 1987; Lakshmanaperumalasamy, 1987; Gopalan et al., 1988; Nair et al., 1988; Joy et al., 1990; Nair et al., 1990; Kunjukrishna Pillai, 1991; Paul and Selvaraj, 1993; Mohandas and Ramamritham, 1993; Meenakumari and Nair, 1993; Revichandran et al., 1993; Balchand and Nair, 1994; Nair et al., 1994; Sunil Kumar and Antony, 1994; Mohan, 1995; Bijoy Nandan and Abdul Aziz, 1995b; Balachandran et al., 1996; Beenamma Jacob and Chandramonhanakumar, 1996; Rasheed, 1997; Dineshkumar, 1997; Maheswari et al., 1998; Thresiamma et al., 1998; Sheeba, 2000 and Srinivas, (2000). Partitioning of marine and estuarine sediments of this region has been carried out by Shibu et al., (1990); Nair, (1992) and Rajamani, 1994. The levels of trace metals in the water and particulate matter of Cochin estuary are reported by Nair et al., 1990, 1991.
Suraj et al., (1996) has studied clay mineralogy of Periyar river sediments and their role in the uptake of metals.

Environmental studies of similar nature have been reported from other regions also. Some of the latest references in this regard include the works of Prabhakara Murthy and Satyanarayana, (1999); Padmavathi and Satyanarayana, (1999); Deepak et al., (1999); Panigrahy et al., (1999); De Souza, (1999); Subramanian and Mahadevan, (1999); Bettina M. Loscher, (1999); Hydes et al., (1999); Palanichamy and Rajendran, (2000); Swamy et al., (2000); Corbett et al., (2000); Santchi et al., (2001) and Kieber et al., (2001).