Chapter 1

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Aquatic ecosystems are generally vulnerable to pollution as they receive the waste materials and sewage/effluents from the nearby sources. Estuaries, the transitional zone between sea and rivers are no exception (McCain et al., 1998; Lipp et al., 2001; Keser et al., 2005 and Kessarkar et al., 2009. They are dynamic and complex ecological systems that are the sites of unique ecological features possessing characteristic biological make up. Being an interface between freshwater and marine environments, estuaries give abode to several specific and valuable biota. Estuarine forms when exposed to pollutants will be under stress consequent to changes in the physico-chemical factors of the aquatic systems. Estuaries with freshwater inflow and tidal variations provide highly fluctuating environmental conditions and the organisms exhibit homeostatic mechanisms to cope with such conditions (Eliot and Quintino, 2007). Any factor that disturbs this state is found to inflict adverse effect on organisms and hence stressors.

Indian estuaries are linked to the country’s vast network of rivers and rivulets which are sources of nutrients. Estuaries in Indian subcontinent comprise 113 major and minor estuaries which are linked to a combined river length of 45,000 km (Ramesh and Purvaj, 2009). The Kerala coastal area supports nearly 30 brackish water perennial estuaries covering an area of 2,42,600 ha (Bijukumar and Sushama, 2000).

The environmental degradation and contamination of backwater ecosystem is generally due to anthropogenic activities which lead to the alteration in physical, chemical and biological characteristics of water and results in the ecological imbalance.

1.1 Industrial pollution of estuaries

The past few decades have witnessed an overwhelming increase in the plight of landscape and water quality deterioration of estuaries all over the world (Howarth et al., 2000). Rapid industrialization and incessant anthropogenic pressures are the major driving forces of pollution of estuaries (Kennish, 2002).

Increased population trend and development patterns around the coastal zone have adverse impacts on estuaries. Complicated interconnections exist between the quality and quantity of freshwater inflows and the health of estuaries. Estuarine pollution is considered
as a critical ecological issue because of the high variation in several abiotic factors that impose severe restrictions to the inhabiting organisms (Matthiessen and Law, 2002).


The influence of industrial and domestic sewage on eutrophication and bacterial pollution in Baixada Santista estuarine system has also been reported (Braga et al., 2000). Davis et al. (2000) highlighted the massive pollution of Rio Tinto estuary in Spain as a result of uncontrolled mining industries. The variation of sewage inputs and related contamination of Guanabara Bay (Rio de Janeiro) estuary in Brazil was investigated thoroughly and noted that domestic and industrial effluents together with agricultural runoff are the major contributing factors (Carreira et al., 2004). Scott et al. (2005) documented the pollution status of North American estuaries. Freitas et al. (2008) documented the anthropogenic influence of Sado estuary in Portugal.

The degradation of the upper and middle estuarine stretches of the Danshuei ecosystem in Taipei have been investigated by Liu et al. (2003) and Wang et al. (2007). The study of Hwang et al. (2010) also illustrated the pollution effects on zooplankton distribution and diversity along the marine, estuarine, and riverine portions of the Danshuei Ecosytem.

Estuaries in India are diverse distinctly, by virtue of its geographical extent, varied terrain and climatic conditions. The situation of Indian estuaries is also in peril. Qasim and Sengupta (1983) found out that about 5 million tonnes of fertilizers, 55,000 tonnes of pesticides, and 1,25,000 tonnes of synthetic detergents were used in India alone. Interestingly, about 25% of all these ultimately end up in the coast, especially in estuaries. Some of these are biodegradable while others are persistent with catastrophic ecological implications. Reddy et al. (2009) studied the pollution status of Pennar River Estuary, India with drastic morphological abnormalities in benthic foraminifera.

Several investigators reported the extent of industrial pollution in various Indian estuaries like Hoogly estuary (Dutta et al., 1954); Mandovia and Zuari estuary of Goa (Sengupta et al., 1989); Vellar estuary (Palanichamy and Balasubramanian, 1989); Rushikulya Estuary (Das et al., 2002); Ulhas Estuary (Ram et al., 2003); Tapi estuary
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(Krupadam et al., 2006); Ennore estuary (Padmini and Vijaya Geetha, 2007); Amba estuary (Ram et al., 2009); Uppanar Estuary (Soundarapandian et al., 2009) and Dharma estuary (Prasanna and Ranjan, 2010). The extent of pollution due to fertilizer output in Devi estuary, Orissa has also been investigated (Pradhan et al., 2009).

There are a large number of perennial/ temporary estuaries, present in the Kerala cost covering a total length is about 590 km long. Reports from estuarine pollution in the state of Kerala are also available -Vembanadu estuary (Harikumar et al., 2009); Cochin estuary (Remani et al., 1980; Sankaranarayanan et al., 1986; Anirudhan et al., 1987; Balachandran et al., 2005; Kumar et al., 2010 and Anju et al., 2011); Ashtamudi estuary by (George Thomas et al., 1995 and Geetha Bhadran et al., 1997).

The enrichment of heavy metals due to rapid industrialization and urbanization and their effects of water quality were recorded from Vembanadu Lake (Mohan and Omana, 2007). Industries around Vembanadu release nearly 260 million liters of effluents to the wetland ecosystem and in Cochin alone sixteen major industries, discharge nearly 0.104M m³/d of waste containing organic load into the nearby backwaters (Balachandran et al., 2002). Earlier reports are also available on the estuarine pollution by effluents containing heavy metals (Ouseph, 1987).

Indu et al. (2011) documented the trace metal pollution in Meenachil River at Kottayam, Kerala and observed that the major causes of depletion in water quality is due to the discharge of domestic wastes, municipal wastes, effluents, terrestrial runoff from seepage sites, agricultural sites and also due to geological weathering process. The water quality of Adimalathura Estuary, Kerala, India has been investigated. It is found that all the physico-chemical parameters (transparency, temperature, salinity, pH, dissolved oxygen) and nutrients (nitrate, nitrite, phosphate and silicate) showed considerable spatial and temporal variations (Anilakumary et al., 2007).

Anoop and Suryaprakash (2008) listed the problems faced by Ashtamudi estuary due to pollution, over-fishing, sand mining, bank erosion and loss of mangroves. Ashraf et al. (2008) observed heavy metal pollution in South Indian estuaries such as Vembanad, Ashtamudi and Veli. Cochin estuary alone receives large quantities of untreated industrial effluents and domestic effluents (CPCB, 1996).
1.2 Industrial pollution and distribution of estuarine biota

Aquatic ecosystems are affected by several health stressors that significantly deplete biodiversity. In the future, the loss of biodiversity and its effects are predicted to be greater for aquatic ecosystems than for terrestrial ecosystems (Sala et al., 2000). Estuarine systems are under developmental and pollution pressures because of urbanization and green revolution. Some estuaries experienced heavy industrial pollution by chemicals while others faced uncontrolled sewage inflow. The dumping of deluge of sewage and industrial effluents into estuaries has resulted in a drastic reduction in biodiversity, increased pollution and ecological imbalance (Rajendran et al., 2004).

Estuaries are dynamic water bodies in the coastal area which are the cradle grounds for phytoplankton growth (Ketchum, 1967). Nitrogen (N) and Phosphorous (P) are limiting nutrients (Neill, 2005) which support the growth of phytoplankton to establish a suitable pelagic food web (Adams and Bates, 1999). The physical variables such as flushing rate, salinity and turbidity also have profound influence on the distribution and abundance of plankton communities in estuaries (Cleorn, 1987 and Ferreira et al., 2005). The hydro ecology and phytoplankton diversity in the Coleroon estuary was studied by Thillai et al. (2005).

Phytoplanktons are suitable indicators, as they are simple, capable of quantifying changes in water quality, applicable over large geographic areas and can also furnish data on background conditions and natural variability. The microalgal communities provide immediate response to fluctuations and are suitable bio-indicators of water pollution status which are beyond the tolerance of many other biota used for monitoring (Nwankwo and Akinsoji, 1992).

An immediate decrease in faunal abundance was reported from Bilbao estuary, Spain mainly due to industrial pollution and other human interferences (Saiz-Salinas, 1997). Whitfield (1999) demonstrated factors influencing the ichthyofaunal community structure in South African estuaries due to industrial pollution. Whitfield and Elliot (2002) reviewed the responses of estuarine fishes (both resident and migrant fish species) and concluded that incessant anthropogenic pressure and uncontrolled industrial pollution critically influenced distribution, diversity, breeding, abundance, growth, survival and behaviour of fishes in estuaries.
Arkoosh et al. (1998) observed the bioaccumulation of juvenile salmon *Oncorhynchus* sp. and their prey from estuarine water with chlorinated and aromatic hydrocarbons which lead to immunosuppression and increased disease susceptibility in juvenile salmon. Gyedu-Ababio et al. (1999) established the influence of heavy metal contamination in the sediments on the density and diversity of nematode communities in the Swartkops river estuary, South Africa. The responses of estuarine meiofauna community assemblages against fertilizer enrichment in estuarine complex of Itamaraca Island and north coast of Pernambuco State, Brazil have been studied in detail (Santos et al., 2009).

Abrupt fluctuations in plankton density and abundance of post-larvae were noticed in estuaries of Madras region (Pulicate, Adyar and Ennore) as a result of chemical discharges from the surrounding industries (Joseph et al., 1991). The relation between phytoplankton availability and industrial pollution in Uppanar estuary was studied earlier (Periyanayagai et al., 2007). Palleyi et al. (2011) studied the influence of water quality on the biodiversity of phytoplankton in Dhamra River Estuary of Odisha Coast, Bay of Bengal. Their findings indicates that the major genera observed are *Coscinodiscus, Skeletonema, Nitzschia, Navicula, Thallasiothrix, Triceratium, Biddulphia, Ceratium, Rhizosolenia, Thallasionema, Bacillaria, Chaetoceros, Melosira, Trichodesmium, Podosira* and *Pleurosigma*.

The presence of seventy seven species of phytoplankton was noticed in Mahanadi estuary, east coast of India with 63 species of Bacillariophyceae, 8 species of Dinophyceae and 6 from Cyanophyceae (Naik et al., 2009). They also established the presence of pollution indicating species such as, *Anabena* sp., *Chlorococcus* sp., *Dinophysis* sp., *Gymnodium* sp., *Mycrocystis* sp., *Nitzschia seriata, Oscillatoria* sp., *Prorocentrum micans, Phaeocystis* sp. and *Trichodesmium* sp. from the estuary and throw some light into the pollution status of the estuary by phytoplankton analysis. Perumal et al. (2009) evaluated the seasonal variations in plankton diversity in the Kaduviyar estuary, Nagapattinam, southeast coast of India.

The distribution of zooplankton along Southern Kerala revealed a very high numerical abundance of siphonophores from Veli which indicates the pollution thriving nature of that species especially at low pH and high water temperature (Robin et al., 2009). Latha and Thanga (2010) also analyzed the macro invertebrate diversity and its relation with pollution of Veli and Kadinamkulam estuaries, South Kerala, India. They
reported 24 families represented by mollusca, annelida and arthropoda (crustaceans and insects). The dominant taxon was Mytilidae (molluscan) and the diversity and distribution patterns of some species were clearly related to water quality.

1.3 Industrial pollution and sediment quality

Sediment is a complex matrix of components and sediment quality has considerable influence on the overall status of a water body. Sediments act as a reservoir for contaminants and are a primary source of contaminant exposure for sediment-dwelling organisms and animals that feed on the bottom. This exposure can produce deleterious impacts on benthic communities and can also lead to indirect effects due to bioaccumulation.

Traditionally, sediment quality was assessed by making comparisons between concentrations of contaminants with sediment quality guidelines (SQGs). Based on such a comparison, the potential risks, or hazardous sediment-bound contaminants can be estimated (Den Besten et al., 2003).

Sediments are natural buffers and form an important habitat as well as a main nutrient source for aquatic life which have an impact on ecological quality and well being (Stronkhorst et al., 2004). It is well established that sediments are integral part of biogeochemical cycle of most contaminants, acting as source, sink and transformation centre (Moreira et al., 2006). Estimation of anthropogenic impact on sedimentary composition is pivotal for environmental monitoring studies, as sediments are sensitive and reliable recorders of both natural and anthropogenic interferences (Szefer, 2002). Sediment monitoring are thus considered as vital to evaluate the extent of contamination and pollution histories within estuarine, coastal and shelf regions globally (Zwolsman et al., 1996; Nolting et al., 1999 and Selvaraj et al., 2004).

Numerous contaminants introduced into aquatic ecosystems via industrial and domestic sewage discharge, surface run-off and atmospheric fallout are adsorbed, transported and suspended in sediments. After complex cycles of deposition, resuspension, transport, and biological and chemical interactions, these contaminants associated with particles settled in bottom sediments, which become the ultimate pollutant sink with catastrophic outputs (Luoma and Ho 1993 and Mecray et al., 2001). Sediment contamination is considered as one of the worst environmental problems for estuarine and marine ecosystems. Sediments act as sinks and also as sources of contaminants in aquatic
systems, as heavy inputs of effluents are taking place regularly (Mucha et al., 2003 and Ajay et al., 2008).

Loizeau et al. (2004) studied the sediment quality and its relation with effluents from sewage treatment plant at Bay of Vidy, Lake Geneva, Switzerland. It was concluded that the quantity of heavy metals deposited in the bay was considerable which created sediment instability and consequently constituted a potential hazard for biota.

The relation between watershed stressors and sediment contamination in Chesapeake Bay estuaries was well evaluated (Comeleo et al., 1996). Liu et al. (2003) concluded that sewage discharges from Shanghai, in China provides large quantities of nitrogen and phosphorus to the estuary and the estuary was under the risk of eutrophication and red tide. Riba et al. (2002) studied the influence of the Aznalcóllar mining spill on the vertical distribution of heavy metals in sediments from the Guadalquivir estuary, SouthWest Spain.

Franc et al. (2005) assessed the sediment quality and its relation with pollution loads in various sites in Tagus estuary, Portugal. Binning and Baird (2001) reported heavy metal pollution in sediments due to industrial pollution of Swartkops river estuary, South Africa with an elevation of concentrations of chromium, lead, zinc, titanium, manganese, strontium, copper and tin. Leton and Akpila (2008) reported the deteriorating sediment quality of Woji River, as a result of industrial effluents. Olomukoro and Azubuike (2009) assessed the extent of heavy metal in sediment samples in Ekpan Creek, Warri, Nigeria and suggested the influx of industrial effluents.

The study by Kehrig et al. (2003) suggested that metal concentrations in sediment samples from Jequia mangrove and estuary in Brazil, was very high which indicated a significant anthropogenic input of zinc, lead, chromium, copper and methyl mercury.

Sujatha et al. (2009) studied the sediment quality of Ashtamudi and Vembanadu lakes and concluded that Vembanadu is more deteriorated than Ashtamudi and is due to urbanization, demographic explosion, industrial discharges and enormous use of agrochemicals.

1.4 Impact of industrial wastewater on fishes

Chemicals in industrial effluents are toxic to animals and even cause death or sublethal pathology of various internal organs like the liver, kidney, reproductive,
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respiratory and nervous systems. Fishes are very sensitive to toxicants in water and it can be easily established. Fish is considered as highest in trophic level in aquatic ecosystem. They are excellent bioindicators of pollution as it is easy to collect, enough potential to accumulate toxins, increased lifespan and optimum size for studies (Batvari et al., 2007). The bioaccumulation of toxins and metals in fishes are directly proportional to ecological requirements, metabolic activity, salinity, level of pollution in food, water and sediment (Fidan et al., 2007).

The deluge of chemicals entering the aquatic ecosystem through human activities, cause adverse effects on the aquatic life, including deleterious changes which alter or destruct metabolic activity and rate (Hirth, 1964). When any aquatic animal is exposed to a polluted environment, a sudden and immediate stress is developed by the animal which meets more energy demand to overcome the toxic stress from surroundings (Sreenivasan et al., 2011).

Ahmad and Shuhaimi-Othman (2010) established the presence of Cu, Zn, Pb and Cd in fishes (Puntius schwanenfeldii, P. bulu, Ompok bimaculatus, Cyclocheinichthys apogon, Osteochilus hasseltii, O. melanopleura, Notopterus notopterus, Chana micropeltes, Labiobarbus festiva, Hampala macrolepidota, Chela oxygastroides, Mystus nigriceps, Thynnichthys thynnoides, Barbichthys laevis and Helostoma temmincki) inhabiting lake Chini, Malaysia.

The effect of electroplating industrial effluent with chromium on energy metabolism of air breathing cat fish Mystus cavasius was studied in detail (Palanisamy et al., 2011). Almeida et al. (2001) studied the metabolic responses of Nile tilapia, Oreochromis niloticus after exposure to environmental cadmium. Pathan et al. (2009) noted extreme behavioral changes and toxicity in freshwater fish Rasbora daniconius exposed to paper mill effluent from Kaiogaon paper mill, Aurangabad.

Bainy et al. (1996) studied oxidative stress in gill, erythrocytes, liver and kidney of Nile Tilapia (Oreochromis niloticus) collected from a polluted water body and these changes are detrimental to normal functioning. Severe biochemical and morphological changes in gills of Tilapia (Oreochromis mossambicus) after experimental cadmium exposure was studied earlier (Wong and Wong, 2000). According to SEM analysis they concluded that an augmentation of micro bridges in pavement cells and an increase in the apical membrane of chloride cells was observed after cadmium exposure which leads to
hypocalcemia. Sun and Tsai (2009) reported intersex Tilapia (*Oreochromis* sp.) due to endocrine disruption as a result of exposure to toxic chemicals in Era-Jiin River of southern Taiwan.

Ghazaly (1992a) monitored the effect of nickel on carbohydrate metabolism, blood and mineral contents of *Tilapia nilotica*. Ghazaly (1992b) also reported severe haematological and physiological fluctuations to sub lethal concentrations of cadmium in *Tilapia zilli*. The accumulation of heavy metals from effluents among fishes, especially *Tilapia mossambicus* inhabiting Ureje Dam in south-western Nigeria was also reported (Adefemi et al., 2008).

Ravanaiah and Murthy (2010) observed severe pathologic changes in *Tilapia mossambicca* collected from Pennar estuarine water of Nellore district, in Tamil Nadu. The histopathological changes recorded in the gill epithelium appear to be a primary response to the toxic influence of the industrial pollutants in the region. Navaraj (2003) observed the toxic effect of electroplating industry effluent on respiratory rate and oxygen consumption of *Oreochromis mossambicus*. Ambedkar and Muniyan (2011) observed the accumulation of Chromium, Cadmium, Copper, Lead and Zinc in *Tilapia mossambica* collected from Vellar River, Tamil Nadu, India.

### 1.5 Bacteria in sediments

Sediments form a large global reservoir of organic carbon which contributes to global biogeochemical processes and through the way they influence carbon degradation and preservation (Berner and Lasaga, 1989). Sediments are large repositories of bacterial populations, being found in sediments as deep as 800 meters below the seafloor and as old as 15 million years (Parkes et al., 2000 and Wellsbury et al., 2002). Sediment inhabiting bacteria are of great ecological and economic importance as they are responsible for decomposition, mineralization and recycling of organic matter.

Eze and Okpokwasili (2010) isolated bacteria such as *Nocardia* sp., *Pseudomonas* sp., *Klebsiella* sp., *Lactobacillus* sp., *Flavobacterium* sp., *Escherichia* sp., *Bacillus* sp., *Micrococcus* sp., *Proteus* sp., *Citrobacter* sp., *Staphylococcus* sp. and fungi like *Rhizopus* sp., *Aspergillus* sp., *Fusarium* sp., *Mucor* sp. and *Candida* sp. from industrially polluted sediments collected from Okpoka-Woji river estuary, Nigeria.


Anon (1997) reported a higher bacterial population density in sediments than water due to the rich organic content in sediments and lesser residence time of the microorganisms in the water column than the sediments from Nagapattanam. Karthikeyan *et al.* (2007) noted the fluctuations in heavy metal resistant bacteria inhabiting Uppanar estuary. Mahalakshmi *et al.* (2011) monitored the presence of total heterotrophic bacteria and human pathogens among sediment and water samples in Cuddalore fishing harbor, Tamil Nadu.

### 1.6 Bioremediation of heavy metals using bacterial isolates

Heavy metals are natural constituents of the earth crust which are persistent environmental contaminants as they are non-biodegradable. Heavy metals enter the body through food, air, and water and bio-accumulate over a certain period of time (Lenntech, 2004). They are normal constituents of the aquatic environment (Nieboer and Richardson, 1980), which even at low levels are able to elicit profound biological effects (Duruibe *et al*., 2007). Majority of heavy metals are toxic, but Hg, Cu, Cd and Pb are considered as more toxic than others (Bryan, 1979). The presence of heavy metals in aquatic realm was deleterious to all aquatic life forms.

Pollution due to heavy metals is very prominent in regions with mining and old mine sites (Peplow, 1999). Heavy metals are leached out through slopes and finally reaches water bodies which are emphatically polluted (INECAR, 2000). Heavy metals, after ingestion, are converted to their stable oxidation states ($\text{Zn}^{2+}$, $\text{Pb}^{2+}$, $\text{Cd}^{2+}$, $\text{As}^{3+}$, $\text{As}^{5+}$,
Heavy metal contamination in the environment is uncountable due to the increase in the addition of these metals to the environment either from natural sources or from anthropogenic sources and has become a threat to public health (Roane and Pepper, 1999). The concentration of metal contaminants in a habitat can be divided into three:- (a) contamination indices which compare the contaminants with the clean or polluted stations measured elsewhere; (b) background enrichments indices which compare the results for the contaminants with the baseline or background levels and (c) ecological risk indices that compare the results for the contaminants with Sediment Quality Guidelines (SQG) (Caeiro et al., 2005).

Several techniques are used to remove heavy metals such as chemical precipitation, chemical oxidation or reduction, electrochemical treatment, evaporative recovery, filtration, ion exchange, and membrane technologies (Hussein et al., 2004). Biological methods provide an attractive replacement to physico-chemical methods (Kapoor and Viraraghavan, 1995). Recent investigations with microorganisms, especially bacteria and fungi were promising to mitigate heavy metal pollution. Microorganisms uptake heavy metals either actively (bioaccumulation) and/or passively (biosorption) (Hussein et al., 2001 and Hussein et al., 2003).

It is well established that biosorptive process are more applicable than the bioaccumulative processes as living systems often require the addition of nutrients and subsequent increase in biological oxygen demand (BOD) or chemical oxygen demand (COD). Moreover, the maintenance of viable microbial population is very difficult due to heavy metal toxicity and other inhibitory environmental factors. In addition, potential for desorptive metal recovery is restricted as metals are intracellular bound and metabolic products may form complexes with metals to retain them in solution (Brown and Lester, 1982; Ajmal et al., 1996 and Dilek et al., 1998).

The process by which microorganisms are stimulated for rapid degradation of hazardous organic contaminants to environmentally safe levels is termed as microbial
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bioremediation (Umrania, 2006). The chemical transformations in bioremediation involve cleavage of complex molecules into several molecules in simpler form. In some instances, the byproducts of microbial bioremediation are harmless and in some cases it was proved to be beneficial and favourable (Gupta et al., 2003).

Biosorption, bioleaching, biominalization, intracellular accumulation and enzyme-catalyzed transformation are the principal mechanisms adopted by microorganisms in bioremediation of heavy metals (Lloyd, 2002). Bacteria, fungi, yeasts and algae are proved to be metal biosorbents which can decrease heavy metal ion concentration in polluted habitats (Das et al., 2008).

The past few decades had documented a steady hike in studies regarding the interactions of microorganisms with heavy metals. The newer biotechnological processes such as bioremediation and biobeneficiation through microbial metal re-absorption are cost effective and eco-friendly and got wide acceptance.

Martin-Gonzalez et al. (2006) evaluated the ability of ciliated protozoa to bioaccumulate heavy metals in wastewater treatment ponds. The potential of *Vibrio alginolyticus* in bioaccumulation of heavy metals was well studied (El-Hendawy et al., 2009). Ruiz et al. (2011) reported mercury bioremediation by transgenic bacteria expressing metallothionein and polyphosphate kinase.

*Thiobacillus ferrooxidans*, was industrially exploited for treating heavy metal contaminated soils, and bio-leaching of metal sulfide anduraninite ores (Straube et al., 2003). *Pseudomonas aeruginosa* is very effective for reclamation of soil contaminated with metals (Mathiyazhagan et al., 2011). Carrasco et al. (2005) and Monica et al. (2008) established the association between plant community and abundance and composition of microorganisms in quick and successful bioremediation and subsequent soil restoration.

Mathiyazhagan and Natarajan (2011) reported bioremediation of effluents from Magnesite and Bauxite mines by applying *Thiobacillus* sp. and *Pseudomonas* sp. The capability of *Rhodobacter sphaeroides* in bioremediation of cadmium contaminated environments was also investigated (Bai et al., 2008).

Panwichian et al. (2010) isolated purple nonsulfur bacteria from contaminated shrimp ponds which have capacity to detoxify heavy metals and sodium. Bacteria of genera *Bacillus, Enterobacter, Escherichia, Pseudomonas* and also some yeasts and fungi play crucial role in bioremediation of chromium-contaminated soil and water by bio-

Parungao *et al.* (2007) reported the biosorption of Cu, Cd and Pb by *Stenotrophomonas maltophilia* under controlled conditions. Congeevarama *et al.* (2007) proved the potential of *Micrococcus* sp. in removal of chromium and nickel from industrial wastewater. In short, there is an urgent need to screen indigenous microorganisms which provide new insights into bacterial diversity under unfavourable conditions, with new genetic information on heavy metal resistance, which could be exploited in mitigation of contaminated sites.

Molecular techniques have become the cornerstone in studies of microbial ecology, in the past few decades. It is well evident that classical enrichment techniques often underestimate the bacterial diversity within natural environments and only a minority of bacterial species have been isolated and cultured in the laboratory (Pace, 1997). The phylogenetic analyses of 16S rRNA gene sequences of various microbes were studied (Strous, 2000; Jiang *et al.*, 2006; Gontang *et al.*, 2007 and Quian *et al.*, 2010).

### 1.7 Objectives of the study

The present study was conducted in the Vattakayal estuary, which is near the industrial area of Chavara, Kollam District and was earlier an important backwater for fishing and shell fisheries. The estuary and neighbouring areas are now polluted due to the industrial discharge for more than two decades. The Vattakayal backwaters were supporting the livelihood of the local people before the arrival of the industry, but now the estuary has been deteriorated because of the pollution load affecting the flora, fauna and productivity. Only limited studies have been carried out so far on the pollution status of Vattakayal backwaters. Hence the present study was taken up with the following objectives

1. To assess the seasonal variation of water quality with special reference to the parameters like temperature, pH, electrical conductivity, turbidity, TDS, total alkalinity, total hardness, chloride, salinity, DO, BOD, COD, sulphate, nitrate-N, total phosphorous and heavy metals - Zn, Cu, Cd, Pb, Cr, Fe.
2. To assess the sediment characteristics (pH, electrical conductivity, organic carbon, zinc, copper, cadmium, lead, chromium and iron) during different seasons in the Vattakayal lake system.

3. To evaluate the stress effect of polluted wastewater from the factory on the fish Oreochromis mossambicus (Peters).

4. To study the potentials of selected bacterial isolates from the sediment of Vattakayal estuary for the bioaccumulation of selected heavy metals.
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