CHAPTER II

Literature review
2.0 Literature review

2.1 Studies on Indian wetlands

According to study conducted by Chopra (1985), more than 50,000 small and large lakes in India were polluted to the extent that, it is being considered as dead. The degradation of water quality is a direct consequence of pollution making them unfit for drinking, fishing, bathing or any other recreational activities. Unaware of the ecological consequences, the wetland system have been subjected to uninterrupted reclamation for the past 150 years, for various purposes such as, agriculture, aquaculture, harbor development, urbanization and industrialization. As a result, the system is being destroyed at an alarming rate of one percent per year (Gopal et al. 1993).

Factors that cause wetland deterioration like vegetational changes, deterioration of water quality, siltation, cattle grazing and poaching were recorded in India by Vijayan (1986), Anjaneyulu et al. (1990) and Trisal (1993). Status of wetlands in India was assessed by Anon (1990). A number of studies on various physico-chemical and biological aspects of wetlands were done in India. Important contributions were made by Huthinson (1937), George (1964), Khan and Siddiqui (1982), Kulshreshtha and Gopal (1982), Seshavatharam and Chandramohan (1982), Adoni and Saini (1984), Vyas et al. (1990), Khatri (1984) and Ramalinkam and Jayaraman (1985). Mohanty and Bhunya (1990) studied various physico-chemical properties in relation to faunistic composition of Ansupa lake, Orissa. A brief description of fishes and macro and micro invertebrates were also included in their study. Studies on one of the biggest wetland in the northern region of India, the Harike wetland and its management were carried out by Singh (1990).

Various physico-chemical features of Kawar Lake, a natural wetland of Bihar have been discussed in detail by Ahmad and Singh (1990). Other important contributions include those by Sheshavatharam (1990), in Kolleru lake, Andra Pradesh and Sheshavatharam et al. (1990) in lake Kodakaria, near Visakapatnam.

In a recent attempt at prioritization of wetlands for conservation, Samant (1999) noted that as many as 700 potential wetlands do not have any data to prioritize. Many of these wetlands are threatened

2.2 Status of wetlands of Kerala

The state of Kerala has a total of 217 wetland units, of which 157 units are greater than 0.6 km2 and has a total area of about 1279 km2 (Anon 1990). The wetland of Kerala, especially along the coastal stretch are also polluted to the extend that their fishery and recreational values are fast declining. The major interventions include fishing, over harvesting, subsistence activities, effluents from industries, solid waste and effluents from human habitation, coconut husk retting, stagnation, intensive shrimp farming, lime shell mining, wetland reclamation, construction of roads, railways, weirs, embankments, shrimp farms, mangrove cleaning, alteration of shoreline environment etc. (Nalini et al. 2000).

Details of wetlands of Kerala have been provided by Nayar and Nayar (1997). Various threats faced by wetlands of Kerala and its impact and the need for their conservation was studied by Nair et al. (1998). Geochemical classifications of wetlands in Kerala were also given by IRRI (1985).

The indiscriminate exploitation of wetlands beyond its supportive capacity, and input of residues exceeding its assimilative capacity, pollutes the wetland system of Kerala, the magnitude of which is very alarming. This if continued will cause harm to living resources, hazards to human health, hindrance to aquatic activities, impairment of water quality and reduction of amenities and finally ecological imbalance leading to catastrophic effects (Ajaykumar Varma et al. 2007).

The feverish tempo of wetland reclamation for urban construction and undesirable agricultural practices, construction of levees and dykes for hydrologic manipulation, discharge of industrial effluents, dumping of municipal wastes in the absence of reuse, recycling and disposal facilities, drainage of fertilizer-pesticide residues, over exploitation of resources and domain utilization for mining, construction tourism, coconut husk retting and such other activities are contributing to the loss and degradation of wetlands of Kerala (Nair and Varma 2002). These are in addition to the natural causes such as erosion, storm surge, siltation, drought, eutrophication and biotic interferences.

2.2.1 Environmental Problems Faced by Wetlands of Kerala

2.2.1.1 Industrial effluents

Industrial effluents discharged into the water bodies is a major threat to the wetlands of Kerala. It is a general practice to establish industries on the banks of streams, rivers and backwaters, mainly to avail the ease of discharge of effluents. It is estimated that industrial effluents of the order of 6.5Mm3 are discharged into the water bodies of Kerala (Anon 2003). The Eloor-Edayar region of the Kochi estuary provides a typical example of wetland pollution due to industrial discharge. Edayar region is identified as one of the toxic hotspots in the world by Green Peace, an international NGO campaigning against environmental destruction (Nair et al. 2001). The heavy metal pollution has a long-term impact which is evident from Beypore estuary where considerable amounts of mercury was found retained in the sediments even after the stoppage of industrial effluent discharge (Nair 1994).
2.2.1.2 Municipal effluents

Another important cause for wetland pollution in Kerala is the threat due to untreated municipal sewages and solid wastes. Most of the cities, towns and other urban centers are on the banks of water bodies. None of the urban centers in Kerala has a sewage system, except Thiruvananthapuram with a partial coverage. Kochi city generates about 3 Mm3 per day of waste water that enters the lake directly, through major canals and the pollution load of Kochi Corporation is estimated to be around 200 tones/day of BOD (Nair and Unni 1993). Similarly, the coliform counts observed in river Pumba, near Sabarimala were of the order of 240 to 46,000 MPN/100ml. The domestic sewage containing oxygen demanding wastes, infectious agents, organic chemicals and inorganic minerals, often affect the water quality of wetland system. It is reported that about 1,700 tones of wastes in the urban and about 6000 tones of wastes in the rural areas are left to decay in the drains and on the road sides. It is also indicated that around 80% of the municipal solid waste contain organic matter and appreciable concentration of heavy metals (Anon 2003, Padmalal et al. 2002). The high nutrient content associated with sewage and solid wastes is attributing as one of the main causative factor for the high rate of eutrophication in the wetlands of Kerala. The domestic sewage, which contains oxygen demanding waste infecting waste, infectious agents, biotic organic chemicals and inorganic minerals affect the water quality of wetland system.

2.2.1.3 Fertilizers and Pesticide residues

The residues of chemical fertilizers and pesticides, ultimately reached to the water bodies is another problem in the wetlands of Kerala. The intensive agricultural practices have resulted in the input of large quantities of agrochemicals and pesticides in the state. In the water bodies of Kerala especially in the Vembanad Lake pesticide pollution is acute (Nair and Unni 1993). The analysis of water and sediment samples collected from the creek and adjacent wetlands near Udyogamandal Institute estate indicated high organic contaminants and heavy metals (Labunska et al. 1999). The study indicated that
the sediments from the creek near Hindustan Insecticides Limited (HIL) containing more than 100 organic compounds

2.2.1.4 Tourism

Tourism in Kerala have a direct and greater impact on wetland pollution. Water pollution in wetlands of Kerala is mounting as the number of houseboats and fishing boats increases. The pollution problems created by houseboats are numerous. Houseboats often release sewage and kitchen wastes to the lake. As a result the presence of total coliform, fecal coliform and E coli was very high in the lake waters (Harikumar et al. 2007). The organic pollution is also found to be high in many locations of Ashtamudi lake due to fisheries and direct input of sewage (Nair et al. 2001, Remadevi and Abdul Aziz 1995). Oil and fuel from two stroke engines is being released through motorized boating activity. Numerous oil tankers and fishery vessels playing through the waters are also major source of pollution. The oil spread as film over the water in Akkulam-Veli Lake system inhabits free exchange of oxygen from atmosphere and light penetration resulting in impairment of primary production (Nair et al. 1998). The bacterial contamination of Sasthamkotta Lake, one of the Ramsar site in Kerala is severe and shows high threat in monsoon season (Girijakumari and Abraham 2007).

2.2.1.5 Coconut husk retting

Retting of coconut husk in the backwaters of Kerala has transformed the highly productive estuarine environment into virtual cess-pools of foul smelling sulfide rich stagnant waters, is another pollution problem faced by the wetlands (Bijoy Nandan 2003). The retting of coconut husks results in production of hydrogen sulfide and release of organic substances such as pectin, petosan, fat and tannin by the biological degradation of algae and fungi. Retting of coconut husk, in the wetland ecosystem on the west coast of India, has lead to the creation of stressed ecosystems with aerobic/anoxic trends along the 590 km coastal belt of the state, tremendously affecting the eco-biological stability of these productive systems. The physico-chemical studies of the estuaries revealed that
retting has been identified as a source of estuarine pollution (Sarthre Alex et al. 2002, Nandan and Abdul Aziz 1996)

It is revealed that retting activity has lead to acidic pH conditions with anoxia resulting in the production of high amounts of sulfide and an array of organic compounds like pectin, polyphenols, tannin and others, coupled with carbon dioxide values leading to a drastic reduction in the incidence and abundance of plankton, benthic fauna and the fishery resources. An outstanding observation was that the primary productivity of the retting zones totally collapsed. A study conducted by Central Indian Fisheries Research Centre (ICAR) in 10 hot spots of the wetland ecosystems viz Neeleswaram, Valapattanam, Mahe, Ponnani, Chettuva, Kodungallur, Kayamkulam, Ashtamudi, Anchuthengu and Kadinamkulam, has revealed the retting is converting the wetland ecosystem into a peculiar and complex ecosystem of micro aerobic and anaerobic properties. Kadeeja Beevi et al. (2004) indicated acidic nature of water and significant deterioration of transparency, dissolved oxygen, plankton and benthos population in retting zones.


2.3 Vembanad wetland system

The Vembanad wetland system is a complex aquatic system of coastal backwaters, lagoons, marshes, mangroves and reclaimed lands with an intricate network of natural and manmade channels and associated basins. Of late the wetland is facing serious ecological problems due natural and man made activities. The main problems faced by the wetland include troubles due to man-made interventions such as barrages
and bunds, land reclamation, pollution due to industrial, agricultural and domestic effluents, organic pollution due to coir retting, tourism activities, lime shell mining, and over exploitation of natural resources (Harikumar et al. 2007).

2.3.1 Problems Faced by Vembanad Wetland System

2.3.1.1 Wetland reclamation

The case study of Vembanad wetland may serve to illustrate the reclamation tendencies of wetlands in Kerala. Shrinkage of Vembanad wetland to 37% of its original area due to land reclamation has been the most important environmental consequence of human intervention in this water body (James 1996, Narayana and Priju 2006). Within the wetland system, the earliest human intervention was in the form of dredging for a major natural harbor at Kochi and subsequent reclamation for locating the port facilities. In Cochin harbor effects of dredging was pronounced in bottom waters leading to the ecological imbalance of benthic micro flora due to natural habitat loss (Rasheed et al. 1995 & 2000). The Thanneermukkom bund has been relatively successful in keeping the water in Kuttanad free from salinity. Several drawbacks have been noticed, the major ones: reduction in the upstream migration of marine fish and prawns and increase in weed growth in the upstream. The construction of Thanneermukkom bund and Thottappally spillway to prevent saltwater penetration into the paddy fields during pre-monsoon has lead to serious ecological problems by interrupting the natural ebb and flow of tides (Menon et al. 2000). The structure has severely restricted the natural flushing of pollutants. Another major intervention is the deforestation especially the mangroves (James 1998).

2.3.1.2 Industrial effluents

The Vembanad wetland system is a receptacle of a large variety of industrial effluents especially from Cochin industrial belt. A number of industries situated on the banks of rivers and backwaters in Kochi empty their effluents in to the wetland system. About sixteen major industries such as oil refineries, fertilizer plants and chemical industries discharges nearly 260 million m3 day-1 of wastes into backwaters (Anon 1990,
Balachandran et al. 2003). These effluents contain a large number of toxic ingredients such as acids, alkali, heavy metals, suspended solids and a number of other chemicals, which have immediate and long-term effects on the organisms. The input of acids and alkalis lead to drastic imbalances in the ionic status of water upsetting the living environment of organisms. The suspended solids cause turbidity maxima leading to productivity impairment (Muraleedharan et al. 2002). The Cochin estuarine system receives effluents containing a large dose of heavy metals.

2.3.1.3 Domestic sewage

A major source of pollution in Vembanad wetland is the domestic sewage generated in the urban areas and tourism locations of Alappuzha, Kochi, Vaikom, Cherthala, Chengannery, Kottayam, Kumarakom etc. and the operation of house boats in large numbers. The water quality deterioration due to sewage contamination in Vembanad Lake in the vicinity of Kumarakom tourist village was studied by Suchindan et al. (1999). He observed very high BOD and coliform contamination in the pre-monsoon season. The potential pathogenic hazards of organic pollution in Cochin estuary was studied by Sarthre et al. (2000). The increasing loads of sewage and industrial waste have created conditions that are extremely destructive to the flora and fauna. It is seen that the oxygen content is always low at the bottom which is attributed to oxygen consumption during decomposition of organic matter in deeper strata of water body (Sankaranarayanan et al. 1969). The higher COD values observed are due to domestic sewage and the waste discharged into the wetland (Saraladevi et al. 1979).

2.3.1.4 Fertilizers and Pesticide residues

Residue of chemical fertilizers and pesticides are causing greater problems to Vembanad Lake (Nair and Unni 1993). The studies by Rajiv Gandhi Centre for Biotechnology (Roy and Mathew 2000) confirmed serious deterioration of the ecosystem of Kuttanad, the rice bowl of Kerala as there were high concentration of heavy metals and organo-chlorine pesticides residues in water and sediment. The annual usage of
pesticides/fungicides/weedicides in Kuttanad is reported to be 117 tones during Virippu season and 368 tones during the Mundakan and Puncha season (Nair and Unni 1993). Seasonal and temporal variation of cyclodiene pesticides in the sediments of Kuttanad backwaters was estimated by Babu et al. (2008). Annual fertilizer consumption in Kuttanad is 8409 tones of nitrogen, 5044 tones of potassium. Pesticides/fungicides/weedicides are applied to the tune of about 500 tones/year (James 1998).

2.3.1.5 Coconut husk retting

It is reported that the retting and coir processing yards with in the proximity of the lake around Kuttanad, Alappuzha, Chittur and Vaduthala has converted the once productive lake in to non-productive anoxic areas. The retting yards also act as breeding grounds for mosquitoes. It has been estimated that in Kuttanad, about 157 million coconut husks are subjected to retting annually covering an area of 242 ha. The consequent anoxic condition, excess H2S and increased turbidity drastically reduce the primary productivity of the lake leading to considerable decline in fishery resource (Muraleedharan et al. 2002). Fish kills have been recorded from several retting zones in the wetlands of the state resulting from extensive depletion of dissolved oxygen and associated deleterious changes occurring in the wetlands (Bijoy Nandan 2003).

2.3.1.6 Hydrochemistry

Heavy load of organic materials released into the backwaters is responsible for the decrease of dissolved oxygen in the backwaters, especially during periods when river runoff is minimal (Babu et al. 2006). The marginal variation observed in the concentration of phosphorous and iron between surface and bottom waters as well as between southern and northern sector is presumably due to the near freshwater (monsoon) character of the overlying waters (Padmalal and Seralathan 1991). The geochemical characteristics of Kuttanad water and sediment were studied by Mathew et al. (2001). They found that acidic nature of the sediment and accumulation of the toxic salts made this area less fertile for rice. Variation of DO content of coastal waters along
the southwest coast of India in space and time has been extensively studied (Narayananpillai 1993). The BOD is also increased gradually with commencement of pre-monsoon and shows a decreasing trend with onset of monsoon period. The dissolved oxygen concentration in Cochin backwaters was found to remain under saturated during monsoon period. This may be due to the utilization of oxygen for the decomposition of dead planktonic organisms brought down by flood tide or silt loaded fresh water (Shyanamma and Balakrishnan, 1973). The higher COD values observed are probably due to domestic sewage and waste discharged into the harbor area (Saraladevi et al. 1979). Chemical oceanographic studies of the estuary were also carried by Balachandran, (2001).

2.3.1.7 Tidal study

Stratification and salinity distribution in relation to tides and freshwater discharge have been studied by Joseph and Kurup (1990). Hydrological conditions of Cochin backwaters are greatly influenced by sea water intrusion and influx of river water as shown by the distribution of salinity and temperature (Lakshmanan et al. 1982). The change in salinity has been found to have a profound effect on the sequence of fluctuation in the abundance and ecological succession of the fauna and flora in the estuary (Madhupratap et al. 1977). Distribution of salinity in the Cochin estuary shows marked seasonal variation. A distinct stratified layer is observed near Cochin bar mouth during monsoon and pre-monsoon and the estuary is well mixed throughout, whereas the post-monsoon is a transition period (Anirudhan and Nambeesan 1990). Hydrographic characteristics and tidal prism at the Cochin bar mouth was studied by Ramaraju et al. (1979). The overall change in salinity at the harbor region is in the range of 34.31ppt in April, to 1.11ppt in July. The change in salinity has been found to have a profound effect on the sequences of fluctuation in the abundance and ecological succession of the fauna and flora in the estuary (Madhupratap et al. 1977).
2.3.1.8 Nutrients

Distribution and variability of nutrients in Cochin backwaters have been extensively studied by Lakshmanan et al. (1987). Bindu and Harikumar (2007) studied the eutrophication of Vembanad Lake using a dynamic model. The eutrophication of the system is mainly determined to be phosphorous limited. Speciation of phosphorous in marine sediment of Cochin estuary revealed that aluminum bound phosphorous was maximum compared to iron, calcium and organic bound phosphorous. Phosphate fractions varied with locations and exhibited seasonal fluctuations (Ashraf et al. 2006). The organic phosphate pools play a crucial role, wherein it acts as an inducer in the triggering mechanism of aquatic life in coastal zone (Balchand and Nair 1994). Other studies in relation to phosphorous fractionation include Nair et al. (1993), Nair and Balchand (1993), Balchand and Nair (1994). In the Cochin back waters the nutrient distribution is largely dependent upon two main components, the marine influence and freshwater discharge (Shankaranarayanan and Quasim 1969). It is estimated that the backwater is receiving 42.4x10³ mol/d of inorganic PO₄ and 37.6x10³/d of organic nitrogen through Periyar. The export to coastal waters is only 28.2x10³ mol/d inorganic PO₄ and 24x10³ mol/d of inorganic NO₃. Thus estuary seems to act as a sink for nutrients. Associated with the diminishing of flushing rate, a nutrient build up is taking place for the backwater system (Balachandran et al. 2003).

2.3.1.9 Heavy metals in water

Concentration of dissolved and particulate trace metals (Ni, Pb, Zn, Mn) and their partitioning behavior between the dissolved and particulate phases in Vembanad lake was studied by Unnikrishnan and Nair (2004). They found that lack of proper flushing of backwaters, which receive large amount of trace metals through the application of pesticides and agro-chemicals, due to the presence of salinity barrier has significantly affected the water quality of southern half. Other studies on the trace metal distribution of the water column include those of Babukutty (1991), Babukutty and Chacko (1995).
Ouseph (1995), Ouseph (1987), Nair et al. (1991), Shibu (1992), Luther et al. (1986), Nair et al. (1990), Shibu et al. (1990), Senthilnathan and Balasubramanian (1997).

2.3.1.10 Geochemical studies of sediment

Geochemical studies of sediment with respect to organic carbon were done by Geetha et al. (2008). The results indicate that the main source of sediment organic carbon is plant remains. C/N ratio showed decrease towards the depth. Significant variations due to seasonal changes were observed (Lizen and Chandramohanakumar 2003). Textural characteristics of the sediment were also done by Nair et al. (1993). Surficial sediments indicated variation in texture resulting from detritus settlement influenced by mixing conditions in the estuary. Textural and geochemical studies in the southern half of Vembanad Lake were also carried out by Harikumar et al. (2007). Other geochemical studies include those of Nath et al. (2000) with regard of weathering and sedimentary process on the elemental ratios in Vembanad Lake. The coastal landforms of this region consist of Quaternary sediments, overlying a precambrian terrain consisting of granulites, gneisses and greenstones (Veerayya and Murthy 1974, Narayana and priju 1999).

Sediment distribution, grain size and suspended sediment characteristics of Cochin estuary have been reported by many scientists (Sundaresan 1990, Ajith 1996), but scanty reports by Sundaresan (1991) are available on sediment transport and related sedimentation process in this estuary. The sedimentation rate of the Cochin estuary was carried out by Rasheed and Balchand (2008) in an experiments using sediment trap. The surface sediments of the Vembanad Lake are mostly a mixture of clay, silt and sand. The northern part of the lake is covered with clay sand and silty sand, the central part with clay sand and sandy silt, and the southern part is covered with silty sand and clay silt (Veerayya and Murthy 1974, Narayana and Priju 1999). Presence of desiccated clays beneath the peat deposits suggests arid climate prior to the humid climate during 40,000 yrs BP (Narayana et al. 2002).
2.3.1.11 Sediment organic carbon

A comparative evaluation of the organic carbon content of the Cochin harbor area indicated substantial increase during the last two decades (Seralathan et al. 1993). The anoxic conditions prevail in the Vembanad estuary for most part of the year (Padmalal and Seralathan 1991), favors the preservation of sediment organic carbon. Seasonal variation in the organic carbon with lower values post-monsoon was attributed to the constant tidal flushing, while higher values reflected seclusion of organic residues in sediment layers (Sunilkumar 1996). Variation of organic carbon due to sediment texture showed higher values in highly grained sediments (Bijoy Nandan and Abdul Aziz 1996). Tidal activity and sediment has a good role in the preservation and retention of organic matter (Rini Sebastian and Jacob Chacko 2006). The strong correlation of sediment iron and phosphorous with organic carbon suggests that the major source of these elements in the lake system is from the organic decay (Padmalal and Serelathan 1991). It has been shown that organic carbon in sediments is higher during monsoon due to contribution from land runoff (Remani et al. 1980). While organic associations for most of the metals with seasons are preferential, absence of any correlation for Zn and Mn with organic carbon and clay on all occasion is striking (Balachandran et al. 2003). The potential value of Allochthonous organic matter, accumulated in the estuary as a result of microbial decomposition of Salvenia has been pointed out.

2.3.1.12 Heavy metals in sediments

iron, manganese, zinc, copper, cobalt and nickel in Cochin backwaters are being presented. The special trend for cobalt, iron and nickel was stationary at surface where as the metals copper, zinc and manganese showed special variations (Sankaranarayanan et al. 1998).

2.3.1.13 Studies on Lime shell

The occurrence and recovery of lime shell deposits of Vembanad Lake was studied by Maya et al. (2008). The study revealed that indiscriminate mining of shells over the years has imposed serious environmental problems to the lake system. The idea of subterranean flow through lime shell beds initiating formation of mud banks may apply globally to any coastal regions hugged by wetlands and of similar geological conditions (Balachandran 2004).

2.3.1.14 Biomonitoring

Biomonitoring in terms of hyperaccumulator plants were also done by Manorama Thampatti et al. (2007). They found that plants like Hydrilla Verticillate, Eichornia Crassipes and Cyperus Pangorci were found to poses hyper accumulation capacity for iron, manganese, zinc copper and aluminum in the wetlands of Kuttanad. The threat due to aquatic weed population in Vembanad Lake is quite alarming and these may dominate in future weed flora of Kuttanad (Joy et al. 1993). The study of aquatic weed, Salvenia molesta as a bio-pollutant for aquatic ecosystem has been carried out by Sydney et al. (1975). The fauna associated with the floating weeds as well as the influence of the floating weed mat on the estuarine benthos has been studied by Gopalan and Nair (1975).

The benthic organisms such as mussels and oysters are found to have high accumulation of Zn beyond the permissible limit. High concentration of Zn, Cu, Fe etc were also observed in Crassostrea madrassesnsis from Kochi region (Sankaranarayanan et al.1978). The distribution of trace metals (Cd, Cu, Fe, Mn, Zn and Hg) in the back water oyster, Crassostrea madrassesnsis (preston) of Kochi harbour was found to exhibit seasonal variation (Nair and Nair 1986). The oyster is found to be a suitable indicator organism for
metal pollution in backwaters (Rajendran and Kurian 1986). The use of detergents add chromium, cobalt etc to the wastewaters. Sewage sludge, discharged into the waters may be a significant source of copper, zinc and lead in aquatic weeds (Harikumar and Madhavan 2003). The possible role of cumulative deposition of macrophytic biomass in bringing about a gradual alteration in the estuarine benthic communities and its significance in food chain has been discussed in detail by Gopalan and Nair (1975).

The concentration level of copper, zinc, manganese and iron have been determined in marine fishes from Cochin area, which is one of the major fishing zones along the west coast of India. The concentration of heavy metals varied from species to species. Copper, zinc, iron and manganese showed increased level in the gills and alimentary canal compared to the muscle. Difference in heavy metal concentration in various species studied is attributed to the varying feeding habits. The observed levels were below the toxic limit (Nair et al. 1997).

The major studies reported above are mostly carried out in the northern region (estuarine region) of the Vembanad wetland system and hence the present study aimed to conduct in the southern part of the wetland with respect to water, sediment and aquatic macrophytes.

2.4 Groundwater studies of India

Groundwater constitutes 0.614% of earth’s fresh water resources, compared to the 0.008% in lakes and 0.005% in rivers (Mandel et al. 1981). Groundwater is the major source of drinking water in both urban and rural India. Besides, it is an important source of water for the agricultural and the industrial sector. Till recently it had been considered a dependable source of uncontaminated water.

The geological survey of India (GSI), for first time in 1969, setup a basic network of 410 hydrologic stations in different hydrological settings. The central groundwater board (CGWB) has increased the number to 3640 by 1981 and by now the number is much more. In this monitoring program water levels are monitored five times a year water
qualities are monitored twice a year. Most of the state government has also set up groundwater departments and they have their own network stations.

2.4.1 Major water quality problems of India

The subsurface water quality is degraded mainly due to natural reasons along with over withdrawal of water, insanitary conditions in rural and urban areas and increased application of fertilizers and POP’s. The parameters of concern in subsurface water are higher level of Fluoride in several pockets of the country (about 200 districts are being affected); Arsenic problem in parts of West Bengal, specially in 24 paragana’s of West Bengal; Nitrate problems observed in many parts of the country especially in intensively irrigated and high productivity regions from agriculture point of view; and in urban areas due to improper and inadequate sewage collection; Salinity problems in intensive irrigated (command areas) and coastal areas of the country; Micro pollutants, especially pesticides due to their intensive applications in certain parts of the country; and Pathogenic pollution in urban areas, due to in-sanitary conditions.

2.4.1.1 Fluoride

The incidence of fluoride above permissible levels of 1.5ppm occur in 14 Indian states, namely, Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal affecting a total of 69 districts, according to some estimates. Some other estimates find that 65 per cent of India’s villages are exposed to fluoride risk.

The groundwater in some districts of Andra Pradesh and Karnataka in the south and some districts in Punjab and Haryana in the north has excess quantity of fluoride acquired naturally and not through anthropogenic activity (Siddiqui 1962, Kanwar and Mehta 1968). In Rajastan more than 80% of the districts have high fluoride level in their drinking/groundwaters. (Teoltia and Teoltia 1984, Susheela 1993). The first cases of fluoride toxicosis were reported from Jaipur district (Kasliwar and Solomon 1959). A few reports on endemic flourosis have also been reported from Jhunjhunu (Thergaonkar and
Bhargava 1974) and Ajmer. Purohit (1988) observed that well waters of several villages of Nagaur and Churu districts contain 60-100 ppm fluoride.

2.4.1.2 Arsenic

High levels of arsenic above the permissible levels of 50 parts per billion (ppb) are found in the alluvial plains of Ganges covering six districts of West Bengal. An alarmingly large population of India and Bangladesh, 66 million in the Gangetic belt of India 79.9 million in Bangladesh (Bose and Sharma 2002, Ahmed et al. 2004) is exposed to arsenic poisoning due to continuous usage of arsenic contaminated groundwater. Arsenic poisoning reported in West Bengal few years back caused a lot of panic (Muraleedharan 1998, Bhattacharya et al. 2002, Ahmed et al. 2004). It was also reported in 24 Paraganas (south) district close to Culcutta. The reported cause was due to two reasons, first due to dissolved chemical pesticides with arsenic salts which seeped into subsoil level and second due to over drawl of subsurface water to ensure supply to multistoried buildings those sprang up recently in south Culcutta.

2.4.1.3 Nitrate-Nitrogen

Non-point pollution caused by fertilizers and pesticides used in agriculture, often dispersed over large areas, is a great threat to groundwater systems. Intensive use of chemical fertilizers in farms and indiscriminate disposal of human and animal waste on land result in leaching of the residual nitrate causing high nitrate concentrations in groundwater. Excessive occurrence of nitrite-nitrogen in groundwater has been observed in several districts of Punjab, Madhya Pradesh, Rajastan and Tamil Nadu. In Assam and adjoining areas in north east, liquid petroleum crude often comes with water when pumped. Trivendi et al. (1988) observed greater quantities of nitrate in the well waters of Maharashtra. Excessive use nitrogenous fertilizers in agriculture have been one of the primary sources of high nitrate in groundwater. Nitrate level in groundwater for different concentration ranges in few districts of Rajasthan show that 74% of groundwater samples in Barmer and 40% in Jaipur district exceeded nitrate concentration of 0.3 mg/l (Gopal et
al. 1983, Gupta 1981). Nitrate in groundwater of Delhi indicate that the shallow groundwater bearing high nitrate concentration were unfit for drinking (Central Ground Water Authority (Times of India16-11-98)).

2.4.1.4 Industrial pollutants

There are several reports of groundwater pollution due to industrial discharges. During 1977-79, CGWB analyses the groundwater in Ludhiana where electroplating and textile (cotton and wool) units are the more common types of industry. It was found that the groundwater in Ludhiana contained 1-2mg/l cyanide concentration due to the cyanide containing effluents discharged from electroplating units (Gosh 2002). Another major threat to the groundwater is the contamination by oil pollution (Aggarwal et al. 1993)

There are a number of areas in the country where serious groundwater pollution problems have been caused due to the seepage of effluents from various sources. Olaniya and Saxena (1977) reported that 25 wells around a refuse dumping site in Jaipur have been found to have high dissolved solids, chlorides, iron salts, COD and hardness. The effect was noticed up to distance of 450 meters. Siva and Ramamoorthi (1977) reported that the well waters were generally high in mineral contents and had harder water in the areas where a subsurface method of sewage disposal is practiced. The chlorides and the total dissolved solids of these wells were very high in these wells. Narayan and Madhyastha (1985) reported that water of well in Mukka village near Mangloor have become polluted as oily effluents seeped continuously from the north-eastern and south-eastern sides of the well at a distance of 10 meters dumping pits of a fish oil extracting small scale industry.

Similarly, where the tanneries are concentrated in some pockets of Tamil Nadu, well water has been affected even at a distance of 1Km. Total dissolved solids up to 1200mg/l were reported. In addition cases of pollution of groundwater by fluorides from superphate fertilizer plants and chromates from metal plating industry have been reported (Gosh 2002). Contamination of subsurface waters due to percolation of sewages is also a major
concern. An analysis of India, American and English sewage indicate that Indian sewage is comparatively richer in various parameters than those of American and English.

In Rajasthan the concentration of zinc, cobalt, molybdenum, silver and strontium in the groundwater was found to be in excess of the permissible limit for drinking purpose. Khetri Copper Project was identified as the source for this pollution of groundwater. The effluent of the Hindustan Zinc Ltd, in Debari (Rajastan) was also found to be the cause for the higher concentration of zinc and lead in well water (Gosh 2002).

2.5 Groundwater quality status of Kerala

The state of Kerala has the highest density of dug wells in India. This is a reflection of the high population density and peculiar hydrological conditions of the state. In Kerala 65.5% of the urban and 44% of the rural populations are getting protected water. The rest still depend on groundwater sources for domestic purposes. Generally the groundwater problems in Kerala are due to the presence of excess salinity, iron, fluoride, hardness and coli forms. Seawater intrusion, domestic sewage, mineralogical origin, agricultural and industrial activities are the major causes (Remani and Harikumar 1998). According to the CWRDM reports the quality of the groundwater resources in Kerala can be discussed in terms of coastal, midland and highland areas.

2.5.1 Problems in the costal stretch

The water quality problems in the coastal areas are mainly due to the presence of excess chloride (CWRDM 1997). The study on the interaction of seawater with top unconfined aquifer along the Kozhikode coast revealed that there is definite relation. A study on the water quality problems related to excess fluoride in Alappuzha reported to have fluoride concentrations greater than the permissible limit in all the pumping wells of KWA (CWRDM 1997a).
2.5.2 Problems in the midlands

In the midlands of Thiruvananthapuram, Kottayam, Muvvatupuzha, Kannur and Kasargode, the water quality problems are mainly associated with pH and iron. In Palakkadu the problem is mainly due to fluoride. In Trichur problems are especially due to fluoride, chloride, and coli form bacteria (CWRDM 1997b).

2.5.3 Problems in the highlands

In the highland regions of Idukki, the bore well samples were contaminated mainly due to high concentration of iron and coli forms (Remani and Harikumar 1998).

In addition to the CWRDM reports there are many other studies on groundwater quality in different parts of Kerala. Localized problems of fluoride are reported from Alappuzha and some parts of Palakkad (Antu and Harikumar 2007). Hydrochemical studies of Muthalamad region of Palakkadu was carried out by Antu and Harikumar (2007). They reported that most of the waters are of Na-Ca-Mg-HCO3-Cl type. By taking 3243 samples from three panchayaths of Chittur block, a mapping of fluoride contaminated area was done by Raveendran and Kadeeja Beevi (2007). The dissolution mechanism of fluoride in the groundwater of Alappuzha was carried out by Noushaja et al. (2008).

The quality of groundwater and pipe water in Fort Cochin area was studied by Shaju et al. (2007). They found that most of the physico-chemical parameters are above the limit for drinking purposes. The pollution of waters in terms of coliform bacteria is also high in these regions. Urbanization has a direct impact on the quality of groundwater. Seasonal changes in the water level and quality of subsurface waters of Neyyattinkara municipal area was carried out by Suvarna Kumari et al. (2002).

Industrial activity is one of the major causes of groundwater contamination in Kerala. Sathyanarayanan (1998) has conducted a study on the effects of industrial activity to the nearby groundwater resources of three major industrial cities namely Kochi, Kozhikkode and Kannur. Apart from the acidity, hardness, excess concentration of fluoride, chloride
and nitrate than the permissible limits, heavy metal concentrations far beyond the permissible limits were found in the water samples. In the Kochi industrial area, around 505 are found to be contaminated with heavy metals or nutrients. Effluents from different industries like textile, refinery and chemical manufacturing are polluting the groundwater. A study on the water quality of groundwater samples in Athani industrial area of Trichur was conducted by Vijayalakshmi Amma et al. (2002).

2.6 Isotope studies on precipitation

Realizing the importance of stable isotopes in hydrology, the International Atomic Energy Agency (IAEA) and the World Meteorological Organization (WMO) established a Global Network of Isotopes in Precipitation (GNIP), in which samples are collected regularly to monitor the $\delta^{18}O$ and $\delta D$ of precipitation. The data produced by this network are essential for environmental isotope hydrology. They are available on the World Wide Web at http://www.isohis.iaea.org. Over the last three decades, the data have been useful in understanding the systematics of isotope hydrology as also in tracing large-scale atmospheric vapor transport systems. Unfortunately, long-term precipitation isotope data are available only for two Indian stations, namely New Delhi (1967–2000) and Mumbai (1960–78). No data on isotopes in precipitation from anywhere along the east coast of India exist (Gupta and Deshpande 2005).

2.6.1 Global precipitation

The variation of $\delta^{18}O$ and $\delta D$ in global precipitation has been studied by several investigators (Dansagaard 1964, Rozanski et al. 1993). An interesting relationship between $\delta^{18}O$ and $\delta D$ exists in the precipitation and based on this a Global Meteoric Water Line (GMWL) has been constructed by Craig (1961). The dependence of the isotope variations on the local temperature (or the closely related parameter of the precipitable water content) appears as the overriding parameter (Fricke and O'Neil 1999). An extreme case of the absence of an inland effect over thousands of kilometers, in spite of strong rainfalls enroute, was reported over the Amazon (Salati et al. 1979). The
continental effect in δD is nicely shown by the iso-δD contours reported by Taylor (1972) for the United States. Siegenthaler and Oeschger (1980) calculated the deviation of δ value due to altitude and temperature effect. The variation of δ18O with altitude in the mountain regions in Czechoslovakia (Dinçer et al. 1970), Nicaragua (Payne and Yurtsever 1974), Cameroon (Fontes and Olivry 1977) and Switzerland (Siegenthaler and Oeschger 1980) has been studied. Moser and Stichler (1974) observed pseudo-altitude effect in inter-mountain valleys and on the lee side of a mountain range. Dansgaard (1964) observed a relation between the amount of precipitation and 18δ.

The regional scale spatial and temporal variation of stable isotope composition of precipitation over Southeast Asia and the western Pacific region, with emphasis on China, has been explained in terms of meteorological and pluviometric regime of climatology and atmospheric circulation pattern (Araguas-Araguas et al. 1998). The variation of stable isotopes in monsoonal rains of Sri Lanka has been studied by Dharmasiri and Atuluwage (1992).

2.6.2 Indian precipitation

The hydrology in India is largely controlled by precipitation during the summer (SW) and winter (NE) monsoons. The SW monsoon operates during the months of June-September and NE monsoon during the months of October–January. The causal mechanism (Das 1985) for these monsoon systems is the seasonal reversal of temperature and pressure gradients and associated wind circulation following the annual northward and southward motion of the sun. These two seasonal circulation systems are part of the larger monsoon circulation of South Asia. Because of the geography of the continental drainage area, the river discharges into Arabian Sea (AS) and Bay of Bengal (BOB) differ by an order of magnitude. As a consequence, the surface waters of the BOB get more diluted by freshwater. In terms of average sea water isotopic composition, the BOB has been shown to be ~1‰ depleted in δ18O with respect to the AS (Duplessy et al. 1981) due to large influx of monsoon run-off from Himalayan rivers. As a result, the BOB is
expected to have large seasonal changes in isotopic composition of its surface water, similar to large seasonal surface water salinity changes (Rao and Sivakumar 2003).

The annual hydrological cycle begins with the onset of SW monsoon over Lakshadweep, Minicoy and Kerala, which brings copious rain over the Western Ghats. Slowly, the monsoon current advances over the southern peninsular region and crosses over to the east coast (Ghosh et al. 1978). This is the AS branch of the SW monsoon. Over the BOB, the monsoon current turns anti-clockwise and re-enters India across the central and northern parts of the east coast, giving rise to the BOB branch. During winter and spring, winds originating in the east and central Asia and moving towards the southwest direction pass over the BOB before entering the southeast parts of India in the form of NE monsoon (Menon 1995). Roughly around the same period, the northern and northwestern parts of the country receive rains due to western disturbances that originate over the Mediterranean and West Asia.

By the end of the rainy season in September – early October, the inflow of water vapor from the sea surface gradually decreases and the resident moisture within the country in different components continues to redistribute through evapotranspiration to the atmosphere, soil moisture drainage to the groundwater and effluent groundwater discharge to the rivers. Finally, with the beginning of summer in March–April, the evapotranspiration of the surface water and soil moisture becomes the dominant process controlling the hydrological cycle in the country until the end of May, when the yearly cycle begins afresh.

The synoptic hydrology of India, based on the regional maps of amount-weighted monthly distribution of $\delta^{18}$O and $d$-excess of precipitation, for different seasons over the Indian subcontinent, has been described by Gupta and Deshpande (2003). The differing seasonal distributions of isotopes at Mumbai (Bombay) and New Delhi representing two different regions of the Indian monsoon have been explained by differing mechanism of precipitation and moisture source regions by Bhattacharya et al. (2003). Data et al. (1991) explained the seasonal difference in the isotopic composition of rain water at New Delhi,
which was contributed by evaporation from falling rain drops. Other than New Delhi and Mumbai, precipitation isotope data of shorter length (1-5 years) are available from Kozhikode, Allahabad, Shillong, Hyderabad and a few closely spaced stations in Lower Maner Basin.

2.7 Surface water isotopic studies

The isotopic characteristics of the surface water systems have great importance in hydrological studies (Jong-Sik Ryu et al. 2007). There are few surface-water isotopic measurements in the subcontinent to establish the identity and origin of stream-water in any given part of the year to different parts of the catchments. Available data do indicate that during non-monsoon months most streams derive their base flow from local effluent groundwater discharge, which also indicates signatures of evaporative enrichment in isotopes (Dalai et al. 2002). Additionally, the following observations have also been made.

Data on isotopic composition of the headwaters of the Indus and its tributaries, surface ice in glaciers, saline and freshwater lakes and thermal springs in Himalayan and Kashmir region showed (Pande et al. 2000) high $d$-excess that could be due to precipitation from western disturbances with unique signature of vapor source in the Mediterranean Sea (Raina 1997). All along the path of the western disturbance (Iran, Afghanistan, Pakistan and Kashmir) the precipitation is characterized by high $d$-excess. In this region the ‘altitude effect’ decreases with elevation.

In another study of the Ganges river system, high-altitude tributaries showed $\delta^{18}O–\delta D$ relationship close to GMWL, but streams from the lowland region showed a significant evaporation effect (Ramesh and Sarin 1992).

Seasonal variations in isotopic composition of the Yamuna and its tributaries were explained in terms of amount effect with most depleted values during the monsoon period and from high altitude samples (Dalai et al. 2002). The observed high $d$-excess during
October was ascribed to the inherent signature of a source with a significant component of high $d$-excess vapor, possibly western disturbances.

Temporal variations in isotopic composition of Nainital Lake have been used to estimate subsurface components of the water balance to the lake (Nachiappan et al. 2002), and the dynamics of the lake in terms of seasonal process (Gupta and Deshpande 2004). The variation of $\delta$ along the estuaries was also done by different isotope hydrologists. In both Krishna and Godavari estuaries, $\delta D$ was shown to behave conservatively during mixing between sea water and stream water (Sarin et al. 1985).

**2.8 Groundwater isotopic studies**

Understanding the effect of evaporation on stable isotopes is an important factor in discussing the relationship between precipitation and groundwater (Boronina et al. 2005, Maki Tsujimura et al. 2007). Compilation of published isotopic data on groundwater samples from across India analyzed over the last three decades is given in a downloadable tabular form at (URL:http://www.prl.res.in/%Ewebprl/web/announce/ind-gw.pdf). Several groundwater measurements for which geographic coordinates could not be ascertained are not included in the table. Observations from those few locations, where multiple measurements are available, suggest that temporal variation are likely to be $<1\%$ in $\delta^{18}O$ of groundwater’s that may not be near ($<1$Km) a large surface water bodies and/ or not located in areas with thin soil cover or do not have secondary porosity.

A large number of groundwater samples have been analyzed in the country principally by the four active groups, viz. PRL, BARC, NGRI and NRL. These studies, spread almost over a quarter century, indicate the following: Repeat measurements of isotopic composition of groundwater samples (Datta et al. 1996a & 1996b) do not show significant temporal variation in several parts of the country, indicating mixing of soil water of several years before groundwater recharge. However, regions with secondary porosity and/or otherwise fast recharge, particularly during storm events (Shivanna et al. 2004) have shown significant temporal variations in groundwater.
Groundwater’s show a significant evaporation-related modification of isotopic signals of precipitation in large parts of the country, particularly in the western and central parts comprising Rajasthan, Gujarat, Haryana, Madhya Pradesh; on the eastern side of the Western Ghats in Maharashtra, Karnataka, parts of Andhra Pradesh and Orissa. In Lower Maner Basin of Andhra Pradesh, the extent of enrichment was found to vary with recharge characteristics of various soils and rock types in the basin.

In these regions, the groundwaters are enriched with respect to the precipitation in $\delta^{18}$O and show (Dalai et al. 2002, Datta 1999, Krishnamurthy and Bhattacharya 1991) lower values of $d$-excess. This indicates that there is little to significant kinetic evaporation of the precipitated water before groundwater recharge. In a study of groundwater in Pushkar valley a decrease in $\delta^{18}$O with depth of water table was observed (Datta et al. 1994), which may be due to stratification of groundwater with shallower zones being recharged from relatively modern rainfall.

Several other cases, particularly from Rajasthan and Gujarat in India, and in Bangladesh have indicated that older groundwater’s have lower $\delta^{18}$O, suggesting a somewhat different past climatic regime with less aridity and/or increased precipitation (Aggarwal et al. 2000, Nair et al. 1997)

Using the groundwater $\delta^{18}$O values from the Kolkata–Delhi segment and departure from the expected continental gradient due to rainout (Gupta et al. 2004), it was estimated that atmospheric return back of precipitation by transpiration was as high as ~40%.

In southern India with dual monsoon influence, groundwaters from the regions dominated by NE monsoon showed distinctly depleted stable isotopic compositions compared to those dominated by the SW monsoon. The $\delta^{18}$O–$\delta$D regression line slope of ~6 in the east coast region was lower than that expected for local precipitation, suggesting secondary evaporation (Deshpande et al. 2003).
The large difference in $\delta^{18}O$ values in groundwater samples from the west and east coast samples confirms the inferred $\delta^{18}O$ difference in precipitation along the two coasts during principal rainy seasons (Deshpande et al. 2003). It may be recalled that there are no direct precipitation isotope data from any station along the east coast of India and the isotopic signatures of precipitation on this coast have been interpreted from neighboring stations of Hyderabad and Shillong in India and few stations in Sri Lanka, Myanmar and Thailand with data only of few years.

Deshpande et al. (2003) was undertaken oxygen and hydrogen isotopic investigation of groundwater and river water samples from the southern Indian peninsula to characterize the isotopic nature of the near surface water sources. The $\delta^{18}O$ characteristics of the groundwater samples from continental areas of central Asia and oceanic areas of the Bay of Bengal were investigated by Deshpande et al. (2003). Gupta and Deshpande (2005) have done a compilation of studies using tritium tagging of soil moisture for estimating fractional groundwater recharge in the country and found that the highest fractional recharge of groundwater occurs in the region of Eastern Plateau, the Ganga Plains, North and South Central Highlands and Western Plains. There have also been two important studies from India (Gupta et al. 2004) employing radiocarbon dating of groundwater and found that the recharge to the aquifers have occurred at the time around the last glacial maxima about 20 thousand years ago from the present day of recharge.

It is thus seen that with the available isotope data on groundwater, isotopic modifications due to evaporation during rainfall and subsequent percolation through soil zone can also be understood, which may in turn, be useful to correlate the isotopic character of various components of the hydrological cycle. However, to make quantitative estimates, a much larger databank of isotopes in both precipitation and groundwater is required (Gupta and Deshpande 2005).
2.9 Surface water subsurface water interconnection

The most effective in quantifying mixing between groundwater and surface water is $\delta^{18}$O and $\delta$D (Katz et al. 1997). Understanding the effect of evaporation on stable isotopes is an important factor in discussing the relationship between precipitation and groundwater (Boronina et al. 2005, Maki Tsujimura et al. 2007). Repeat measurements of isotopic composition of groundwater samples (Datta et al. 1996a & 1996b) do not show significant temporal variation in several parts of the country, indicating mixing of soil water of several years before groundwater recharge. Due to the enrichment of $\delta^{18}$O and $\delta$D in surface water that undergoes evaporation, the resulting isotopic signature is different than that of groundwater and provides an ideal conservative tracer for evaluating the extent of mixing of surface water and groundwater (Gonfiantini 1986). Differences between the composition of the water isotopes ($\delta^{18}$O and $\delta$D) in rainfall, groundwater, stream runoff to a sinkhole, and lake water are used to quantify mixing of groundwater and surface water. Results are presented for three study areas that represent various types of interactions between groundwater and surface water (Green, 1997). Natural recharge of water from sinking streams to this aquifer can result in water quality contamination, such as high concentrations of iron, hydrogen sulfide, and organic material, and undesirable bacteria, protozoa, and fungi (Krause 1979, McConnell and Hacke 1993). There are few studies on interconnection of surface and subsurface waters in India (Nachiappan and Bhishm Kumar 1999).

2.10 $\delta^{34}$S of Sulphate

The isotopic composition of sulfate in water reflects the sulfur sources. The isotopic composition of oxygen-18 and sulfur-34 can be used to identify the sources and conversion of sulfates in water (Caron et al. 1986). It is well known that the $\delta^{34}$S value of marine sulfates remained constant at $+20\%$ for millions of years (Holster et al. 1986). Shahul hameed (2002) studied the isotopic composition of sulphate in groundwater sources around a clay mining industry in Kannur, Kerala. The data indicate the sulphate contamination is derived from the mine effluents.
2.11 Sedimentation rate using radioisotopes

Inflow of eroded material and other contaminants from the lake catchments has accelerated the rate of sedimentation and eutrophication process (Chakrapani 2002, Kumar et al. 1999). Higher rate of sedimentation has diminished the usefulness of several small lakes and many others are shrinking at an alarming rate. Hence, knowledge of accurate sedimentation rate and its causes are of utmost importance for appropriate management of lakes and future planning. Radiometric dating techniques are reliable tools for estimating sedimentation rates in lakes and are used worldwide. Although several radioisotopes are useful in geochronological studies of lake sediments, lead-210 ($^{210}\text{Pb}$) and caesium-137 ($^{137}\text{Cs}$) isotopes find the largest application (Edgington et al. 1991, Ritchie and McHenry 1985).

The different models connecting the $^{210}\text{Pb}$ specific activity profile of sediment cores with sediment deposition rates or the rate of sedimentation are described in the literature (Carroll and Lerche 2003). The most widely used method for the lakes, coastal zones or estuaries, where sedimentation processes are intensified by anthropogenic actions is the constant rate of supply (CRS) of unsupported $^{210}\text{Pb}$, proposed by Appleby and Oldfield (1978). An alternative method, based on the Weibull distribution of anthropogenic $^{137}\text{Cs}$, which originally was proposed for soil samples (Dahm et al. 2002), has been later developed also for dating of the bottom sediments (Lu X 2004). This method has been very recently applied by the authors for preliminary determination of the sediment rates for two bottom sediment cores from the Kuwait Bay (Al-Zamel et al. 2005).

Physico-chemical and biological characteristics of various lakes in the country have been studied in detail, but few studies (Das et al. 1994, Kumar et al. 1999, Sarvana Kumar et al. 1999) have been carried out to estimate the sedimentation rate and deposition pattern in lakes. Kumar et al. (1999) have observed large variation in life-expectancy estimation of Nainital lake using dating techniques ($^{137}\text{Cs}$ and $^{210}\text{Pb}$) and bathymetric data due to errors associated with the lake sounding data. Recent sedimentation rates in Nainital,
Bhimtal, Sattal and Naukuchiatal lakes, Uttarakhand; Mansar and Dal lakes, Jammu and Kashmir, and Sagar and Bhopal lakes, Madhya Pradesh have been determined employing $^{210}$Pb and $^{137}$Cs dating techniques. (Bhishm Kumar et al. 2007). $^{210}$Pb and $^{137}$Cs were used to calculate the rate of sedimentation of the floodplain sediments of the Yamuna river basin (tributary of the river Ganges, India).

The work presented in the present study had been carried out covering both the southern and northern part of the wetland. The present study also reports the heavy metal toxicological aspects of the core sediments collected from the lake. The dynamics and sedimentation rate of the lake is reported using isotopes such as $^{18}$O, $^2$H and $^{137}$Cs. The surface water groundwater interconnection was studied using isotope. The biomonitoring of heavy metals by macrophytes and speciation of phosphorous in the sediments has been attempted as part of the study. To the best of our knowledge, isotope studies of the Vembanad Lake have not been reported elsewhere.