CHAPTER - 5

SEDIMENT ANALYSIS

5.1 Introduction

Sediments of wetlands are generally known as hydric soil and they are defined as soils that formed under the conditions of saturation and flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part (U.S. National Technical Committee for Hydric Soils (USNTCHS) Federal Register, 1994). Wetland sediments are relatively smooth, seen adjacent to river channels, built up of recent alluvium carried by the rivers during the flood period and deposited in the sluggish waters beyond the influence of the strong current. These are accounted as the most fertile land for the agriculture and naturally the fertility is moderate. Under natural conditions, sediments are either saturated or inundated long enough during the growing season to support the growth and reproduction of hydrophytic vegetation.

The sediments act both carriers and potential sources of natural geochemical constituents derived principally from rock weathering. The sediments mostly govern the nutrient economy of an aquatic system and knowledge on the role of sediment nutrient is especially useful in determining the sediments-water interaction, which eventually affects the productivity (Balakrishnan et al., 1984). The sediment acts as a sink and plays a vital role in changing the quality of the overlying water column. The geochemical characteristics of aquatic sediments in different parts of the world have been worked out in detail (Jitts, 1959; Aston and Hewitt, 1977).

Sediment plays a very important role in the ability of a wetland to perform certain functions such as nutrient retention, providing habitat for living organisms and pollution sinks (Richardson, 1985; Stolt et al., 2000). Additionally, sediments are important for the cycling of nutrients including nitrogen, phosphorus and carbon within a wetland ecosystem (Mitsch and Gosselink, 2000). The chemical makeup of water that exist a wetland is, in effect, fairly dependent upon the specifics of these nutrient cycles in wetland sediment (Richardson, 1985).

5.1.1 Sediment characteristics

Sediment variables are also important in determining the composition of plant communities (Fitter, 1982; Keddy, 1984; Nisson et al., 1989). Although soil/sediment variables may be more important in determining spatial variation in plant community composition and structure, the lack of data on soil variables that influence plant distribution makes it almost impossible to evaluate
these relationships at present. In particular, the vegetation dynamics of many plant communities are thought to be strongly influenced by the nutrient heterogeneity, but few experimental studies have investigated this relation (Baek et al., 1997).

The relatively dark colour of hydric soils is a result of anaerobic conditions, which reduces many compounds in the soil resulting in the exposure of the soil matrix, which is generally black or gray in color (Mitsch and Gosselink, 2000). Net primary productivity often dominates over decomposition rates in anaerobic conditions, leading to an accumulation of organic matter in the soil within many wetlands (Craft, 2001). Increased organic matter further contributes to the darkening of soil and also tends to cause bulk densities to decrease (Collins et al., 1987). However, soil conditions are also affected by many other factors, which must be taken into consideration. Wetland hydroperiod, nutrient availability, chemical cycling, climate, biota and many other factors can have pronounced effects upon wetland soils (Craft, 2001).

The main chemical changes brought about by flooding or water logging on air dry soil are the disappearance of oxygen, accumulation of carbon dioxide, anaerobic decomposition of organic matter, transformations of nitrogen, reduction of Fe$_3^+$, Mn$^{4+}$, and SO$_4^{2-}$. Nitrogen is the most limiting nutrient in the flooded soil, where the flooded soils are in natural wetlands or agricultural wetlands such as rice fields. The decomposition of organic materials also contributing the high level of nitrogen in the soil. Sediments covered by macrophytes differ from other wetland habitats in redox potential, light exposure, texture, stability, organic matter content and variability of temperature and oxygen levels (Sagova et al., 1993).

Wetland soils have been classified into 12 soil orders in the soil taxonomy (USDA, 1975). Most wetland soils are Entisols or Inceptisols which are characteristic of alluvial low lands. Limited areas of Histosols are also found in coastal area paddy soils of wetland have also been classified based on the drainage patterns such as very poorly drained, well drained and average water table (Moormann and Van Breeman, 1978).

### 5.1.2 Scope and significance of the study

During monsoon season, river systems carries the runoff from the upland areas into flood plains of Kuttanad and the anaerobic condition of this system turns the organic matter into partially decomposed loose clayey sediment with black colour. Indiscriminate use of synthetic chemical fertilizers in the paddy fields causing nutrient enrichment in the sediments. The decaying of organic
materials especially the paddy straw and aquatic plant debris increases the organic matter content in the sediment. The absence of seasonal salinity intrusion and reduction in outflow due to Thaneermukkom barrage is also helped in the accumulation of organic materials in the wetlands of Kuttanad which in turn a static pool of nutrients within the system.

Studies on sediment characteristics of Cochin estuary part of Vembanad lake was reported by Murthy and Veerayya (1981); Batcha, (1984); Nair et al. (1990 and 1993); Sunilkumar (1996). But very few studies have been reported from Kuttanad wetland ecosystem (KAU, 1994; Kurup, 1994; Thampatty and Jose, 2005) and no reports on different systems like river, canal and abandoned fields. Hence the present study aims to find out the seasonal variation of pH, organic carbon and nutrients like available nitrogen, phosphorus and potassium in sediments of different systems of Kuttanad. The study also aims to find out the relation between the nutrient status of the sediments and the occurrence of macrophytes in the Kuttanad wetland ecosystem.

5.2 Review of Literature

Sediments are one of the possible media in aquatic monitoring (Mitsch and Gosselink, 2000). Apart from water, sediments are also responsible of nutrients and pollutant transportation in aquatic environment. Sediments are known to capture hydrophobic chemical pollutants entering water bodies (McCready, 2006). According to Marcus (1991), sediment serves as diffuse sources of contamination to the overlying water body; slowly releasing the contaminant back into the water column. Therefore, ensuring a good sediment quality is crucial to maintain a healthy aquatic ecosystem, which ensuring good protection of human health and aquatic life.

Sediments have been widely used as environmental indicators and their ability to trace contamination sources is well documented (Forstner and Muller, 1973; Ramses et al., 1999; Soares et al., 1999; Camusso et al., 2002; Bermejo et al., 2003). The sediment at the bottom of the water column plays a major role in identifying the pollution scheme of the wetland systems (Pardo et al., 1989; Jha et al., 1990; Huang et al., 1994; Lapaquellerie et al., 1995; Borovec, 1996; Wardas et al., 1996). They may reflect both the current and past discharges to the water system and can be used to study the contamination of the wetlands.

A study on the influence of the potassium source (sediment Vs. open water) and sediment composition on the growth and nutrition of a submerged fresh water macrophyte, _Hydrilla verticillata_ was conducted by Barko in 1980. He reported that the biomass production and shoot morphology
varied significantly between water and sediments in contrast to N, P and K where N and P were readily mobilized from sediments.

Reddy et al. (1996) reported that the uptake of available phosphorous by wetland vegetation was estimated at 28 to 70% of the available P transported to the wetland. This P uptake was dependent upon plant growth rate, growth structure (woody or herbaceous material), P concentration in the soil and the physical and chemical characteristics of the soil. However, aquatic plant storage of P was a temporary phenomenon as approximately 80% of the nutrients are released to the water column by decaying vegetation (Agami et al., 1990, Reddy et al., 1996), suggesting that wetland plants are acts as nutrient storages and not sinks.

Nair et al. (1995) studied the phosphate-mined created wetlands in Florida and found that the pH at these sites were near neutral to slightly alkaline due to an increase in available calcium. Stolt et al. (2000) concurred that hydrologic regime played a role in organic matter accumulation. They observed that wetland sites with longer periods of saturation at or near the soil surface had higher amounts of organic carbon, presumably due to anaerobic conditions inhibiting decomposition.

Gi et al. (2007) studied the relationship between vegetation and soil characteristics in Wangsuk stream and Gwarim reservoir in Korea. They reported that the distribution of nitrogen, organic carbon, phosphorus, calcium, magnesium, potassium and sodium has a significant role in the distribution of aquatic plants in the system.

Several authors found changes in wetland community assemblages due to agrochemical loading (Anderson and Vondracek 1999; Bedford 1999; Kolozsvary and Swihart 1999; Maul and Cooper, 2000). Agrochemical application within a wetland basin may also affect wetland processes and functions. Movement of pesticides, herbicides and agrochemical fertilizers into wetlands is generally related to either direct or drift application or absorption of the chemical into soil particles, which are subsequently mobilized into the wetlands during rainfall events (Anderson and Vondracek, 1999; Freeland et al., 1999). Martin and Hartman (1987) reported the influx of sediments to wetlands in cultivated landscapes at twice the rate from uncultivated landscapes. Euliss and Mushet (1999) noted that chemicals and chemical-laden soil particles transported from uplands into wetlands could be toxic to zooplankton and reduce foraging and food assimilation rates of aquatic invertebrates.
Agrochemical fertilizers, as well as direct application of cattle wastes on the landscape, increase nutrient loading into aquatic systems (Flaig and Reddy, 1995; Reddy et al., 1996, Reddy et al., 1998). Alterations in soil pH, specific conductivity and available nutrients among other changes, may be indicative of wetland loading from agrochemical fertilizers and cattle wastes (Fore and Grafe, 2002; USEPA, 2002).

In 1981, Murty and Veerayya studied the sediment characteristics of Vembanad lake and found that organic carbon was higher along the surficial sediments than the bottom layer. Distribution of organic carbon in the sediments of Cochin mangroves was studied by Sunil Kumar (1996) as a mean to assess the nutrient input into the surrounding mangrove waters. He found that relatively high organic carbon values at the mangrove areas during mid and high tide levels, irrespective of seasons.

Sankaranarayanan and Panampunnayil (1979) studied the distribution of seasonal changes and ratios of organic carbon, total phosphorous, and total nitrogen in the sediments of the Cochin backwaters. They also correlated the organic carbon and total phosphorous. Lakshmi and Unni (2003) studied the seasonal distribution of organic carbon, nitrate, nitrogen and available phosphorous in the sediments of three biotopes i.e., mangrove, estuary and freshwater in Thalassery and Valapattanam riverine ecosystem of Kerala state.

Balakrishnan et al. (1984) studied the physico-chemical characteristics of water and sediment of Asthamudi estuary. They found that the nutrient concentration in sediment was the reflection of the overlying water column.

Santhosh (2002) studied the sediment characteristics of Paravur-Kappil backwater systems of Kollam district, Kerala. The study reported that the organic matter content varied between 0.29% to a maximum of 6.5 % and it may be due to the accumulation of organic materials from the uplands during the monsoon season. But in Karamana river, Krishnakumar (2002) reported that the organic content was higher than 6.5% in most of the sites studied.

Sobha et al. (2009) studied the variation of texture, pH, conductivity, total nitrogen, total phosphorous, organic carbon, sodium, potassium and some heavy metals of different aquatic systems of Thiruvananthapuram. They also reported that the anthropogenic sources of pollution were the major factors behind the increased nutrient level in these systems.
Kurup (1994) studied the nutrient status of various parts of Kuttanad and he observed that the available N content varied from 175 to 270 kg/ha. He also noted that the available K content was in between about 85 and 130 kg/ha and the available P content varied from 0 to 180 kg/ha.

A report from Kerala Agricultural University in 1994 showed the chemical properties of the soil of different horizon of Thuravoor and Thottappally regions of Ambalappuzha and Cherthala respectively. The surface soil of both the profile was slightly acidic. Organic matter content was comparatively higher in Thottappally profile and was sufficient to designate it as peaty soil. Upper horizons of the both profiles showed higher contents of phosphorous and potassium. The studies in the Thuravoor area revealed that the available nitrogen content and phosphate content was up to 0.4% and that of K$_2$O was up to 1.25%. Organic matter content was nearly 10%. In Thottappally region organic matter content was 40%, available nitrogen content of Thottappally was up to 5% and that of P$_2$O$_5$ 0.07%. K$_2$O has a percentage of 0.4%.

Thampatty and Jose (2005) studied the impact of prevention of natural saline washing on the nutrient dynamics of Kuttanad Ecosystem. From the study it was observed that annual closure of the Thanneermukkum regulator has resulted in an increase in soil acidity, availability of nitrogen and iron and a decrease in salinity, cation exchange capacity, electrical conductivity and available potassium, calcium, magnesium and manganese during the period of closure (December to mid April) compared to the period when the regulator was kept open.

### 5.3 Objectives of the Study

1. To assess the spatial variation of pH, organic carbon, available nitrogen, available phosphorus and available potassium in the sediments of different systems of Kuttanad.

2. To determine the seasonal variation of the pH, organic carbon, available nitrogen, available phosphorus and available potassium in the sediments of different systems of Kuttanad.
5.4 Materials and Methods

5.4.1 Sediment sampling

Sediment samples were collected from different systems like rivers, canals, cultivated fields and abandoned fields on seasonal basis. Samples were collected using a grab sampler, which is then transferred to a polythene cover for further analysis.

Sediment samples were air-dried and impurities including decayed wood pieces, leaves and rhizomes of macrophytes were removed. The dried sediment was then passed through a 2 mm sieve to remove coarse particles; the sieved soil was then sub-sampled and ground to a fine powder using a mortar and used for chemical analysis.

5.4.2 Parameters of sediment quality

a. pH

The pH of the sediment was determined in 1:5 sediment water suspension using pH meter (Potentiometric method). The procedure involved was 10 gm of sediment mixed with 50 ml of distilled water in a beaker, the solution was stirred well using a glass rod and kept for 30 minutes. It was stirred again before taking the reading.

b. Total Organic Carbon

Organic carbon in the sample was determined by Walkley and Black method (Jackson, 1973). This method oxidises a lower percentage of the total organic carbon in the biofertilizer under standard condition with excess of K₂Cr₂O₇ in H₂SO₄ acid solution. The excess of K₂Cr₂O₇ not reduced by organic matter was titrated back against a standard solution of ferrous ammonium sulphate, in the presence of diphenylamine indicator.

c. Available Nitrogen

Available nitrogen in the sample was determined by Alkaline potassium permanganate method (Subbiah and Asija, 1956). The organic nitrogen present in the biofertilizer was oxidized by the nascent oxygen liberated by KMnO₄ in the presence of NaOH and thus, the ammonia released was distilled, which was absorbed by sulphuric acid, the excess of which was titrated with a standard alkali, using methyl red as the indicator.
d. Available Phosphorous (Bray – II method)

The available phosphorous in the sample was determined by Brays II method (Baruah and Barthakur, 1997). The sample was shaken with extracting solution of NH₄F & HCl which dissolves the fraction of phosphorus. Ammonium fluoride complexes, Al and Fe ion in the acid solution, with the consequent release of phosphorus, held by the sample. The combination of HCl and NH₄F helps in removing easily acid soluble forms of Phosphorus, largely calcium phosphate, aluminium and iron phosphates.

In the filtered extract, phosphorous was estimated colourimetrically by adding ammonium molybdate and thereafter reducing the molybdenum - phosphate complex with stannous chloride in the acid medium. The phosphomolybdate complexes were formed with a blue colour. The intensity of the colour was measured at 660 nm using spectrophotometer. The colour measurement has to be done after 10 minutes but before 12 minutes after adding stannous chloride.

e. Available Potassium (Morgans extraction method)

Both water soluble and exchangeable potassium are most accessible to plants. Available potassium, which includes both the water soluble and exchangeable are potentially available or fixed. The neutral normal ammonium acetate extract contains both water soluble and exchangeable potassium. Five gm of sample was weighed into a 150 ml of conical flask. Twenty five ml of neutral N NH₄OAc solution was added and shaken well. Filtered and feed the filtrate into the atomiser of the flame photometer using potassium chloride as standard (Baruah and Barthakur, 1997).

5.5 Results

5.5.1. pH

In the present study, all the sediment samples were acidic in nature and shown pH <5. In general, the pH of the samples ranged between 2.4 and 4.8 (Table 5.3). The least acidic value of 2.4 was recorded from VA1, VA 2, S1, S2, S4 and PURA sites during the premonsoon season.

In river systems, the higher values of 4.8 was recorded from P3 river site during the postmonsoon season, followed by 4.6 at KV1 during monsoon and P4, KR1 and P2 during the postmonsoon season (Figure 5.1.a). The season's average value was ranged from 2.83 to 4.47 (Table 5.2). The least value was recorded from S2 followed by 2.90 from VA1 and S1 sites. The season's maximum average value was recorded from P3 site. Among the river systems, THOT (Achenkovil) site recorded the least value of 3.8 and the maximum from P3 site (Kodurar) with 4.8.
In canal systems, the pH ranged from 2.4 to 4.6 (Table 5.3). The least value was recorded from VA1, VA2, S1 and S2 sites during the premonsoon season and the highest from KR3 site during the post monsoon season (Table 5.3).

In cultivated fields the pH also ranged from 2.4 to 4.6 and PURA site recorded the least value during the premonsoon season and the high value recorded from P2 site during the postmonsoon season (Table 5.3).

From abandoned field N2 recorded the least pH value of 2.8 during premonsoon season and the high value of 4 was recorded from KR2 during the postmonsoon season (Figure 5.1.a).

During premonsoon season, all the sites recorded high acidic values ranged from 2.4 to 4.4 followed by the postmonsoon season with 3 to 4.8. During monsoon season, the pH ranges between 2.8 to 4.6. There was significant seasonal variation of pH (p<0.01) from different seasons and different systems (Table 5.1).

5.5.2 Organic carbon (OC)

In the present study, the organic carbon ranged from 1.86 to 18.82 % (Table 5.1). The least value was recorded from KV1 site during the monsoon and the highest recorded from P6 site during premonsoon. The season's average values ranged from 2.80 to 15.23% and the KV1 site recorded the least value and the P6 site recorded the maximum value (Table 5.3).

Among the river systems, KV1 (Manimala) recorded the least organic carbon value with 1.86% during the monsoon season followed by KR1 with 1.95 during the same season. The maximum value was recorded from THOT (Achenkovil) site of 8.86% during the premonsoon followed by KODI (Kodur) of slightly lower level of 8.44 (Figure 5.1.b).

Among the different canal systems studied, P6 site recorded higher values throughout the season and premonsoon recorded the peak value (Figure 5.1.b). Sites like N1 and ACC6 showed higher values of organic carbon more than 10% throughout the season (Table 5.2).

In the cultivated fields, the organic carbon ranged from 3.08 to 9.24% (Table 5.3). The least value was recorded from KV3 during the monsoon and the peak value reported from site PILA during the premonsoon season. Abandoned field site N2 recorded the least value of organic carbon of 4.88 during the monsoon followed by P1 (5.08). The maximum value was recorded from KR2 during premonsoon of 12.04% followed by N2 of 8.86 during the same season (Figure 5.1.b). Seasonal average values indicated that the KR2 has maximum organic carbon content (Figure 5.1.b).
Statistical analysis showed that there was significant seasonal variation \( (p<0.01, F = 17.07) \) and system wise variation \( (p<0.01, F = 7.66) \) of organic carbon content in the sediments of Kuttanad (Table 5.1).

### 5.5.3 Available Nitrogen

The available nitrogen varied from 0.04 to 0.88mg/g in different systems of the Kuttanad wetland ecosystem during the study period (Table 5.3). The least value was from the THOT site during the monsoon season and the peak value recorded from S2 during the premonsoon followed by ACC5 with 0.86mg/g.

Among the river systems studied, ACC4 (Manimala) recorded the peak value of 0.482 mg/g during postmonsoon followed by KR1 (Meenachil) and VPM (Pampa) of 0.48mg/g.

In canal systems, available nitrogen varied between 0.08 and 0.86mg/g (Table 5.3), the least value from site KARU during the monsoon followed by ACC 1 of 0.13mg/g. The peak value was recorded from ACC 5 during premonsoon followed by P6 0.66mg/g. The seasonal average values were maximum at P6 site followed by ACC 5 site.

In the cultivated fields, the available nitrogen nearly tripled between 0.32 and 0.88mg/g (Figure 5.1.c). Both KV3 and PILA recorded minimum during the monsoon and the maximum from S2 during the premonsoon season. The average seasonal value was higher in kayal land of 0.69mg/g followed by PILA with 0.56mg/g (Table 5.3).

Among the abandoned fields, the maximum was recorded from KR2 during the postmonsoon season followed by N2 with 0.48mg/g during the same season. Seasonal maximum was recorded from KR2 site. Cultivated fields recorded comparatively higher values than other systems (Figure 5.3). Results of the statistical analysis showed that there was significant variation between season \( (p<0.01, F=30.87) \) and systems \( (p<0.01, F=8.14) \) (Table 5.1).

### 5.5.4 Available Phosphorus

The available phosphorus varied from 0 to 1.6mg/g (Table 5.3). The absence of available phosphorus was recorded from ACC4, VA1, KR3, KARU, S2, KR4, PILA, N2 and KR2 sites during the monsoon season (Table 5.3). The maximum value recorded from P6 during the premonsoon season followed by ACC 1 with 1.22mg/g and ACC 5 with 1.2mg/g during the same season (Figure 5.1.d).
Absence of available phosphorus shows its absorption by macrophytes. Kodurar at Kodimatha reported high values of available phosphorus both premonsoon and postmonsoon season of 0.22 and 0.124 respectively. Both KV1 and ACC4 sites noted the absence of available phosphorus during the monsoon season.

In canal systems, the highly polluted canal site at Pallom, P6 site recorded the maximum value with 1.6 during the premonsoon season followed by ACC 1 site with 1.22mg/g during the same season. Sites like VA1, KR3, KARU and S2 has not recorded the available phosphorus during the monsoon season (Table 5.3).

In cultivated field, the available phosphorus ranged from 0 to 0.08mg/g and the absence was noted in sites like KR4 and PILA during the monsoon season and PURA during the postmonsoon season (Table 5.3). P2 site has the season’s maximum average value and the least recorded from both PILA and SIV CF.

Among the abandoned fields, P1 site recorded the maximum value with 0.102 during the premonsoon season and the absence was noted from both KR2 and N2 sites during the monsoon season. During premonsoon, most of the sites have high values compared to other season and the absence or very low values were noted during the monsoon season (Figure 5.1.d).

Analysis of variance showed that there was no significant variation of available phosphorus between seasons but significant variation (p<0.05, F=2.91) between systems (Table 5.2). Canal systems showed comparatively high level of available phosphorus than other systems (Figure 5.1).

### 5.5.5 Available potassium

The available potassium ranged from 0.01 to 2.6mg/g (Table 5.3). The maximum was recorded from P6 during premonsoon followed by ACC 1 site (Figure 5.1.e). The least value was recorded from KV 2, VA 2 and KR 3 during monsoon and S4 CF during postmonsoon.

In river systems, available potassium ranged from 0.02 to 0.42mg/g and the maximum from KODI (Kodurar) during premonsoon. KV1, P4 and THOT recorded least value during the monsoon season. KODI site showed the season’s maximum average of 0.24mg/g.

Among the canals systems studied, P6 has the highest value of 2.6 mg/g during the premonsoon season followed by ACC 1 of 1.22 mg/g (Table 5.3). The least value, 0.01mg/g was recorded from KV1, VA2 and KR3 sites during the monsoon season. The maximum seasonal
average value of 1.56 mg/g was recorded from P6 and the least 0.14 mg/g from KV2 and THRP sites.

Among the cultivated fields, KR4 recorded the maximum of 0.44 mg/g during the premonsoons season followed by S2CF (0.38 mg/g) (Table 5.3). KR4 had the highest seasonal average of 0.31 mg/g and the least values, 0.13 mg/g from both KV3 and S4CF.

In abandoned fields, available potassium ranged from 0.02 to 0.61 mg/g (Table 5.1). The maximum value was recorded from N2 during the postmonsoon and the least from N2 and KR2 during the monsoon season. N2 site recorded the highest seasonal average value with 0.35 mg/g and the least value of 0.29 mg/g at KR2 site.

During monsoon most of the sites recorded low values and during the premonsoon season, the highest from most of the sites (Figure 5.1.e). Canal systems recorded high values of available potassium than the other systems (Figure 5.2). It showed significant variation between seasons (p<0.01, F=10.35) and not much significant variation between systems (p<0.05, F=2.83) (Table 5.1).
Figure 5.1: Seasonal Variation of Sediment parameters in different systems* of Kuttanad

a. Variation of pH

b. Variation of Organic carbon (%)

c. Variation of Available Nitrogen (mg/g)

d. Variation of Available Phosphorus (mg/g)

e. Variation of Available Potassium (mg/g)

*On X axis:

CF = Cultivated fields and
ABF = Abandoned fields
Table 5.1: Results of Analysis of variance (ANOVA) between parameters, seasons and systems

<table>
<thead>
<tr>
<th>Sediment Parameters</th>
<th>Between Seasons Significance level (p value)</th>
<th>Between systems Significance level (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>0.00** ($F = 13.14$)</td>
<td>0.00** ($F = 11.53$)</td>
</tr>
<tr>
<td>Organic carbon</td>
<td>0.00** ($F=17.07$)</td>
<td>0.00** ($F = 7.66$)</td>
</tr>
<tr>
<td>Available Nitrogen</td>
<td>0.00** ($F=30.87$)</td>
<td>0.00** ($F = 8.14$)</td>
</tr>
<tr>
<td>Available Phosphorus</td>
<td>0.06 ($F = 2.93$)</td>
<td>0.04* ($F = 2.91$)</td>
</tr>
<tr>
<td>Available Potassium</td>
<td>0.00 **($F=10.35$)</td>
<td>0.04* ($F = 2.83$)</td>
</tr>
</tbody>
</table>

** Significant at the 0.01 level, * significant at the 0.05 level.

5.6 Correlation analysis between sediment parameters

pH showed negative correlation with organic carbon ($r = -0.480$, p < 0.01) and available potassium ($r = -0.219$, p < 0.05). Correlation with other parameters was insignificant. Organic carbon was positively correlated with available nitrogen ($r=0.267$, p < 0.01), available phosphorus ($r = 0.468$, p < 0.01) and available potassium ($r = 0.581$, p < 0.01). Available nitrogen has significant (p < 0.01) correlation with available phosphorus (0.246) and available potassium (r = 0.338). Available phosphorus and potassium has significant correlation (0.872) at p < 0.01 level (Table 5.2).
Table 5.2: Correlation matrix for sediment parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>pH</th>
<th>Organic carbon</th>
<th>Available Nitrogen</th>
<th>Available Phosphorus</th>
<th>Available Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic carbon</td>
<td>-0.480**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Available Nitrogen</td>
<td>0.084</td>
<td>0.267**</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Available Phosphorus</td>
<td>-0.137</td>
<td>0.468**</td>
<td>0.246**</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Available Potassium</td>
<td>-0.219*</td>
<td>0.581**</td>
<td>0.338**</td>
<td>0.872**</td>
<td>1</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

5.7 Discussion

In tropical Asian countries like India, Philippines, Kampuchea, Laos, Vietnam and Thailand, wetland soil conditions are comparable in physicochemical aspects. In these countries where aquatic habitats called ‘Aquants’ dominate mainly the alluvial coastal plains like Mekong river delta in Vietnam and Red river delta in northern Thailand. Rice is the major crop in these areas. Ponnampuruma (1972, 1978), Patric and Reddy (1978), Moorman and Breeman (1978), Yamane (1978) have provided excellent reviews of water chemistry of submerged soils in Philippines.

Sediments play very important role in the ability of a wetland to perform certain functions such as nutrient retention, providing habitat for living organisms and pollution sinks (Stolt et al., 2000; Richardson, 1985). Additionally, sediments are important for the cycling of nutrients including nitrogen, phosphorus and carbon within a wetland (Mitsch and Gosselink, 2000). The drying up and flooding of submerged soils in wetland can produce significant stress on soil pH, active Fe and organic carbon content. Extremely low pH (< 4.5) causes toxicity (high active) of iron, aluminium and deficiency of phosphorus. Between pH 4.5 and 5.5, low active Fe and iron toxicity interact with potassium deficiency, pH >7.5 also causes deficiency of P, Fe, Zn, K associated with high calcium. Salinity also causes deficiency of Zn and Boron toxicity (Ponnamperuma and Ikehasil, 1979; Patnaik et al., 1991).
5.7.1. pH

The chemical properties of wetland soils are prevailed by the water regime. Submerged soil decreases the redox potential (Eh) and increases the pH of acidic soil. An excellent review following several studies on wetland soil (Ponnampuruma, 1972) from Philippines where submerged land similar to Kuttanad are used for cultivation of rice for centuries. The major factors governing the pH of the soil include the concentration of reduced iron, manganese, hydroxides, carbonates, carbonic acid and humic acid (Patric and Mikkelson, 1971). The concentration of H+ ions is only of secondary importance for plant growth, except at low pH where the H+ ion itself may become harmful (Kinzel, 1983). However, pH regulates a large number of soil processes (Scheffer and Schachtschabel, 1989). Many of these are related to the solubility of macro and micronutrients, some of which may become toxic at higher concentrations. Most macronutrients reach their maximum availability at intermediate pH, where the activity of micro-organisms is also highest (Rieley and Page, 1990).

Patnaik and Mandal (1982) for the first time reported the occurrence of acid sulphate soils in the west coast of Kerala comprises Kari and Kayal soils depending on their location. Kuruvila (1974) found that high salt content due to sea water intrusion resulted in very low pH and high Fe and Al under submerged conditions. Van Breeman and Pons (1978) observed that acid sulphate soil within the upper 50 cm depth have a pH below 3.5 for Entisols and pH 4 for Inceptisols. Acidity due to formation of H2SO4 by oxidation of pyrites (FeS2). Pyrites get accumulated in the tidal swamp soils which under drainage conditions are oxidised to form H2SO4 causing low pH around 3.5 to 4. The flushing of soils of this type reduces acidity and lime was applied to increase soil pH to 6.4 for rice cultivation.

Acid sulphate soils have pH below 3.5 for ‘Entisols’ according to Van Breeman and Pons (1978) and mean pH values reported from Vaikom Kari soils of 2.93 and 2.90 (Table 5.1), 2.85 from Purakkad Kari of the present study is in agreement with that of Jose et al. (1993), Patnaik and Mandal (1982) and Patnaik et al. (1991). All the canal soil samples have pH range between 3.2 to 4.2 in different parts of Kuttanad wetlands. These soils are well derived from acid sulphate through reactions for centuries and used for rice cultivation after treatment with lime. The ‘Kayal’ lands have saline soils in which S1 and S2 have mean pH of 2.83 and 2.9 respectively but slightly high ranges 3.4 to 3.9 at S2 and S3. Highly acidic ‘Kayal’ land resulted from the saline intrusion and concentration of salt making these lands infertile and are cultivated similar to ‘Kari’ land after treatment with lime.
In the present study, all the sediment samples were acidic in nature and acidity ranged from 2.4 to 4.8. The high acidic value, 2.4 recorded from VA1, VA 2, S1, S2, S4 and PURA sites during the premonsoon season. This is due to the partial decomposition of organic matter accumulated in the system formed the ‘kari’ (acid sulphate enriched with iron) nature of the soil (Kurup, 1994; KAU, 1994; Mathew, 2003). VA1, VA2 and PURA sites are come under the Vaikom and Purakkad kari agroecological zones respectively (KAU, 1994). The slow oxidation of organic sulphur compounds resulting in production of sulphuric acid and due to the presence of humic acids (Mitsch and Gosselink, 1993). In Kuttanad, farmers are practising the lime application in the paddy fields for reducing the acidity problem (KAU, 1994, Thampatty and Padmakumar, 1999; MSSRF, 2007). The maximum pH reported in Kodurar at Pallom 4.4 and 4.7 is due to input of pollutants from factories. The cultivated fields also reported similar ranges. Application of lime raises the soil pH to 6.5 which decreases the salt content remarkably to give good rice crop all over this wetland over many years as a management practice.

5.7.2 Organic carbon

Organic matter is the driving force behind many wetland functions; thus it is a frequent parameter used to assess hydric soil development (Shaffer and Ernst, 1999; Campbell et al., 2002). Organic carbon improves cation exchange and supplies nutrients such as nitrogen and phosphorus (Rieley and Page, 1990). In the present study, it showed significant positive correlation with nutrients (Table 5.3) Increased organic matter further contributes to the darkening of the soil (Ponnampuruma and Ikehasil, 1979) and generally sediments from Kuttanad have black colour with high organic matter especially during the premonsoon season. Stolt et al. (2000) explained that hydrologic regime played a role in organic matter accumulation. They observed that wetland sites with longer periods of saturation at or near the soil surface had higher amounts of organic carbon, presumably due to anaerobic conditions inhibiting decomposition. In the present study, the organic carbon in the study area ranged from 1.86 to 18.82%.

Mean organic carbon was very low in Pampa and Meenachil rivers (3.1 – 3.5%) and it nearly doubled to 6.5% in Kodurar. Kodurar at Kodimatha, Kottayam reported high organic carbon, compared to the downstream stretches where much lower values were reported. This can be attribute to the prolific growth forming mats of Eichhornia which decompose sink to the bottom adding much of the carbon to the sediment especially during premonsoon. The sewage of the Kottayam township get discharged at Kodimatha enabling almost continuous 3 - 4 population of Eichhornia throughout the year.
The maximum organic carbon reported during premonsoon, almost double compared to that of monsoon period due to the luxuriant growth of *Eichhornia* and its complete cover on the Kodurar at Kodimatha. The decaying of the *Eichhornia* mats enriches the organic carbon in the sediment. During flood the mats get detached and flow downward. Other river systems, Meenachil, Pampa and Manimala recorded almost 3 to 4% of moderate mean organic carbon.

In the present study 20 canal systems were sampled compared to 8 river courses and cultivated fields. Canal system vary widely due to their nature, ranging between stagnant to slow flowing, a few meters to several hundred meters wide in different parts of Kuttanad wetland system. These interconnectivity canals are manmade for transportation. Organic carbon varied widely between these canal systems. The mean organic carbon at different sites shows three ranges. The least mean value showed 4 to 5%, the least in Kayal lands (S1 to S4), and Kumarakom. It was nearly doubled to 8 to 10% in the canals of Kari lands at Vaikom (VA1 and VA2), Neendoor and ACC3. Floating mats of *Eichhornia* enhanced it three fold at P6 to 15.2 (mean) and 12.3 at ACC6. *Eichhornia* mats play significant role in organic matter content through decomposition and sink of the same to the bottom sediment.

Cultivated and abandoned rice fields reported moderate ranges between 4 and 7% with an exception of 9.3 at Kumarakom. Seasonal distribution of sediment organic carbon showed distinct mean high values in the canal and abandoned fields during premonsoon, least values during monsoon. Post monsoon values were greater than the monsoon and pre monsoon. The high organic content in Karilands was well documented by Balachandran *et al.* (2002) ranging between 10 to 30%. Emergent macrophytes however, may also be susceptible to organic matter accumulation. Although Brink *et al.* (1995) found a stimulating effect of organic matter on the growth of macrophytes, many studies have found that growth is reduced in flooded organic sediments, where the organic matter originated from emergent macrophytes (Clevering and Putten, 1995).

In the cultivated fields, the organic carbon ranged from 3.08 to 9.24%. In Kuttanad, the cultivation is mainly depending on monsoon and from the study it was noted that the organic carbon content was low during the monsoon season. Ploughing and continuous flooding results the washing out of organic matter from the fields (Pillai and Subrahmanyan, 1929) and after harvesting, the weed biomass and paddy straw enriches the organic matter (Fores and Comin, 1987). In abandoned fields, organic carbon and nutrient levels were comparatively lower than the cultivated fields.
5.7.3 Available Nitrogen

Nitrogen is an important nutrient element in the sediment that controls the quantity of overlaying waters in an aquatic system. Nitrogen sources are mainly from the oxidation of nitrogenous organic matter (D’ Angelo et al., 1994; 1979; Mitsch and Gosselink, 2000). Nitrogen content in the sediment is depending upon local condition of rainfall, quantities of freshwater inflows, turbulence and biological activities (Kemp, 1971). In the present study, the available nitrogen is varied from 0.04 to 0.88mg/g. In a rice field, fifty percent of the straw biomass is buried in the sediments, which later decomposes to release the nutrients like nitrogen, phosphorus and potassium to the sediments (Fores and Comin, 1987). In Kuttanad, after harvesting, around 30% of the straw biomass is remained in the field which later decomposes in the sediments. The fertilizer addition in the rice fields can also cause the high nutrient concentration in the paddy fields (Ponnamperuma, 1972; Fores and Comin, 1987). In the cultivated fields, the available nitrogen, available phosphorus and potassium were high during the premonsoon season and it shows the decreasing trend during the monsoon and it again shows an increasing trend towards the postmonsoon season. Similar results were reported by Pillai and Subrahmanyan (1929) in Kuttanad rice fields.

Comparatively low concentration of nitrogen in the abandoned field may be attributed to the denitrification process that takes place in the overlying water due to the anoxic condition that prevails in the system (Santhosh, 2002). Similar results were obtained in the present study. The abandoned fields were completely covered with the floating mats of Ischaemum travancorense and Eichhornia crassipes. Results of the physico-chemical parameters of water quality also reflect the anoxic condition prevailed in the abandoned fields.

In the present study least available N2 values reported during monsoon and maximum during the post monsoon period. Canal system recorded 0.28 to 0.48 mg/g during pre monsoon, AC canal reported maximum (0.86 mg/g) followed by 0.76 mg/g at the polluted sites. Both these sites have very thick mats of Eichhornia contributing via organic matter decomposition to the N2 status of the sediment through absorption and recycling. Biological fixation of N2 is by anaerobic bacteria, blue green algae and Azolla (Patnaik et al., 1991). Fertilizer application is essential for rice fields for good yield and most (91%) of the N fertilisers are absorbed (Velu and Ramanathan, 2000).
5.7.4 Phosphorus

Phosphorous is one among the chief nutrients in an aquatic environment (Reddy et al., 1998). The increased phosphorous loading in aquatic systems from cultivated lands, domestic and industrial sewages have created the eutrophication problems (Parry, 1998). In the present study, the available phosphorus was ranged from 0 to 1.6mg/g. The 0 values (below detectable value) were recorded mainly during the monsoon season and may be due to the removal of nutrients through the mixing and dilution of flood water. Phosphates in wetlands are easily taken up by the aquatic plants (Richardson, 1985; Haycock et al., 1997) and in the present study most of the samples were taken up from the macrophyte beds. Release of phosphorus to the water from decaying macrophytes due to leaching and decomposition can occur rapidly (Richardson, 1985). Among different systems, canal systems have the highest value of available phosphorus when compared to the other systems. Canal systems receive runoff from the rice fields and washing of cloths in canals using of soaps and detergents are common in Kuttanad. It can also contribute the phosphates in sediments and water (Thomas et al., 2001).

Absence of available phosphorus or values reported in traces (0.001 – 0.02mg/g) in river systems, canal and cultivated fields evidently show deficiency of this most important nutrient in the Kuttanad wetlands during the monsoon. The high rainfall received during the south west monsoon washes out the available nutrients from the system (sediment and overlying water). Relation of P in the sediment is there for ruled out for the whole year premonsoon and post monsoon reported slightly higher values ranging from 0.08 to 0.2 mg/g in some canal systems. During premonsoon, high values of 1.2 to 1.2 mg/g were reported from P6, ACC5 and ACC1, which receiving pollutants. These observations are in agreement with that of Patnaik (1978) who reported similar values from Philippines. Premachandran et al. (2002) also reported P deficiency associated with Aluminium toxicity as a result of insoluble aluminium phosphate formation fixing phosphorus. Kabeerathuma and Money (1974) reported all the nutrients are limiting the yield of paddy in Kuttanad soils.

5.7.5 Available Potassium

Potassium is one of the major nutrient for the plants especially the rice (Patnaik et al., 1991; Bajwa, 1994; Dobermann, et al., 1996; Nguyen et al., 2006). Major inputs of potassium in sediments from fertilizer, irrigation water, sediments, outputs or removal via harvested products, residues, leaching, erosion and water runoff (Nguyen et al., 2006). In the present study, potassium
concentration ranged from 0.01 to 2.6 mg/g. It was generally found that the potassium concentration was high during the premonsoon season in all the systems but it showed a decreasing trend towards monsoon season. Similar results were reported in the studies of Murty and Veerayya (1981) in Vembanad lake; Santhosh (2002) in Paravur-Kappil backwaters of Kerala; Sobha et al. (2009) in different aquatic systems of Thiruvananthapuram. But in abandoned fields, potassium concentration was comparatively higher during the postmonsoon season and Babu et al. (2009) reported the similar observations from Asthamudi estuary in Kerala.

According to Ramanathan (1976) potassium deficiency in wetland soil is less compared to nitrogen and phosphorus. The present study well supported the above observations. Potassium was present during all the seasons and sites. The least mean values were found in river systems ranging between 0.03 to 0.17 mg/g, followed by canal systems 0.14 to 0.26 mg/g in most sites except sites receiving pollutants at P6 (1.56mg/g) and 0.83 at Acc1. Abandoned field reported greater values compared to cultivated fields. Most wetland soils according to Ramanathan (1976) have a high K content in the exchangeable form and primary minerals may also act as a source.

5.8 Conclusion

Generally Kuttanad soils were acidic in nature and the pH was <4. The high acidic values (<2.3) were recorded from kari (acid sulphate) lands viz., Vaikom and Purakkad. Spatial and temporal variations of pH, organic carbon and nutrients were observed during the present study. Seasonal flooding and macrophytic vegetation growth has significant role in the distribution of nutrients in sediments. All the canal sediments have pH range between 3.2 and 4.2 in different parts of Kuttanad wetlands. Canal systems have high accumulation of organic carbon and nutrients, this may be due to the runoff from the rice fields and decay of organic materials. Due to continuous flow of water in the river systems, organic carbon and nutrients showed least values when compared to other systems. The organic carbon content showed significant correlation with nutrients and negatively correlated with pH. Cultivated rice fields recorded comparatively high amount of available nitrogen than other systems which indicates the remnants of nitrogenous fertilizers in the system. There was significant seasonal variation (p<0.01) of pH, organic carbon and nutrients in different systems of Kuttanad.
### Table 5.3: Results of the seasonal variation of sediment parameters in Kuttanad wetland ecosystem during the study period.

<table>
<thead>
<tr>
<th>Sites</th>
<th>pH</th>
<th>OC %</th>
<th>Available N (mg/g)</th>
<th>Available P (mg/g)</th>
<th>Available K (mg/g)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Mon</td>
<td>Post</td>
<td>Avg</td>
<td>Pre</td>
</tr>
<tr>
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<td>4.20</td>
<td>4.23 (+0.35)</td>
<td>0.34</td>
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<tr>
<td></td>
<td>2.08</td>
<td>1.86</td>
<td>4.46</td>
<td>2.80 (+1.44)</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>3.86</td>
<td>2.04</td>
<td>3.64</td>
<td>3.12 (+0.94)</td>
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<tr>
<td>P5</td>
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<td>4.20</td>
<td>4.80</td>
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<tr>
<td>P4</td>
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<tr>
<td>ACC4</td>
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<td>4.34</td>
<td>4.40</td>
<td>4.31 (+0.10)</td>
<td>0.44</td>
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<tr>
<td>AVG</td>
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<td>4.00</td>
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<tr>
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<tr>
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<td>4.20 (+0.20)</td>
<td>8.44</td>
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<tr>
<td>AVG</td>
<td>4.23</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00 (+0.00)</td>
<td>4.23 (+0.00)</td>
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**River systems**

**Canal systems**
## Chapter 5

### Sediment quality of Kuttanad

<table>
<thead>
<tr>
<th>Sites</th>
<th>pH</th>
<th>OC %</th>
<th>Available N (mg/g)</th>
<th>Available P (mg/g)</th>
<th>Available K (mg/g)</th>
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<tr>
<td></td>
<td>Pre</td>
<td>Mon</td>
<td>Post AVG</td>
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</tr>
<tr>
<td>KR3</td>
<td>4.10</td>
<td>4.40</td>
<td>4.60</td>
<td>4.37±0.25</td>
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<tr>
<td>ACHIN</td>
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<td>3.60</td>
<td>3.13±0.42</td>
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<td>S2</td>
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<td>2.80</td>
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<td>2.83±0.45</td>
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<tr>
<td>S3</td>
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<tr>
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<td>3.75</td>
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### Cultivated Field systems

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<td>4.20±0.30</td>
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<tr>
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<td>PILA</td>
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### Abandoned Field systems

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<td>3.00±0.12</td>
<td>3.07±0.12</td>
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<td>3.67±0.31</td>
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An Ecological study of the Macrophytic Vegetation of the Kuttanad Ecosystem

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