Land Use Changes and Soil -Water Degradation of Thrissur Kole Wetland System, Kerala

Thesis submitted for the Degree of

DOCTOR OF PHILOSOPHY IN ENVIRONMENTAL SCIENCE

Under the Faculty of Science

University of Calicut

by

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Under the supervision of

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MAY 2022

May 2022

DECLARATION

I, Sinta K.B, hereby declare that the work embodied in the thesis "**Land Use Changes and Soil–Water Degradation of Thrissur Kole Wetland System, Kerala"** submitted to the University of Calicut in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Environmental Science a Bonafede record of the research work carried out by me under the supervision of Dr. Sreekumar. S, Former Associate Professor, Department of Geology & Environmental science, Christ College (Autonomous) Irinjalakuda & Prof. (Dr). Harilal. C. C, Head of the Department, Department of Environmental science, University of Calicut, Malappuram. No part of the thesis has formed the basis for the award of any degree, diploma or other similar titles of any university.

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Abstract

The Kole wetland, a Ramsar site, spread over Thrissur and Malappuram districts remains one of the major fresh water wetlands of Kerala. It is a flat saucer shaped low-lying area containing fluvial - estuarine deposits and flanked by lateritic hills on the eastern and western margins. The main objective of this study was to comprehensively understand the land use changes in the Kole land, the surface and ground water quality status and the soil characteristics before and after the 2018 deluge. An attempt was also made to assess the effect of pesticides on plants and water. It has been revealed that though the area under paddy cultivation declined from 1980 to 2007, a significant increase occurred during the period 2008 to 2017. In a span of 37 years beginning from 1980 a reduction in the extent of mixed agriculture crops was also noticed. During Pre monsoon the surface water samples have mixed facies with Ca > Na or K > Mg and HCO_3 > Cl > SO_4. During post monsoon Na/K > Ca > Mg in cationic and Cl > HCO_3 > SO_4 in anionic facies. The surface water quality analysis was evaluated on irrigation parameters such as salinity hazard, % Na and USSL diagram. The results revealed that the water samples collected from Annakara were not suitable for irrigation during post-monsoon period. Based on SAR values two samples fall in unsuitable category during post monsoon. The result of One-way ANOVA indicated that there was significant difference in the parameters of surface water in two seasons – pre monsoon and post monsoon of Thrissur Kole wetlands. According to the map prepared using kriging method the NW part of the wetland area is under the threat of saline intrusion during Pre monsoon period. The concentration of iron become maximum in post monsoon period at the NW segment of the wetland area. In this study, surface samples of the selected locations had higher Dieldrin and α- BHC concentration than the permissible limit. Dieldrin residue was also found above the permissible limit in samples of rice and plants. Examining the ground water chemistry, the order of cation abundance is Ca > Na/K>Mg in both seasons. The anionic abundance was Cl>HCO_3 >SO_4 in pre-monsoon and HCO_3 > Cl>SO_4 in post-monsoon. Based on the USSL diagram, 95 % and 50% of the ground water samples were categorized as bad quality for irrigation purposes during pre-monsoon and post-monsoon respectively. This indicated that the

wetland system was under the threat of salinity hazard. In the majority of the areas ground water was acidic in pre monsoon season and after monsoon the water in the northern segment remained acidic whereas the southern tip of the wetland area turned alkaline due to intrusion of saline water and its leachate.

In general, the soils of the Kole wetland were found to be acidic. The organic carbon, available nitrogen and sulphur of majority of the sample locations decrease with depth. The presence of available phosphorous was found to be below detectable limit. The concentration of micronutrients such as Fe, Mn and Zn were very high while Cu concentration is low in samples. B was deficient and heavy metal content was low in all samples. All samples in the study were found to have potassium exceeding the upper limit. In the Kole wetland this could be due to the application of fertilizers. The Ca and Mg content in the Kole wetland soils indicate the presence of intrusion of saline water. Iron and aluminium toxicity badly affects the total rice productivity in the Kole lands. pH of the soil samples became more acidic after flood. The sample locations showed high electrical conductivity after flood due to the deposition of salts in the upper parts of soil profile and relatively low EC values indicated the leaching of top soil. General trend shows a decline of OC, Na, Mg, N, P, K, Zn and Al after flooding. The soil samples enriched in calcium, sulphur, boron, copper and manganese after the flood. Soil carbon sinks can be increased by carbon enhancing land management practices. The significant disturbances in land use practices cause initial decrease in the soil carbon level. The nitrogen and carbon content in the wetland soil were found to be high with increase in depth. The area is dominantly composed of clay rich soil which have low bulk density and greater carbon sequestration potential. Based on the finding's recommendations were drawn to conserve the precious ecosystem.

CHAPTER 1
Introduction

INTRODUCTION

1.1. Introduction

Wetlands are an integral part of river basins or extension of sea and are considered one of the most productive ecosystems of earth's surface. Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which at low tide does not exceed six meters (IUCN, 1971). According to Asian Wetland Bureau (1991), the Wetlands of South and West Asia include estuaries and deltas, salt marshes, mangroves, mudflats, coastal lagoons, freshwater lakes and marshes, oases, seasonal flood plain wetlands, swamp forests, rivers and streams, man-managed systems such as rice fields, fish ponds and reservoirs. Wetlands, the cradles of biodiversity which supports the survival of countless number of plants, animals and human beings are commonly referred to as nature's kidneys and its main function is to remove pollutants including toxic materials from natural water sources. The role played by wetlands to recharge the groundwater is also noticeable. The wetlands are capable of sequestering and storing carbon through photosynthesis and accumulation of organic matter in soils, sediments and plant biomass. This is a complex process that occurs in wetlands, contributing to a net annual carbon sink.

1.2. Ramsar convention

Ramsar is an intergovernmental environmental agreement by countries and non-governmental organizations for the protection of wetlands. It was held in the Iranian city of Ramsar in 1971 and came into force in 1975. The Ramsar writ now runs in 108 million square kilometers except Antarctica; this cover 75% of the world's lands. They form the largest global network of "protected areas", covering over 168 million hectares in over 1,822 sites as of November 2008.

1.3. Types of wetlands

There are a number of different types of wetlands found all over the world. The Cowardin system (1979) categorizes five major wetland types which include **Marine** (coastal wetlands including coastal lagoons, rocky shores, and coral reefs); **Estuarine** (including deltas, tidal marshes, and mangrove swamps); **Lacustrine** (wetlands associated with lakes); **Riverine** (wetlands along rivers and streams); and **Palustrine** (meaning "marshy" – marshes, swamps and bogs).

1.4. Ramsar Classification of Wetland

The Ramsar Convention has adopted a Ramsar Classification of Wetland type which includes 42 types, grouped into three categories: **Marine and Coastal Wetlands, Inland Wetlands and Human-made Wetlands**. In addition, there are man-made wetlands such as fish and shrimp ponds, farm ponds, irrigated agricultural land, salt pans, reservoirs, gravel pits, sewage farms and canals (www.ramsar.org).

1.5. Importance of Wetlands

The natural and managed ecosystems support man with a range of goods and services. Wetlands provide humanity with countless benefits or "ecosystem services" ranging from freshwater supply, food and building materials and biodiversity, to flood control, groundwater recharge and mitigations of the effects of climate change.

Wetlands act like giant sponges absorbing water during wet times and slowly releasing it throughout the course of the year to aquifers, streams and the atmosphere. Wetlands provide a significant portion of fresh water recharge points for aquifers and recharging dilutes salinity in ground water. Wetlands are highly productive systems. The natural processes such as runoff and erosion deposit nutrients into wetland ecosystems where they accumulate to support diverse and complex living communities. Degradation of wetland ecosystems breaks the natural cycling process of filtration of sediments and nutrients. Excessive amounts of nutrients are prevented by wetlands from mixing with marine environments. A degraded wetland system may lead to concentration of excess nutrients in our rivers and lakes favouring a general decline in water quality and results outbreak of toxic blue green algae. The rapid and unscientific developmental activities and encroachment divert or break the natural drainage of floodplains, allow the water in the landscape to exit rapidly to the sea, reduce freshwater within the soils and reduce recharge of aquifers. The reduced moisture content of soil during the summer period causes reduction in the quality and quantity of vegetative growth, including grass growth available for stock grazing.

Wetlands are vital parts of the natural infrastructure required for addressing climate change. Climate change cause uncertainty in water management and make it more difficult to fill the gap between water demand and supply. Wetlands evaporate large amounts of water, providing moisture to build weather systems and increasing rainfall. Landscape alteration through processes such as sand and clay mining, reclamation of wetlands, increased channeling and drainage to remove water from the landscape as rapidly as possible, reduce the distribution of water within the landscape. By limiting the quantity and duration of water that remains within the landscape, evaporation rates are reduced leading to changes in the distribution and behavior of weather patterns (Aidan, 2003).

Carbon got deposited through decaying vegetation into the beds of wetlands, progressively turning to peat and eventually forming coal. Here the fresh carbon act like an activated carbon filter, extracting nutrients and impurities such as heavy metals, biogenic salts and other compounds from the water. Those processes make functioning of wetlands vital for providing an effective method of removing carbon from the atmosphere for a long term. The forested wetlands, temperate and tropical peatlands and vegetated inter-tidal wetlands including salt marshes and mangroves are the carbon stores (Danone Fund of Nature, 2009).

1.6. Threat to wetlands

Wetlands, the most threatened part of the environment, support the vital roles of ecosystem. The high population density makes a stress on this productive ecosystem. The major anthropogenic threats are reclamation, pollution caused by industrial, agricultural, domestic and medical wastes, sand and clay mining, nitrate and phosphorous accumulation causing eutrophication, saline intrusion and climate change. Wetlands appear to be the most preferred landfills for dumping solid wastes from a variety of origins and an ultimate end point for discharging untreated industrial and domestic effluents.

The reclamation of wetlands for commercial development, including tourism facilities, and agriculture highly alter the soil hydrology processes. The conversion of water-logged areas to dry lands changes the drainage, flood control, recharging of ground water and salinity intrusion. Vegetation removal exposes soils to higher evaporation rates and decreases the surface moisture levels. In certain areas excessive abstraction of fresh waters, diversions and catchment degradation have led to increased salinity (www.kenyawetlandsforum.org). A good example is Thrissur city in Kerala which is fast-growing and is facing serious threat to water-availability due to unscientific land use practices. The rural areas of Kerala mostly depend on dug wells for individual household requirements. Fall in the water table level and water quality deterioration is observed in many of the wells (Nikhil Raj and Azeez, 2009).

Drainage and runoff from fertilized crops and pesticides used in industry introduce nitrogen and phosphorous nutrients and other toxins like mercury to water sources. The chemicals can affect the health and reproduction of species, posing serious threat to biological diversity. The quality of many water sources was declining as a result of municipal, agricultural and industrial wastes/ discharges. These have negatively impacted water quality and biodiversity within the wetland ecosystems. Increased nutrient loads have led to eutrophication and episodes of algal blooms in wetlands near major settlements (www.kenyawetlandsforum.org). Soil phosphorus and microbial biomass responds positively to phosphorus enrichment in wetlands, mineralized phosphorus in wetland soils appears as the most responsive microbial indicator to nutrient enrichment in wetlands. Therefore, phosphorus internal loading is the critical factor in regulating eutrophication status of wetlands. N_2O and N_2 emissions by wetlands can be enhanced in the future as nitrate availability in wetlands continues to be high due to increased pollution (Sanchez-Carrillo et al., 2010). The main sources of pollution in the atmosphere were from industries and automobile exhaust without proper filtering systems. The increased sulfide and salt content induce physiological stress in the wetland ecosystem and affect its productivity. This lead to the disruption of the interspecific interactions (Herbert et al., 2015). Some areas of wetlands are suffering from environmental degradation due to continuous encroachment and waste dumping. In Assam, the Guwahati Municipal Corporation dumps all its wastes in the vicinity of Deepar beel wildlife sanctuary. As a result, the wildlife sanctuary, which originally had spreads over 4,000 ha, has now shrunk to 500 ha, and faces various natural and anthropogenic threats. Continuous garbage dumping causes health problems to local residents (Gurvinder Singh,2021).

The process of saltwater intrusion was a common phenomenon which related to large climatic and oceanographic conditions and the natural physiography of the area. Salinization of freshwater wetlands along some parts of the coastal plain was a regular event particularly in dry months (Report of Department of Environment and Heritage Protection, 2011). Sea level rise is another threat to coastal wetlands. Coastal ecosystems were among the most economically productive areas and densely populated regions in the world (Barbier, 2012), yet rapid development and increasing consumption of water resources lead to lowering of the water table and reduction of the surface water flow. The major development and infrastructure projects aimed at alleviation of poverty actually cause the degradation of wetlands ultimately leading to the aggravation of poverty. Saltwater intrusion into freshwater coastal rivers and aquifers has been, and continues to be, one of the most significant global challenges for coastal water resource managers, industries, and agriculture (Ferguson and Gleeson, 2012; Niemi et al., 2004). The landward movement of saltwater into freshwater environments was also likely to accelerate as a result of sea level rise, climate variability, and drought (Meisler et al., 1984).

Changes in land use also affect microclimatic patterns. Degradation and loss of wetlands make climate change worse. Increase in atmospheric temperature causes polar ice to melt and sea levels to rise. This in turn leads to shallow wetlands being swamped and some species of mangrove trees being submerged and drowned. At the same time, other wetlands - estuaries, floodplains, and marshes - are being destroyed by drought. There are now over 40,000 dams worldwide which alter the natural flow of water and impact the existing ecosystems.

1.7. Global extent of Wetlands and Status

Wetlands occupy an estimated 6 % of the world's land surface (Edward and Hook, 1988). The global extent of wetlands is estimated to have declined by 64 -71% in the 20th century, and wetland losses and degradation continue worldwide (Davidson, 2014). Providing a historical perspective, Walter et al., (2005) reported that more than 50% of the area of certain wetland types had been lost during the 20th century in parts of Australia and New Zealand, Europe and North America. Junk et al., (2013) reported that the amount of loss of wetlands around the world varied between 30 to 90%, depending upon the region under consideration.

Asia has 204,345,000 ha area covered by wetlands. Wetlands occur in all climatic regions of Asia and majority of them are seasonal in nature. Saline wetlands and fresh wetland categories are based on the hydrological and vegetation types. Africa, the second largest and populated continent has a wetland area of 121,322,000 – 1 24,686,000 ha. The African wetlands are biologically the most diverse and endemic in nature. Eastern Europe has 229,217,000 ha area of wetlands. Western Europe which includes coastal, fresh water and marine wetlands with an area of 28,822,000 ha., is subtropical and semi-arid in nature. Neotropics includes tropical rain forests and extends from Southern Mexico, Central America to Brazil including Amazon rain forests with an area ranging from 134,804,000 to 1,782,103,000 ha. North America has a wetland area of 244,903,000 to 2,057,369,000 ha. Oceania, the south East Asia Pacific region has a wetland area of 35,750,000 ha (Table 1.1).

Table 1.1: Global extent of wetland

No.	Region	Area (ha).
1	Africa	121, 322,000 – 124,686,000
2	Asia	204,345,000
3	Eastern Europe	229, 217,000
4	Neotropics	134,804,000 – 1,782,103,000
5	North America	244,903,000 – 2,057,369,000
6	Oceania	35,750,000
7	Western Europe	28,822,000

*Source; Ramsar Convention Secretariat, 2010.

1.8. Wetlands of India

The directory of Indian wetlands published by WWF for Nature – India and Asian Bureau in 1995 records 141 wetland sites. Further, out of an estimated 4.04 m ha of wetlands, 1.45 m ha is natural, while 2.59 m ha is manmade. This implies that majority of the wetlands in India is man-made. The coastal wetlands occupy an estimated 6,750 km^2, and are largely dominated by mangrove vegetation. There are more than 100 identified wetlands under the National Wetland Conservation & Management Programme (www.envfor.nic.in.).

The available estimates about the areal extent of wetlands in India vary widely from the lowest of 1% to a highest of 5% of geographical area, but do support nearly the fifth of the known biodiversity (Space Applications Centre, 2011). These wetlands are distributed in different geographical regions ranging from the Himalayas to the Deccan plateau. Initial attempts to prepare a wetland inventory of India were made between 1980s and early 1990s. As per the Country report of Directory of Asian Wetlands (Woistencroft et al., 1989); and the Directory of Indian Wetlands WWF and

AWB (1991), the areal spread of wetlands in India was around 58.3 m ha. Paddy fields accounted for nearly 71% of this wetland area. However, as per the Ministry of Environment and Forests (1990) , wetlands occupy an area of about 4.1 m ha and the coastal wetlands and mangroves occupy 6740 km^2 (Trisal and Kaul, 1996). The first scientific mapping of the wetlands of the country based on the Ramsar Convention definition was carried out using satellite data of 1992–1993 by Space Applications Centre (SAC), Ahmedabad. The estimates did not include paddy fields, rivers, canals and irrigation channels.

National Wetland Atlas 2011, prepared by SAC, is the latest inventory on Indian wetlands. The entire country was considered for assessment and a total of 201,503 wetlands were identified and mapped on 1:50,000 scale (SAC, 2011). In addition, 555,557 wetlands (area <2.27 ha, which is smaller than minimum measurable unit) were identified as point features. Area estimates of various wetland categories have been carried out using GIS layers of wetland boundary, water spread, and aquatic vegetation. As per the estimates, India has about 757.06 thousand wetlands with a total wetland area of 15.3 m ha, accounting for nearly 4.7% of the total geographical area of the country. Out of this, area under inland wetlands accounts for 69%, coastal wetlands 27%, and other wetlands (smaller than 2.27 ha) 4% (SAC, 2011). In terms of average area under each type of wetland, natural coastal wetlands have the largest area. In terms of the proportion of the geographical area, Gujarat has the highest proportion (17.5%) and Mizoram has the lowest proportion (0.66%) of the area under wetlands. Among the Union Territories in India, Lakshadweep has the highest proportion (around 96%) and Chandigarh has the least proportion (3%) of geographical area under wetlands (Nitin et., 2014). Water-spread area of wetlands changes over seasons. The States of Sikkim, Nagaland, Mizoram, Meghalaya, and

Jharkhand have more than 90% of the total wetland area as water spread area during post monsoon season. In Kerala, the natural coastal wetlands comprise 67% of the total wetlands and inland wetlands are 25.72 % (Sankaran et al., 2005).

1.9. Wetlands of Kerala

The imposing presence of the Western Ghats as the Eastern boundary of Kerala with its western slopes merging with the midland plains and the zigzag boundary of the western sea coast all provide an ideal topographic feature for the development of a hybrid form of wetlands in their small segment of land at the southern tip of the Indian peninsula. The wetland of Kerala falls under 5 major systems viz., marine, estuarine, riverine, lacustrine and palustrine. Out of the various wetland types recognized by Ramsar Convention (1971) there are at least 10 different wetlands available in Kerala, such as shallow sea (where depth of the water is <6m), rocky sea coast and sea cliffs, sea beaches (sand, pebbles), fresh water ponds (palustrine), fresh water lakes (lacustrine), estuaries and back waters, reservoirs of dams, rice fields, swamp forests and mangrove forests.

The forty-three rivers that originate from the Western Ghats create and maintain almost all major wetlands of Kerala. Among the various States of the country Kerala stands first in India, in having the largest area under wetlands (Nayar and Nayar, 1997). Three wetlands of Kerala which are identified as Ramsar Sites are the Vembanad Kole, Ashtamudi and Sasthamkotta lakes. District-wise distribution of wetlands showed that four districts can be called wetland rich. Alappuzha has the highest area with 26079 ha under wetland. District-wise wetland distribution is given in Table 1.2.

Table 1.2 District-wise wetland areas

Sl.No	District	Geographic area (Sq.km)	Wetland area (Sq.km)	% of total wetland area	% of District geographic area
1	Kasaragod	1961	7561	4.71	3.86
2	Kannur	2997	10870	6.77	3.63
3	Wayanad	2132	3866	2.41	1.81
4	Kozhikode	2345	7690	4.79	3.28
5	Malappuram	3548	9511	5.92	2.68
6	Palakkad	4480	11892	7.41	2.65
7	Thrissur	3032	13285	8.27	4.38
8	Ernakulam	2408	25065	15.61	10.41
9	Idukki	4998	10655	6.63	2.13
10	Kottayam	2204	9523	5.93	4.32
11	Aalapuzha	1256	26079	16.24	20.76
12	Pathanamthitta	2731	4948	3.08	1.81
13	Kollam	2579	13703	8.53	5.31
14	Thiruvananthapuram	2192	5942	3.70	2.71
	Total	38863	160590	100	

*Source: National Wetland Atlas Kerala (SAC, 2011)

1.10. Vembanad Kole Wetlands

The Vembanad Kole wetland system is a complex aquatic system of coastal back waters, lagoons, marshes, mangroves and reclaimed inland with intricate networks of natural and manmade channels. This system includes a chain of lagoons from Kuttanadu in the South to the Kole land of Thrissur in the North. It has a single, narrow opening to the Arabian Sea near Kochi. It is aligned north-south, parallel to the shoreline and widest at the southern side. Vembanad - Kole Wetland has been designated as a Ramsar Site on 19th August of 2002.

Hence wetland provides refuge during adverse conditions to threatened species; regularly supports 20, 000 or more water birds; regularly supports 1 % of the individuals in a population of one species or sub species (Plate 1.1). The Vembanad-Kole wetlands which form one of the rice granaries of Kerala is part of the unique Vembanad- Kole wetland ecosystem comprising of 151250 ha (Plate 1.2). The Vembanad Kole wetland system is fed by 10 rivers. The area is also exposed to diurnal tidal cycles. The majority of wetlands of Kerala are brackish; however, there are a few fresh water wetlands also seen (Plate 1.3). Thrissur Kole Wetland is one among the eight fresh water wetlands of Kerala (Nayar and Nayar, 1997).

1.11. Kole Wetlands

The word Kole is a Malayalam word, and means a bumper yield. It is a particular cultivation method adopted in wastelands in Thrissur District from December to May which otherwise is submerged from June to November, half of the year. In olden days the Kole lands were reclaimed from kayal area by putting up temporary earthen bunds and cultivation of rice was done by enterprising farmers during summer period from December to May (Johnkutty and Venugopal, 1993). The Kole land which is spread over Thrissur and Malappuram districts remains one of the major fresh water wetlands of Kerala. It is a flat saucer shaped low-lying area containing fluvio estuarine deposits and flanked by lateritic hills on the eastern and western margins. The Kole land is said to be the rice granary of three districts at par with Kuttanad 'the rice bowl of Kerala.' Rice cultivation in Kole lands is said to have started way back in the eighteenth century.

Kole Wetland extend over an area of 13,000 ha and account for about 40% of the State's rice production. Kole land lies between Bharathapuzha in the north and Chalakudy in the south and is located between 10^{o} 20' and 10^{o} 40' north latitudes and 75^{o} 58' and76^{o}11' in east longitudes (Johnkutty and Venugopal, 1993). The fields are low lying tracts located 0.5 to 1M below MSL. Karuvannur and Kecheri rivers drain into the Kole lands and finally gets discharged into the Arabian Sea. The Kole land originally was the flood plains of these rivers. Kole lands are divided into the Thrissur Kole and Ponnani Kole (Fig. 1.1). The wetland area comes under the administration of the civil authorities of Mukundapuram, Chavakkad and Thrissur Taluk of Thrissur district and Ponnani Taluk of Malappuram district.

Fig. 1.1. Thrissur Kole and Ponnani Kole

The Kole Wetlands remain submerged under flood water for about six months in a year and this seasonal alteration gives its unique terrestrial and water related properties which satisfy the ecosystem structure and functions.

The uncontrolled clay mining for the past several decades has already altered the southern parts of Thrissur Kole Wetland system. Reclamation of the wetland for housing plots and coconut and plantain cultivation is usual in several areas (John Thomas, 2002). At present, the most serious threat faced by the Muriyad wetland which forms part of the Kole is the indiscriminate sand mining that takes place in different parts of the wetland. The unusual rise in the cost of rice cultivation also has augmented the present wave of conversion of paddy fields for several purposes other than rice cultivation. Existing land use laws prohibit conversion or use of paddy fields for any purpose other than rice cultivation. In spite of the warning from the authorities, water is polluted by waste disposal and oil and grease from vehicles. The disposal of organic waste from chicken farms and non-biodegradable wastes like PET bottles and other plastics continue to be an insurmountable problem not only in Muriyad wetlands but also in other parts of the Kole lands.

The North Kole Wetlands of Thrissur are degraded by the rapid urbanization and waste disposal. The improper waste management plan of Thrissur Corporation has severely polluted the wetlands by dumping the waste materials from the poultries and vegetable markets. The most important fresh water source for Thrissur city is the Puzhakkal Wetland of North Kole. Filling the wetland will disturb the hydrologic regime of the wetland. The reclamation of wetland will create everlasting problems to both surface and groundwater including hurdles in drainage, flood control, recharging ground water and vulnerability to salt water intrusion (Sreekumar and John Thomas, 2004). Construction of roads, permanent bunds and other structures like pump houses, embankments etc., alter the natural hydrological regime and in turn affects the fauna and flora associated with the wetlands. It is found that the construction of a permanent bund has considerably augmented the rice production in the Kole land area (Ashok, 2001).

1.12. Need for conservation of Wetlands in Kerala

The shrinkage of wetland area poses threat to water and food security of Kerala. The water availability is a serious issue in many parts of Kerala and the water table is dropping day by day in different parts of the State. Out of a total of 152 assessment units (blocks) in the State for which the assessment was carried out, Chittoor block of Palakkad district and Kodungallur block of Thrissur District have been categorized as **Over-exploited**, whereas Malampuzha block of Palakkad district and Kasaragod block of Kasaragod district has been categorized as **Critical**. A total of 23 blocks located in different districts have been categorized as **Semi critical** and the remaining blocks are Safe. In spite of the relatively low level of ground water development in the State. Shortage in drinking and domestic uses and contamination of water due to natural and anthropogenic causes are felt in different areas of the State (CGWB, 2012). The Kerala State Disaster Management Authority took a decision to declare Alappuzha, Kannur, Idukki, Kasaragod, Kozhikode, Malappuram, Palakkad, Thrissur and Wayanad districts as drought hit areas.

Agriculture sector is the single largest user of fresh water resources, using a global average of 70 % of all surface water supplies. Agriculture is both cause and victim of water pollution. Polluted water acts as sinks and carriers at the same time, diminishes or destroys the aquatic population and increase the algal growth. The toxic pollutants present in the water bodies decrease the diversity and total number of the species. Some water pollutants which become extremely toxic in high concentrations are, however, needed in trace amounts. The toxicants like Aluminum, heavy metals and pesticides, Dieldrin, Dichloro diphenyl trichloro ethane (DDT) and its metabolites, Endrin, Heptachlor, Lindane, Pentachlorophenol, Polychlorinated biphenyls (PCBs) and free ammonia are very lethal to living organisms.

The major part of the pesticides applied in any area for a specific reason (about 99%) remains unused and it gets mixed with air, soil, water and plants which by several means causes harmful effects on the people, pets, and the environment. Not only the farmers in rural areas but also the people in urban areas use pesticides in their homes and home gardens, in and around the schools, business areas, and hospitals etc., (Agrawal et al., 2010). Hundreds of people have died in India due to consumption of parathion contaminated wheat flour (Karunakaran, 1958). The Indian Council of Agricultural Research (ICAR) has constituted a committee to suggest possible remedies to combat the toxicity caused due to presence of pesticides and their residues in the edibles (Wadhwani and Lall, 1972).

Farmland is often well drained and natural drainage is often enhanced by land drains. The pesticides and residues (nitrates and phosphates) can be quickly transported to contaminate ground water and fresh water supplies over a large geographical area. Another factor effecting pesticide pollution of water is rainfall which increase the risk of pesticides contaminating water. It can also occur within the soil structure by displacement of pesticide from absorption sites by water and on treated soil which has moved in to water through soil erosion.

Agricultural land conversion, especially of paddy fields, has been a burning issue in recent times both from the perspective of food security and its environmental impacts (Shaharban and Shabana, 2015). In this context, changes in land use pattern and productivity and food security are a matter of major concern. The agricultural sector is facing the most serious threat from over- exploitation and conversion of land for other uses.

Rice is the most important food crop in Kerala. The State has a long history of food grain deficit, especially in rice. Deficit in rice has increased steadily in the State from 45 to 85 % between 1957 and 2008. The total paddy area and production is presented in table 1.3. It is found that the production of rice declined from 13.65 to 5.10 lakh metric tons from 1970 to 2013 (State Agriculture Statistics, 2012). The area under paddy was around 8.8 lakh hectare in 1970s which shrinked to 1.97 lakh hectare in 2013. The area under paddy cultivation and annual production of rice in Kerala from 1960 to 2014 is illustrated in Table.1.3 and Fig. 1.2.

Table 1.3. Area under paddy and its yield in different periods

Year	Area in ha	Yield in tonnes
1960-1961	780,000	1067,000
1970-1971	880,000	1365,000
1980-1981	850,000	1290,000
1990-1991	560,000	1090,000
2000- 2001	390,000	760,000
2009-2010	254,000	693,000
2013-2014	197,000	510,000

The steady loss of paddy fields will have a serious impact on the State's economy and ecological sustainability, and food and water security. In the name of infrastructure development alone the State government has reclaimed considerable extent of paddy fields and wetlands. Between 2004 and 2011, the State lost 160,000 ha of wetlands (Suchithra,2015).

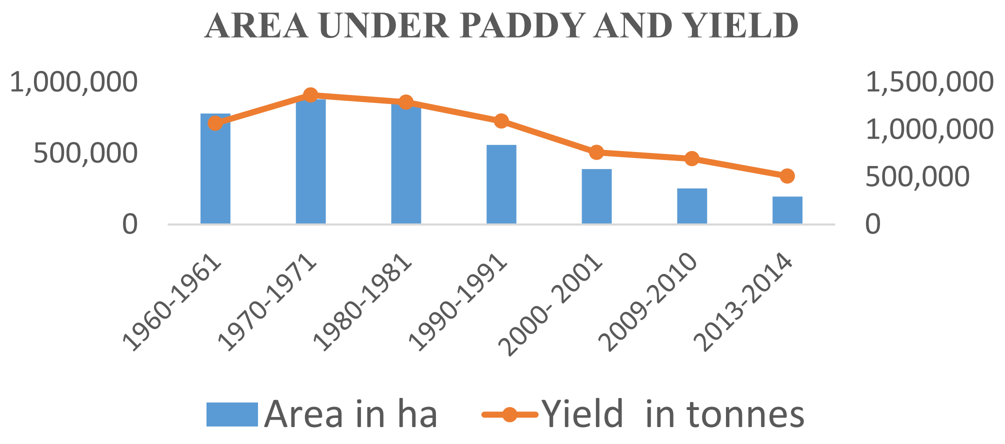


Fig. 1.2 Area under paddy cultivation and annual production of rice in Kerala during 1955- '56 to 2009- '10

Food grains produced in the State account for only 15% of its consumption of food grains (Economic Review, 2010). Kerala imports food grains from Tamil Nadu, Andhra Pradesh, Madhya Pradesh, Bihar and Gujarat to meet its needs fully. During 1960-61, Kerala had a shortage of rice of 40.12 %, which increased to 83.45% in 2009-10 (Karunakaran, 2013). The study clearly reveals the increasing demand for rice in Kerala in the coming years compared to the existing supply. Reclamation of paddy fields has resulted in the shrinkage of living space for aquatic organism, specifically the fishes. Fragmentation of wetland due to the construction of permanent bunds and roads also has several adverse impacts on the sustainability of fishery resources. One of the major impacts is the formation of impediments in the migratory routes of fresh water fishes to their spawning grounds, during the reproductive seasons. Shrinkage of water spread area also results in the decimation of brood stocks because fish larvae need large expanse of water.

The usually flooded areas of Thrissur Kole also used to suffer from salinity through Chettuva and Kottappuram backwaters (James, 2002). The studies show that saline water reaches up to 7 km in Karuvannur River towards the land. Similarly, a number of brackish water fishes migrates to the fresh water of Karuvannur River indicating the presence of salt water intrusion in the water body during the months of February to April. The mining of flood plain sand deposits and deforestation in the upstream stretches of rivers draining the Kole land area has caused the ingression of salt water in the shallow coastal aquifers (Gopalakrishnan et al., 2003).

A study by John Thomas et al., (2003) revealed that Muriyad wetland provides habitat for two important migratory fishes from the estuaries. *Caranx carangus* (Bloch) and *Lutjanus argentimaculatus* (Forsskal) are known to be residents of estuaries, which are available in plenty during the post monsoon periods. The fish catch in Kuttanad and Vembanad before the construction of barrier- Thaneermukkam was 429 tonnes in 1960 and 189 tonnes in 1962. Later during 1988 -1989, the fish catch got reduced to 39 tonnes (Kurup et al., 1992). The studies in Muriyad wetland reported that there was alarming decline in the availability of two economically important species of fish population. Information regarding the earlier species diversity and abundance of fishes of the wetland collected from the traditional fishermen of the area reveals that *Wallago attu* and *Clarias batraches* were abundant during yester years. It is said that Wallago of about six feet in length was common in certain parts (Kokrachal area) of the wetland.

Evaluating an ecosystem in terms of the services delivered to the local community is more relevant in the current scenario of increasing human interference (Costanza et al., 1997 and James,2002). One of the pioneering attempts in this line is that of Costanaza et al., (1997) who evaluated the total value per hectare of different types of ecosystem all around the globe. Although the above evaluation has several drawbacks it remains a baseline for future works. The total value of Kole wetland in terms of ecosystem services based on the values suggested by Costanaza et al., (1997), and other benefits that are calculated as direct market values is an amount about 278 million dollars (Nikhil Raj and Azeez ,2009).

1.13. Review of Literature

Wetlands are facing severe degradation pressure due to human intervention. Every parcel of land on the Earth's surface is unique in the cover it possesses (Frankenbach and Meyer, 1999). Land cover categories could be crop land, forest, wetland, pasture, roads or urban areas. The term land cover was originally referred to the kind and state of vegetation such as forest or grass cover but it has broadened in subsequent usage to include other things such as manmade structures, soil types, biodiversity, surface and ground water. Land cover can be modified by human interferences and natural processes such as climate change, flooding and fire. According to Frankenbach and Meyer (1999), there are also incidental impacts on land cover from other human activities such as forests and lakes being damaged by acid rain from fossil fuel combustion. Hence in order to use land optimally, it is necessary to have information on the present and past land-use practices. The occurrence of deep sandy layers is a good evidence to show that some parts remained submerged in the recent geological past (Kurup and Varadachar, 1975). Any alteration in the pattern of land use change can fundamentally modify the input of energy, water, and nutrients and then affect the natural processes of an ecosystem (Adger and Brown, 1994).

The conversion of wetlands, deltas and flood plains of most rivers in India to paddy fields is rampant, following the green revolution of the early 70's. It is an ecological irony that the gross aerial extent of wetlands on Indian subcontinent is greater today than it was 3000 years ago owing to increased paddy fields being treated as wetlands (Lee Foote et al., 1996). Vembanad Lake has been reclaimed or converted into paddy fields for agriculture or fishing activities (Gopalan, 1991). Reclamation of Kuttanad another important wetland system of Kerala started in 1834. By the end of 1995 about 63-76% of the total area was reclaimed for further purposes (WWF, 1993). Roads and bridges are frequently constructed across wetland since wetlands have low land value. It is often considered to be more cost effective to build roads or bridges across wetlands than around them (Winter, 1988). Roads can also disrupt habitat continuity, driving out more sensitive species.

Wetlands and mangrove forests have been cleared for pisciculture and aquaculture as demand for shrimps and fishes has increased (Jhingran, 1982). It is believed that the Vembanad-Kole Wetland system has been formed by an uplifting of the shoreline subsequent to the advance and recession of coastal waters in the yesteryears (James et al., 1997). The studies indicated that the area Vembanad lake has shrinked 37% of its original size. It is estimated that 21% of the reclamation occurred in the last 15 years (James, 2002).

At the same time, uncontrolled mining for clay and sand is damaging large areas of Kole wetlands (Sreekumar and John Thomas, 2004). Paddy fields are manmade wetlands with monoculture, shallow temporary water, plenty of light on the water surface, seasonal dynamics, ploughing, flooding, and harvest and are component of a landscape with adjacent land use (Eduardo and Antonio,2004).

The studies (Sheeja et al., 2011) on land use and land cover changes over a century (1914-2007) in the Neyyar River Basin revealed that there was decrease in` areas of paddy cultivation, mixed crops, scrub lands and evergreen forests, and increases in built-up areas, rubber plantations, dense mixed forests and water bodies. Further, large scale exploitation of flood plain mud and river sand has reached menacing proportions leading to bank caving and cut offs at channel bends.

Land use changes such as increased urbanization play a vital role in the environmental and ecological changes. Wetlands are being reclaimed with soil extracted from levelling of hillocks. These indiscriminate activities will have a serious negative impact on the entire ecological system. Hills and wetlands are two important water storing system in the tropical and subtropical regions maintaining the hydrological cycle. Unauthorized encroachment of wetland areas for non-wetland purposes are still continuing in the State especially in areas adjacent to low land paddy fields, mangrove areas and other backwater areas (Sheeba, 2015). The wetlands are characterized by its unique aquatic plants (Butler, 2010). Wetland's filter and purify water as it flows through the wetland system. Plants found in the wetland help to control water erosion (www.defenders.org).

Impoundment of natural wetlands alters hydrology and decreases water circulation. Decreased water circulation causes increased water temperature, lower DO levels and changes in salinity and pH, prevent nutrient out flow and increase the sedimentation. This affects the entire ecosystem richness, diversity and productivity. Toxic substances may accumulate in impoundment causing bioaccumulation of contaminants by wetlands biota. Changes in frequency, duration and timing of wetland hydro period may adversely affect spawning, migration, species composition and thus the food web in a wetland as well as in associated ecosystems (Crance ,1988).

Salim and Ashok (2014) studied the surface water quality of Wular Lake. This study has shown that the variation in water quality is due to either seasonal or anthropogenic factor. The main sources of pollution came from domestic wastewater and agricultural activities and runoff; however, they contributed differently to each station in regard to pollution levels. These results provide fundamental information for developing better water pollution control strategies for the Wular Lake. Eutrophication can produce a progressive change in species composition resulting in the eventual loss of species diversity (Kelly and Whitton, 1998).

The Kole wetland system is facing innumerable problems including flooding, salinity intrusion, deterioration of canals etc. The concentrations of the tested water quality parameters have higher values in the river water samples than Kole lands. The Biological Oxygen Demand was determined to be high at the point of disposal of domestic effluents. The Kole lands are found to have high build-up of iron. The sediment samples recorded high concentration of calcium, magnesium, manganese, iron and chromium. The results show that during monsoon, there is normal distribution of nutrients and other water quality parameters due to highly oxygenated conditions resulted from the tidal flushing and mixing. But the sediment samples have high organic carbon, total nitrogen, phosphorous and metals (Harikumar, 2006).

High concentrations and fluxes of dissolved organic matter (DOM) in paddy soils from plant debris trigger microbial activity and thus the emission of greenhouse gases. Frequent irrigation intensifies mineral weathering and leaching processes. High concentrations of DOM during flooding seasons enhance the changes and the release of iron in clay minerals. This also results in higher total iron oxide contents in paddy compared to non-paddy soils (Knabner, 2010). Irrigation and flooding in sloping terrain change the soil conditions of paddy soils in the down slope. With frequent flooding. drainage and ferrolysis, clay is lost very quickly. Soils in the valley can receive part of the runoff. Crystalline and total iron is lost rapidly because of the artificial surface saturation and reduction of iron and its movement, while its differentiation in the profile becomes stronger through periodic leaching and re-precipitation (Zhang and Gong, 2003).

Frequent cases of cancer, lymphoma, leukaemia and multiple myeloma from the Kuttanad rice area of Kerala and is linked to high pesticide use in the area (Dinham, 1993). A recent survey conducted by a volunteer group makes a similar observation regarding the rising trend in cancer patients in Kuttanad, identifying pollution as one of the reasons. Depletion in the fish population and massive deaths due to ulceration in fish in Kuttanad were also reported (Indiradevi, 2007). Rakhesh (1999) has found that pesticide poisoning leads to both explicit and implicit costs for the applicator/ farmer. In his study, the majority of farmers (60%) reported that they had suffered from health problems caused by pesticides. The study by Krishna and Vijesh (2001) has found skin allergy and headaches to be, among the health hazards induced by pesticides; skin allergy and headaches were found to be the most prominent pesticide-induced health hazards.

The high percentage of organic content in the Kole lands which add fertility to the soil is caused by high deposits of the silt materials which are washed down by the rivers from the mountains (Muraleedharan, 1984). Based on the textural analysis, Kole Wetland soil has been classified into clay, sandy loam, sandy clay loam and clay loam (Johnkutty and Venugopal, 1993). The hydrological connections between watercourses and their associated floodplains are important for the exchange of carbon and nutrients (Thomas, 2003). According to Page and Dalal (2011) an average of 25% of the organic carbon in drained Australian wetland soils would be lost from the top 1m of the profile in the first 50 years following drainage. The magnitude of the effect of drainage is dependent on drainage depth and land use practices.

The total storage for irrigation and power generation of the rivers draining into the Vemband Kole Wetlands is about 6000 Mm^3, which is almost half of the average flood flow to the wetlands. Therefore, the reservoirs help in containing the floods to the wetlands to a greater extent (Indo-Dutch Mission, 1989).

Many freshwater fishes recorded during the present study have already been reported as species that exhibit dwindling population. This is a threat to the inland fishery resources of the State (Thomas, 2003). The main objective of Thanneermukkam barrier is to prevent the entry of saline water in Kuttanad and increasing cropping in the dry season, but it reduces the upstream migration of marine fish and prawns and increase the weed growth in the upstream. It severely restricts the natural flushing of pollutants (James, 2002).

Several studies indicate that lack of coordination among various agencies involved in wetland administration is one of the reasons behind the loss of wetlands. Moreover planners, decision makers and the general public are unaware of ecology and hydrology of wetlands. Inadequacy of protection policies and general apathy of bureaucrats worsen the situation (John Thomas and Sreekumar, 2002). India does not have proper rules and regulations to conserve the wetlands (Nitin et al.,2014). Paddy fields were reclaimed and used for other purposes causes acute shortage of food grains. The people rose against the real estate lobby and in 2008. The Kerala Conservation of Paddy Land and Wetland Act was enacted to preserve the existing paddy fields (Suchitra, 2015). Because of the pressure of the real estate lobby, the Kerala Government made amendment to the Kerala Conservation of Paddy Land and Wetland Act, 2008. It was an environmentally detrimental decision. The revenue department of Kerala Government has failed in formulating an authentic databank of paddy fields and wetlands. This is seemingly to protect the interest of the private sector. It is absolutely necessary for the Government to take environmental and ecological factors into consideration when making decisions for the conservation of paddy fields and wetlands (Chitra, 2016).

1.14. Scope of the study

The status of soil and water bodies are getting degraded due to changes in land use practices in different parts of the Kole Wetland. The causative factors and their extent of influence are to be carefully studied in order to protect the Kole land from further deterioration. The extend of Kole land which is a potential natural water reservoir is shrinking and therefore ground water recharge is getting depleted considerably (Sreekumar and John Thomas, 2004). As Kole wetlands show high productivity levels they meet aquatic food needs of inhabitants.

Recently, large area of the wetlands has been reclaimed for coconut and banana cultivation or for developing infrastructure. In certain other parts, sand mining and clay mining are going on incessantly altering geomorphology and other physical parameters of the wetland. Roads and canals and other such developmental activities break the continuity of the wetland areas altering the flooding pattern. The extent of changes that have taken place in this area were studied by a few workers. Wetland soils play an unusual role in the global carbon cycle. On one hand, they sequester the major greenhouse gas (CO_2) from the atmosphere as organic carbon, while on the other hand they emit large quantities of another greenhouse gas, CH_4 (Whiting and Chanton, 2001). Serious attempts have not been carried out so far regarding carbon sequestration potential of the Kole wetland soil.

However, no serious attempts have so far been made to collate the varied environmental attributes and to examine their interlinkage while considering the whole area as a single unit. Understanding the consequences of ever-increasing anthropogenic pressure on ecosystems has been a major concern for undertaking developmental projects and formulating policies for land use management.

1.15. Study area

The entire Kole wetland (Thrissur and Malappuram districts) is taken for understanding land use /land cover change. Only Thrissur Kole region has been studied for its soil and water quality including the presence of pesticide residues. This area is also considered for the study of Carbon storage potential. The Thrissur Kole land lies between 10º 19’ – 10º 43’ latitude and 75 º58’ – 76º 18’ longitude. The total extent of the area is 2148 hectare (Fig.1.3).

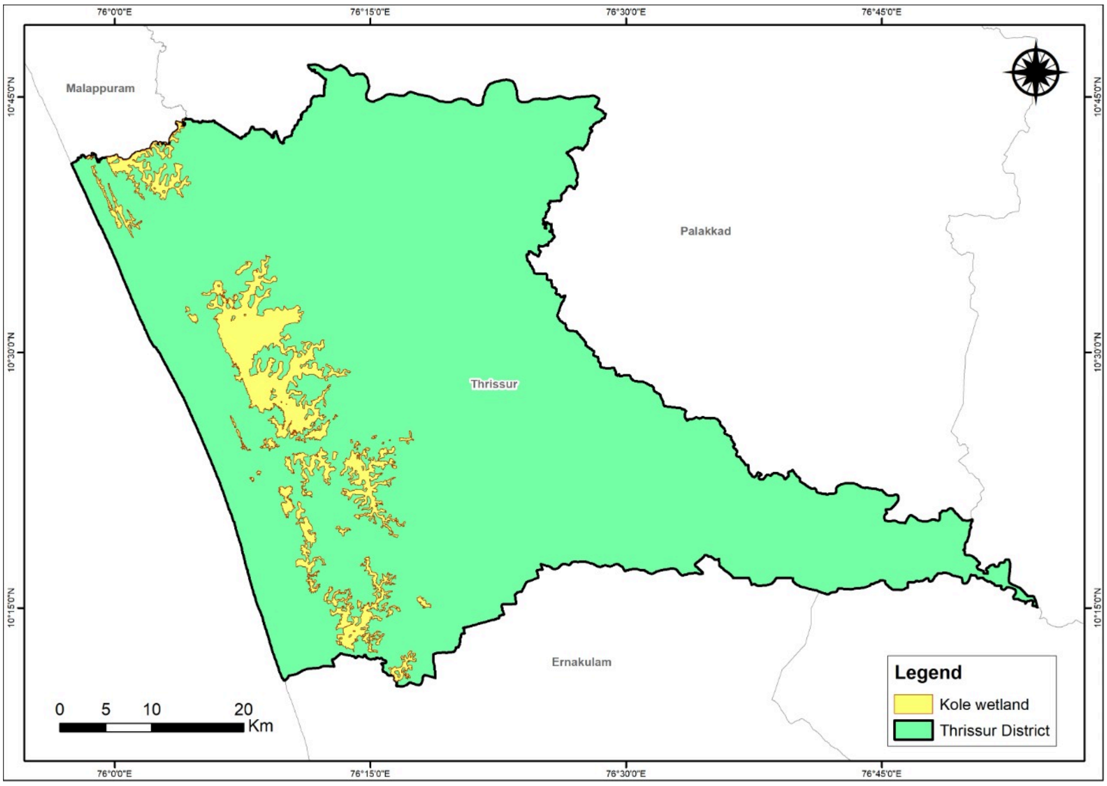


Fig.1.3. Thrissur Kole region

1.16. Objectives

- To prepare land use map of the study area and to understand the land use changes in the Kole lands from 1980 to 2017.
- To characterize the water and soil in terms of physico-chemical aspects.
- To examine the effect of pesticides in water resources.
- To investigate the soil carbon storage potential of the Kole Wetland soil.
- To suggest the possible management strategies to preserve this productive ecosystem.

1.17. General Methodology

Mapping of the Kole lands was carried out from Landsat imageries (1: 25,000 scale) and IRS P6 Images (1:50,000 scale) supplemented with topographic sheets of Survey of India (1:50,000 scale). Remote sensing data from IRS IC–LISS and PAN data was used for spatial mapping of Kole lands and its water shed. Field checks has been carried out using maps of Kerala Land use Board (1:10,000 scale) and corrections to be made. Household survey, semi-structured interview with inhabitants and discussion with Panchayath members and members of co-operative society was carried out to improve the land use map.

Seasonal changes in agricultural crops and other land use practices (brick making, sand mining, fishing, grazing, and lift irrigation programme) and trends in permanent alteration of the wetlands like reclamation for housing or industrial or commercial complexes, construction of roads, bunds and canals etc., were recorded. Land use changes in Kole lands over a period of time from 1980 to 2017 has been assessed.

The physical and chemical quality of water was continuously monitored from selected sites in the Thrissur Kole (APHA, 1998). The effect of pesticides and fertilizers used for the agricultural crops on water sources is critically examined using standard techniques. The physico-chemical parameters such as pH, Turbidity, electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD), alkalinity, salinity, total dissolved solids(TDS), total hardness(TH), calcium(Ca), magnesium(Mg), sodium(Na), potassium(K), bicarbonates(HCO_3), nitrate(NO_3), phosphate(PO_4) sulphate(SO_4) and heavy metals were analysed. Quality of both surface and ground water samples were assessed. A water and soil characteristics map were prepared on the basis of the analysis using GIS. Trilinear diagram, Salinity Hazard Ratio, Percent Sodium, Wilcox Diagram, Sodium Adsorption Ratio (SAR), U.S. Salinity Laboratory Diagram, Permeability Index, Magnesium Hazard (MH) Kelly's Ratio used to find the quality of drinking water and irrigational quality of the surface and ground water in the area. The interlinkage among the parameters were examined using statistical methods. The impact of pesticides in surface water samples were examined. The soil samples were collected from the Kole wetland system for analysing the physical and chemical qualities of soil and prepared a soil characterization map using GIS interpolation method-Kriging. The sampling sites were selected randomly and collected from varying depths. The pH, Electrical conductivity, organic carbon, available sodium, total nitrogen(N), available nitrogen, phosphorus (P) and potassium (K), secondary nutrients calcium (Ca), magnesium (Mg), total sulphur(S), available sulphur, aluminium (Al), boron(B), micronutrients iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and heavy metals lead (Pb), cadmium (Cd) and nickel (Ni) in soil sample were analysed. The impact of 2018 deluge on various soil quality parameters were determined. Based on these findings a restoration plan for the area was prepared.

1.18. Organization of Thesis

Thesis is organized into eight chapters. Chapter 1 is an introductory chapter which deals with wetlands, its importance, threats, extent of wetlands, Kole wetlands, need for wetland conservation, review of literature, scope of the study and objectives. Chapter 2 includes land use changes of Thrissur Kole wetland system, detailed methodology and findings. Chapter 3 discusses the physico chemical characteristics of surface water, detailed methodology for analysis, comparative evaluation of the hydrological parameters and assessment using water quality indices. Chapter 4 focus on physico chemical characteristics of ground water, comparative evaluation of the hydrological parameters and assessment of quality of water. Chapter 5 deals with the pesticide residue analysis in water, plant and rice samples, methodology and results. Chapter 6 explains the soil quality parameters of Kole lands, methods used for soil analysis and spatial modelling of soil quality parameters. An attempt is also made to assess the soil quality parameters after 2018 deluge. Chapter 7 examines with the mechanical composition of soil and carbon nitrogen storage potential of Kole wetlands. The Chapter 8 summarizes of the findings and Chapter 9 discusses various management strategies for the sustainable restoration of the Kole wetlands.

CHAPTER 2

LAND USE CHANGES OF THRISSUR KOLE WETLAND SYSTEM

LAND USE CHANGES OF THRISSUR KOLE WETLAND SYSTEM

2.1 Introduction

Land is a renewable resource if it is utilized carefully. Land can be a non-renewable resource, when it is seriously destructed by human interventions. Human beings need land for building homes and various domestic activities, cultivating food, supporting and providing raw materials for developmental activities in the industrial and urbanization sectors. The human beings need to protect the critically valuable biodiversity. The rational use of land needs careful planning (Erach Bharucha, 2005). Land use pattern has undergone tremendous transformations due to the impact of urbanization and industrialization. Changes in the land use pattern bring associated ecological changes.

2.2 Driving forces behind land use changes

Almost all major biomes of the world have experienced drastic changes due to the geological processes or climatic changes. Land subsidence, upheaval of the earth’s crust and changes in the weather pattern have radically changed the face of the earth intermittently for the past several million years. However, the recent changes that we observe in the environment were strikingly the result of human interference with the functioning of the natural world. Moreover, the pace of the change was so fast that it had become increasingly difficult for all the living organisms to cope up with such unprecedented changes. Any alteration in the pattern of the land use change can fundamentally modify the input of energy, water and nutrients and thus affect the natural processes of an ecosystem (Adger and Brown, 1994). As the wetlands were one of the most fragile ecosystems evolved out of the delicate balance between a water body and the land surrounding it, any change in the land use pattern can alter several vital functions of the wetland (Plate2.1). The major human intervention in the wetlands from time immemorial was its conversion into the agricultural lands. The agricultural expansion in the wetlands profoundly affects the flow of water, energy and materials and lead to substantial indirect environmental effects even beyond the limits of the converted land (Douglas, 1994).

Unlike in other states of our country wetlands of Kerala were under extreme threat. An average Keralite preferred to live in an independent homestead rather than in a flat or in a colony. The high population density of the state, presence of fairly good proportion of middle-income groups and the boom of gulf money had all contributed to the reclamation and development of wetland for residential plots (Plate 2.2). The study carried out by Johnkutty and Venugopal (1993) evaluated the potential of the wetland for rice cultivation. The phenomenal increase in the price of fertilizers, the non-availability of labourers and the general apathy of young people to take up farming as a way of life etc. have their reflections on the perspectives of the human community that were dependent on the wetland for several decades. Thus, large areas of the wetland were reclaimed for housing plots and coconut plantation and very recently these fertile paddy fields were either sold or leased for sand mining (Sreekumar and Thomas, 2004). The boom in the sand mining from the paddy fields was primarily triggered by the stringent direction from the high court regulating extraction of sand from the various rivers of Kerala. So far, no serious attempts have been made to evaluate the long-term impacts of the change on ecology, water and food security of the people of the locality.

Understanding the consequences of ever-increasing anthropogenic pressure on the ecosystems had been a major concern for undertaking development projects and formulating policies for land use management. Land cover changes generally refer to changes on biophysical properties of the earth surface, land use changes can be defined as the changes in the practices due to anthropogenic activities. Land Use Land Cover changes (LULCC) is a continuous process taking place due to various natural and anthropogenic factors. (Sharma et al., 1989). The Land use and land cover (LULC) studies helped in assessing and monitoring the status of the natural resources, detecting the changes on spatial and temporal scale and predict them for the future. Due to changing environment and increasing anthropogenic pressure, the demand for a LULC database at the global level was increasing. The advancement in the concept of plantation providing an accurate evaluation of the spread and health of the world's forest, grassland and agricultural resources has become an important priority, as they were becoming scarce resources due to immense agricultural and demographic pressure. Hence information on land use/land cover assists in monitoring the dynamics of land use resulting out of changing demands of increasing population. In situations of rapid and often unrecorded land use changes observations of the earth from space provide objective information on land utilization of landscape. A survey of plantation and LULCC by conventional methods requires vast human resources and time (Joshi et al., 2008). Earth sensing satellites had become vital in mapping the Earth's features and infrastructures, managing natural resources and studying environmental change. Remote sensing (RS) and Geographic Information System (GIS) are good tools for advanced ecosystem management.

Remotely Sensed data had emerged as an important tool for carrying out various ecological studies and for mapping, monitoring, and inventorying various resources

(Miller et al., 1978, Singh, 1984 and 1986). Landscape metrics reduce the bias, and further enhance the understanding of spatial and temporal changes (Lee et al., 2006; Joshi et.al. 2006).

The collections of remotely sensed data facilitate the synoptic analysis of earth-system function, patterning and change at local and regional and global scales over time (Myers, 1989; Liu et al,1993). Such data also provide an important link between intensive localized ecological research and regional national and international conservation and management of biological diversity (Wilkie and Finn, 1996).

For mapping wetlands, different remote sensing techniques have been used. The advantage of remote sensing technology is that the digital data can be acquired on a repetitive basis.

The land cover and-land use types can be monitored seasonally and /or annually by using digital data. Digital data is integrated using geographic information system. Landsat 5 Thematic mapper (TM) Landsat 7(TM) Enhanced Thematic Mapper Plus (ETM+) and the Spot 4 and 5 satellite systems were found useful for the purpose. More recently however multispectral IKONOS and Quick Bird data, with spatial resolutions of 4 M by 4 M and 2.44 M by 2.44 M, respectively, had been shown to be excellent sources of data when mapping and monitoring smaller wetland habitats and plantation communities. However, there were many constraints in acquiring details of a specific area in the wetland. Analysis of wetlands had proved difficult because to obtain the data, it had to be linked with practical purpose such as analysis of land cover or land use. Preparation of a global map of wetlands had proven to be a large and difficult undertaking. Current efforts using today's remote sensing satellites may not had sufficient spatial and spectral resolution to monitor wetland conditions, although multispectral IKONOS and Quick Bird data may offer improved spatial resolutions, higher by 4 m. Majority of the pixels are just mixtures of several plant species or plantation types and are difficult to isolate. Improved remote sensing information, coupled with good knowledge of wetlands will facilitate expanded efforts in wetland monitoring and mapping.

2.3 Methodology

For the present study the area had been mapped from Landsat imageries (1: 25,000) and IRS P6 images (1:50,000) supplemented with topographic sheets of Survey of India (1.50000 scale). Field checks were carried out using maps of Kerala Land Use Board (1:10,000 scale) and appropriate corrections were made. Household surveys, interviews with inhabitants, discussion with Panchayat officials and members of cooperative societies and field checking were done for preparation of the present land use map. The land used for settlement and agriculture, built upland, fallow land, paddy cultivation, mixed cultivation and water bodies had all been delineated and presented in the land use map.

2.4 Data Sources

Study made use of Survey of India Toposheet (1980) with scale 1.50000, from which the base maps were generated. The areas under different land use were demarcated by digitizing the area in the Toposheet, after geometric projection using ERDAS 9.2 Software. Through field survey and mapping using GPS, the land use type and supporting data were collected. The mapping of recent land use was carried out using satellite imagery of 2008 from IRS P6 LISS 3 Image acquired on 24/1/2008, and Landsat 8 thematic mapper (TM) 2017 acquired on 03/02/2017.

2.5. Mapping and Mapping Techniques

The Survey of India Toposheet of scale 1:50,000 were scanned and the maps were geometrically projected to represent it on a co-ordinate system. The raster image of entire Thrissur Kole lands was generated using the mosaic option available in the ERDAS 9.2 software. A Vector file of wetland including water bodies and paddy fields was generated using the same software. The Vector image was then imported to ARC GIS as coverage after executing in CLEAN command for topology creation. The dangle nod errors were removed interactively in ARC Edit module. After all offshoot/ undershoots errors were removed, Feature Attribute Table (FAT) was created using 'BUILD' in the ARC prompt. A master TIC file was created and then projected coverage was transformed using Polyconic projection. Each land use /landcover category was assigned a code and these codes attached to appropriate records of FAT interactively. A Look Up Table (LUT) was also created to assign a shade symbol for each land use/land cover category.

The temporal changes in the land use pattern of the area for the period 1980 ,2008 and 2017 were extracted as separate coverage using 'RESELECT' options. Then to find out the actual conversion of different land use areas during the period, the two coverage were intersected using the overlay command 'INTERSECT' THE 'INTERSECT' command extracted those parts of input coverage falling within the intersect coverage to a new coverage. Then the area statistics of land use/land cover of selected time periods and intersected coverage, which give the actual conversion, were extracted from the feature attribute table of respective coverage. This was done using the TABLES module ARC GIS.

2.6 Result and Discussion

The land use/land cover distribution for the year 1980 as derived from the Survey of India Toposheet (1980) was presented in the Fig.2.1.

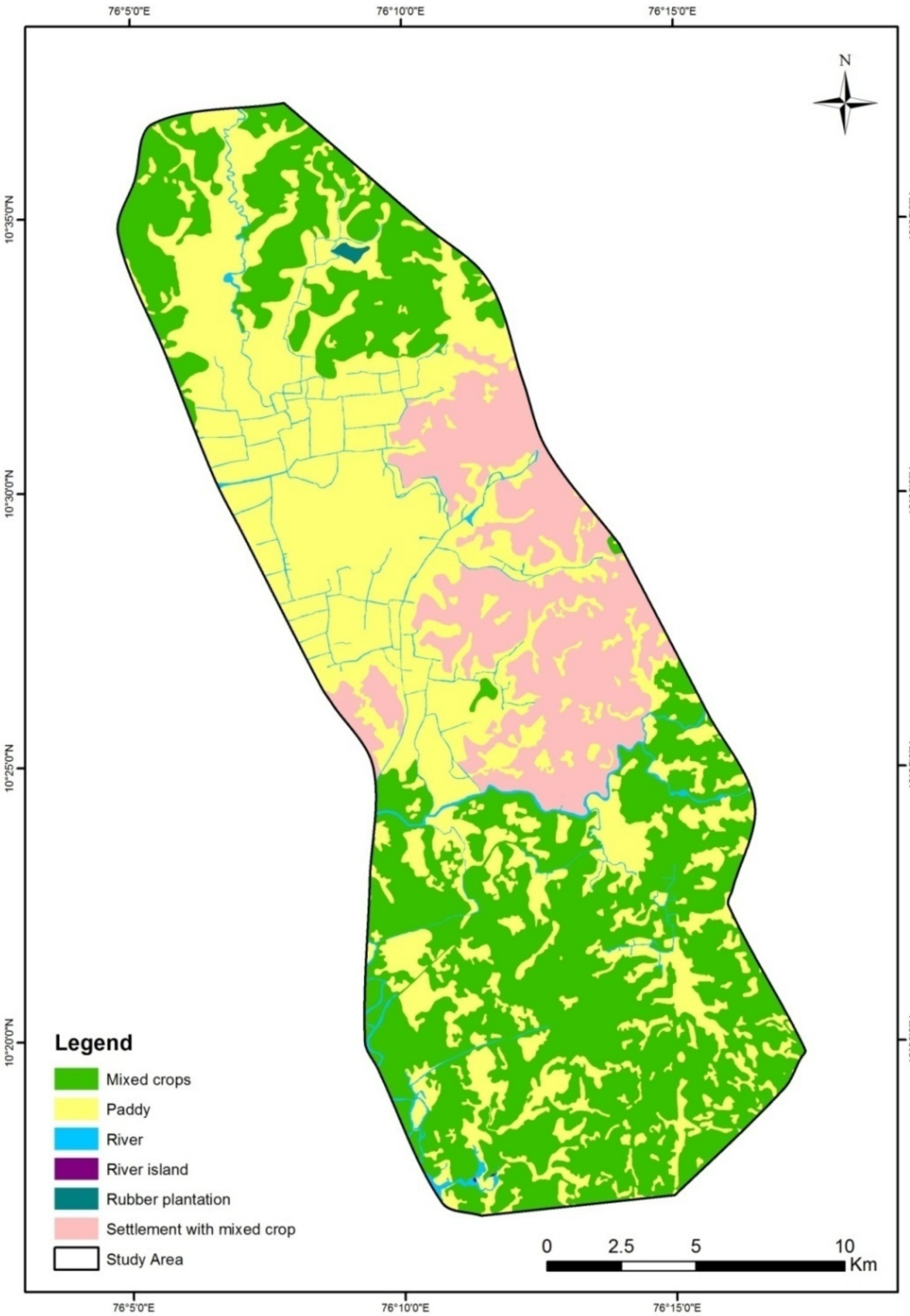


Fig.2.1. Land use/ land cover of Thrissur Kole wetland 1980 based on Survey of India Toposheet

The total area in this study was 431.20 km^2. The major land use categories identified in the year 1980 were mixed crops, paddy, river deltas, rubber plantations, settlement with mixed tree crops and river (Table 2.1). The majority of the area was occupied by paddy (42.38%), followed by mixed crops (40.38%) and settlement with mixed crops (15.04%) (Plate 2.3). The least area shown in land use types was water bodies which occupies 2.06%. Fig. 2.2 is the diagrammatic representation of the land use/ land cover category spread in the year 1980.

Table 2 .1. The land use/land covers distribution (1980) from Survey of India Toposheet

Type of land use	**Area (Sq.km)**	**Area (%)**
Mixed crops	174.18	40.38
Paddy	182.78	42.38
River Islands	0.02	0.01
Rubber plantation	0.44	0.10
Settlement **with** mixed **crop**	64.86	15.04
River	8.92	2.06
Total area	**431.2**	**100**

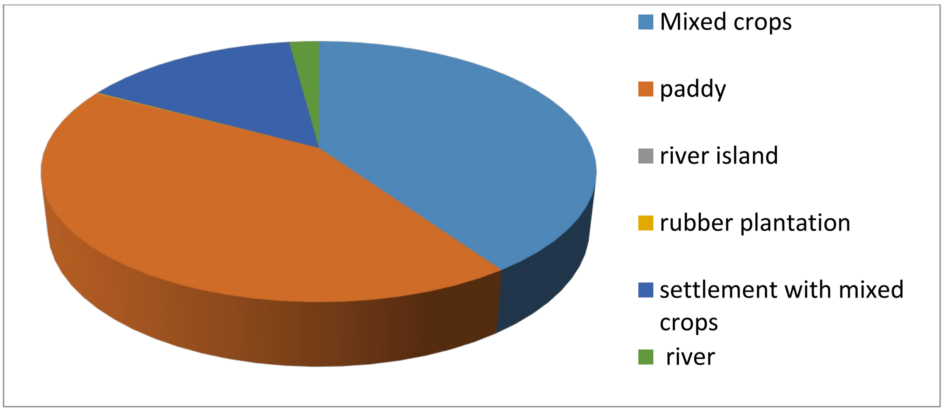


Fig.2.2. The land use distribution of Thrissur Kole wetland (1980)

The total land use/land cover distribution for the year 2008 as derived from IRS P6 LISS image was presented in the Fig. 2.3.

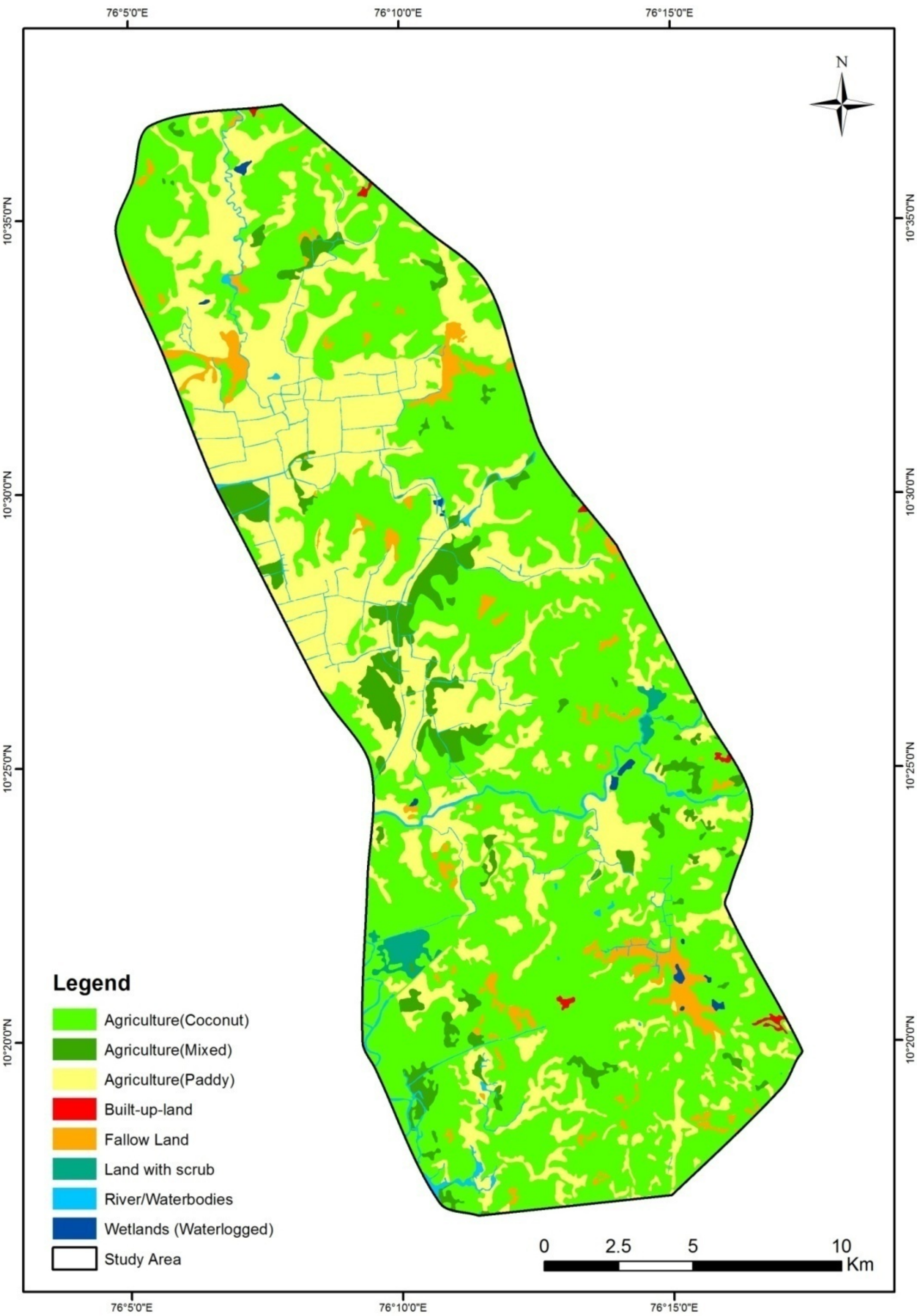


Fig.2.3. The extent of Land Use and Land Cover in the year 2008

The major land use classes delineated were agriculture land (coconut+ settlement), agriculture (mixed), agriculture (paddy), built-up-land, fallow land, land with scrub, river/water bodies, river and water bodies. The agricultural land covers an area of 252.64 km^2 and it constitutes 58.59 % of the Thrissur Kole. The agriculture (mixed) plantation category covers an area of 20.87 km^2 (4.84%) and the paddy field 130.38 km^2 (30.24%). The built-up-land occupies 0.76 km^2 and it constitutes 0.18 % of the total area. The fallow land occupies an area of 13.59 km^2. An area of 9.44 km^2 (3.15%) remains water logged which includes both perennial and seasonal water bodies. The area of each type of land use and its percentage was provided in Table 2.2 and is diagrammatically represented in Fig. 2.4.

Table 2.2. The land use/land covers distribution for the year 2008

Type of land use	Area (Sq.km)	Area (%)
Agriculture land (Coconut+ Settlement)	252.64	58.59
Agriculture (Mixed)	20.87	4.84
Paddy	130.38	30.24
Built up land	0.76	0.18
Fallow land	13.59	3.15
Land with scrub	2.64	0.61
River /Water bodies	9.44	2.19
Wetlands (waterlogged)	0.89	0.21
Total area	**431.20**	**100**

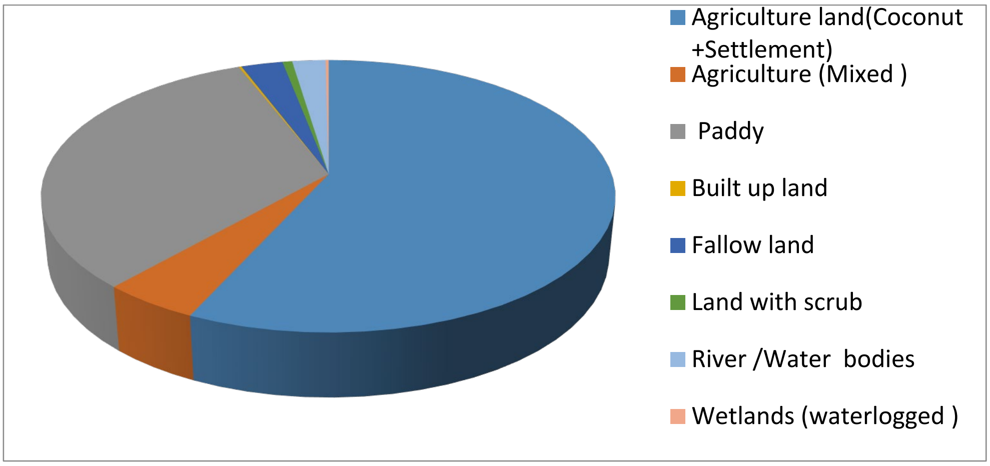


Fig.2.4 The land use distribution of Thrissur Kole wetland (2008)

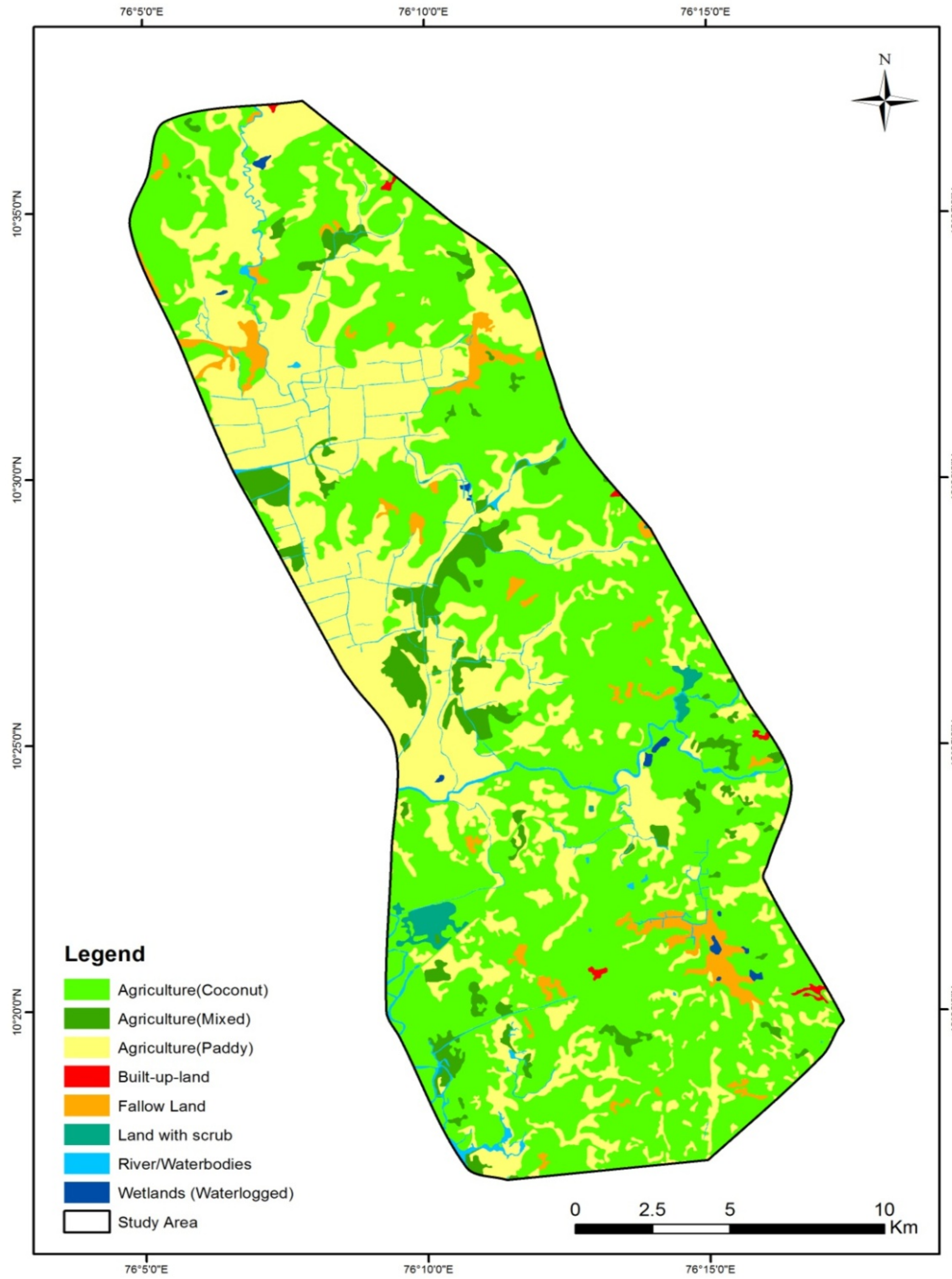


Fig.2.5. The land use/land cover distribution of 2017 Landsat 8 Thematic mapper (TM) acquired on 03/02/2017

The total land use/land cover distribution for the year 2017 as derived from the satellite imagery obtained from Landsat 8 thematic mapper (TM) is presented in the Fig. 2.5.

The detailed area-wise distribution of land use/land cover of the study area for the period 2017 was given in Table 2.3 and Fig.2.6. The agricultural land covered an area of 245.07 km^2 (57%) and 20.45 km^2 of land was covered with mixed crops. The paddy covered an area of 140.03 km^2 (32 %). The built-up land extended up to 0.77 km^2. The fallow land spreaded over 11.81 km^2 (3%) and1% of the area was covered by land with scrub. The river/ water bodies covered an area of 9.44 km^2 (2%). The wetlands occupied only an area of 0.89 km^2 of the total area.

Table 2.3 The land use/land cover distribution for the year 2017

Type of land use (2017)	Area Sq.km	Area %
Agriculture land (Coconut +Settlement)	245.07	57
Agriculture (Mixed)	20.45	5
Paddy	140.03	32
Built up land	0.77	0
Fallow land	11.81	3
Land with scrub	2.74	1
River /Water bodies	9.44	2
Wetlands (waterlogged)	0.89	0
Total area	**431.20**	**100**

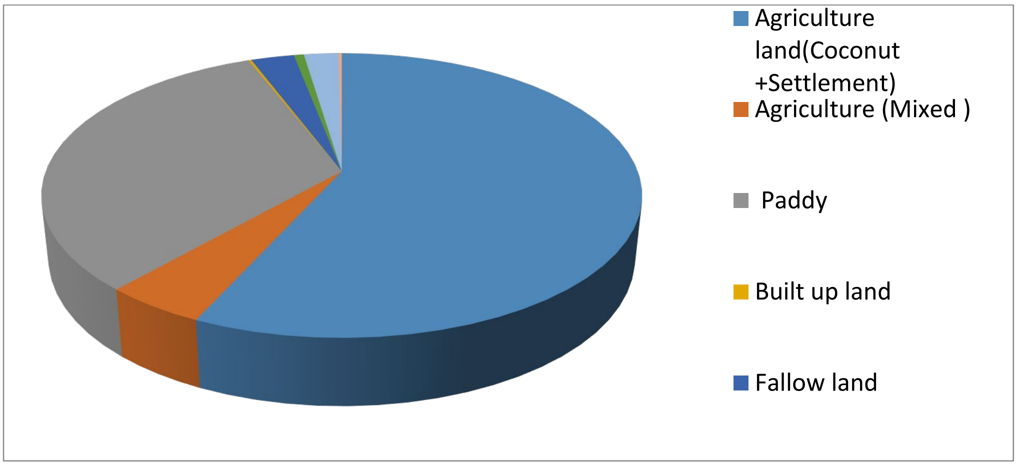


Fig. 2.6. Diagrammatic representation of land use/land covers (2017)

2.7 Comparative analysis of land use/ land cover

The comparative study of land use patterns in 1980, 2008 and 2017 of Thrissur Kole lands showed (Fig.2.7) that there had been a noticeable change in the land use type area from 1980 to 2017. The extent of agriculture land showed a remarkable increase (41.96%) from 1980 to 2017. However, a sharp decline in the spread of mixed agriculture (-35.38%) and paddy field (-10.38%) was observed (Table 2.4). The result showed that people had either shifted their agricultural practice from paddy to agriculture (mixed) or transformed the land for settlement.

Table. 2.4. The change in land use/cover over the years 1980-2017

Landuse /cover type	1980		2017		Land use change analysis 2017 to 1980	
Type	Area (Sq.km)	Area (%)	Area (Sq.km)	Area (%)	Difference (Sq.km)	Difference (%)
Agricultural land (coconut + settlement)	64.86	15.04	245.07	57	180.21	41.96
Agriculture (Mixed)	174.18	40.38	20.45	5	-153.73	-35.38
Agriculture (Paddy)	182.78	42.38	140.03	32	-42.75	-10.38
Built-up land	-	-	0.77	0	0.77	0
Fallow land	-	-	11.81	3	11.81	3
Land with scrub	-	-	2.74	1	2.74	1
River /Water bodies	8.92	2.06	9.44	2	0.52	-0.06
Wetlands	-	-	0.89	0	0.89	0
Rubber plantations	0.44	0.10	-	-	-	-
River islands	0.02	0.01	-	-	-	-
Total area	**431.20**	**100**	**431.20**	**100**		

From Fig.2.7 it was inferred that the area of paddy cultivation showed a decline from 1980 to 2008 and it showed a steady increase from 2008 to 2017. The present trend showed that the fallow land was being converted for paddy cultivation (Table 2.3 and

2.4). A positive response was seen among the local people to cultivate paddy in fallow lands.

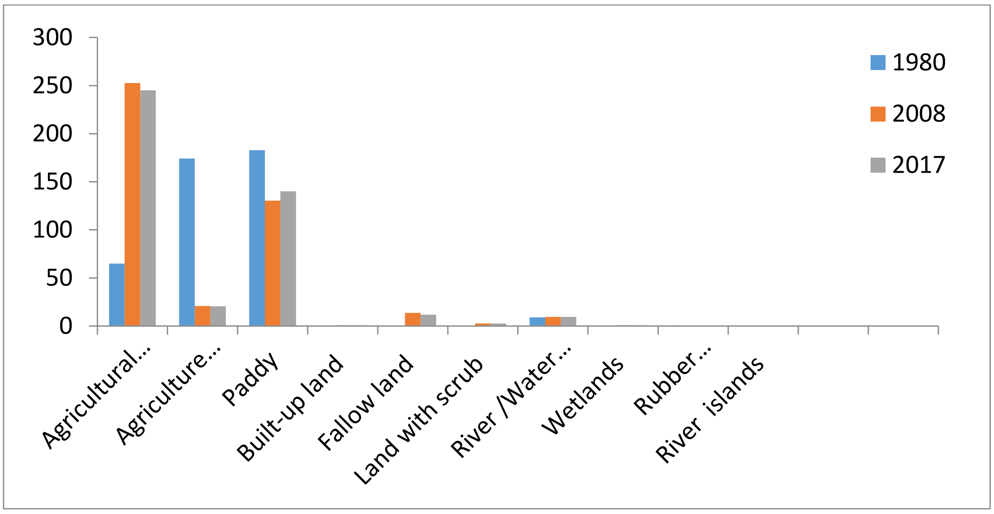


Fig.2.7. The change in land use/cover over the years 1980, 2008 and 2017

Survey and interview revealed that people are changing their mindset towards paddy cultivation. Introduction of co-operative farming has increased the area of paddy cultivation. Impact of land use changes in wetlands had been a subject of study by many (Gopikuttan and Parameswara Kurup, 2004; Mathew et al., 2014; Sreekumar ,2004, Sinta et al., 2019). The conversions of paddy land induce drastic effect on ecology, hydrology and watershed drainage pattern (Plate2.5). The reclamation destroyed the natural plantation which caused reduction in humus formation, increase soil erosion and severely affect the soil fertility (Plate 2.6).

Kole lands of Thrissur and Ponnani were unique ecosystems completely flooded during monsoon. These were natural paddy cultivating areas where the ecosystem dynamics was being utilized effectively, only with transient environmental manipulations, for bumper harvest of grains and for fishery (Mathew et al, 2014). It had been estimated the rain water falling on the high lands of Kerala reaches Arabian Sea within twenty-four hours. Rice paddies exist in the eighth agro-ecosystems act as a repository of the rain water facilitating the recharge of the ground water, largely phreatic and unconfined aquifer, by restricting the pace of the run off (Shaji et al, 2009; 2011). Kerala's ground water resources were highly dependent on the local recharge. Faster runoff, steep slopes from east to west reduced ground water recharging (Plate 2.5). The traditional rice paddies that retain water for a longer duration would play an important role in recharging ground water (Plate 2.7).

The conversion of paddy field affected both surface and ground water storage (Sreekumar, 2004). The flood water regulation was executed by14 wetlands. The diversion of agrarian land for construction has serious ecological implications (George and Chattopadhya, 2001).

2.8 Conclusion

The extent of paddy cultivation area showed a decline from 1980 to 2007. However, a significant increase in the area of paddy cultivation was noted from 2008 to 2017. The extent of coconut plantation together with settlement showed a remarkable increase (41.96%) from 1980 to 2017. This showed that people have either shifted their agricultural practice from paddy to coconut cultivation or transformed the land for settlement. A reduction in the extent of mixed agriculture crops was also noticed from 1980 to 2017. Kerala had a long history of food grain deficit, especially in rice. The State imports food grains from neighbouring states to fully meet its needs. The steady losses of paddy fields pose a serious threat to the State's economy, ecological sustainability, and food and water security. This was a positive trend among the young generation to take up the fallow land and start paddy cultivation. It was a boon to the State's sustainable development.

STATUS OF SURFACE WATER CHEMISTRY

3.1 Introduction

Population growth, rising standards of living, climate changes, industrialization, agriculture and urbanization had resulted in water scarcity which was a limiting factor for economic and social development (Singh, 2007). Water scarcity was being a major concern for world and had become a threat to human activity and as a consequence water reuse strategy should deserve major attention (Fritzmann et al., 2007). The riverine and coastal wetlands had complex hydrological interactions due to periodic water-level changes and flooding. The effects of precipitation, evapotranspiration, interaction with surface water and ground water make fluctuation in water table level. The water quality assessment of Lake Panduit Bodhan of Andhra Pradesh showed that Dissolved Oxygen, Biological Oxygen Demand, Nitrates, Phosphates and nutrient loading were contributing to eutrophication process in the lake and this lake seems to be eutrophic throughout the year (Solanki et al., 2009).

Water quality criteria developed by scientists provide basic scientific information about the effects of pollutants on a specific water use. They also described water quality requirement for protecting and maintaining an individual use. Water quality requirements for different uses of water were scientifically termed as criteria and the permissible level of containments in water for different uses without any negative impacts on environment and society were termed as standards. Those were legally enforced level set up by a governmental or any international agency that have been arrived at after consideration of water quality criteria and the economic, social and political consequences of possible regulatory action.

3.2. Water Sampling preservation and storage of water sample

The samples of surface water (S1 to S 32) were collected from 32 locations (Table 3.1 and Fig 3.1) falling within Thrissur Kole wetland area.

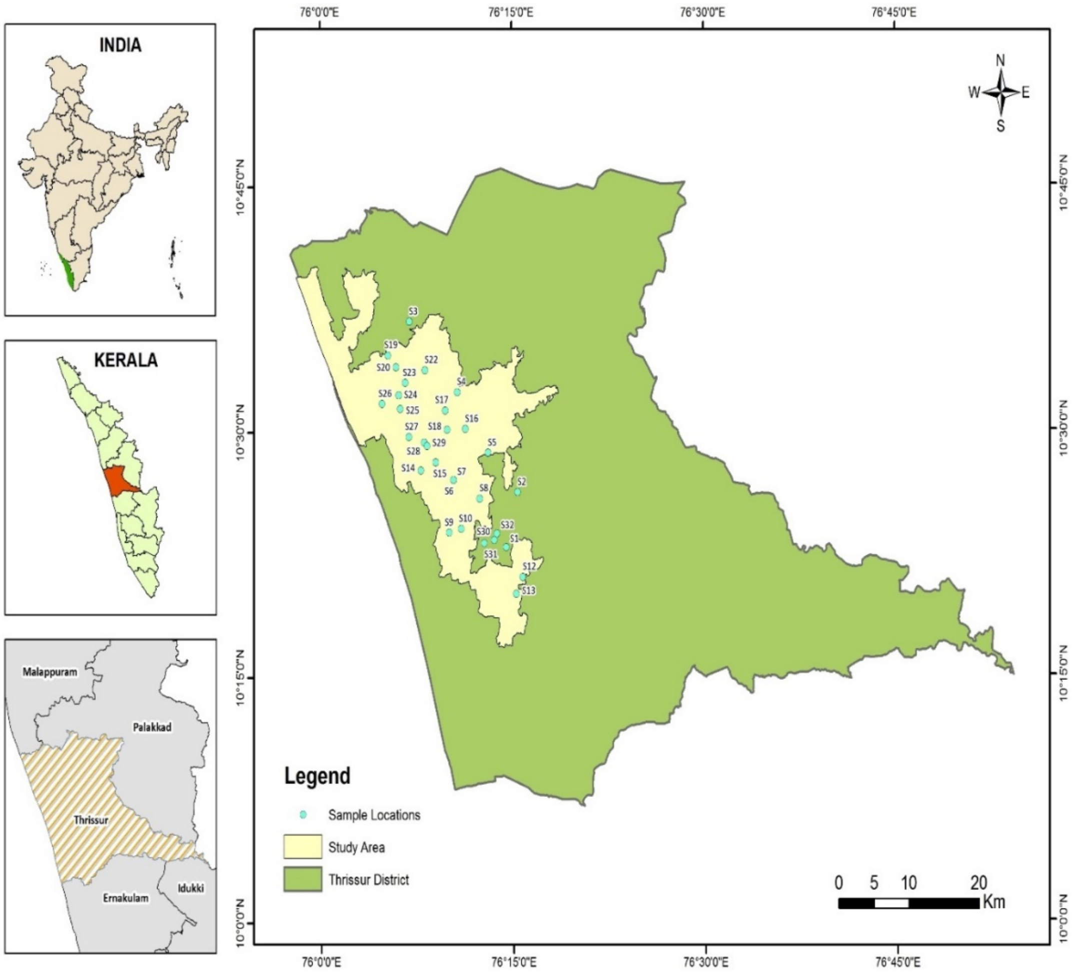


Fig 3.1. Study area map with sampling points

3.3. Methodology

The samples were collected during pre-monsoon (February to April) and post monsoon seasons (October to December) in three consecutive years and average values taken for quality analysis. On site testing was done for certain variables such as dissolved oxygen, turbidity, conductivity, and pH and to a lesser extent by using portable equipment in the field. The samples (~ 2 liters) were brought to the laboratory in glass bottles and kept in chilled storage till the analytical work was carried out. In this study, quantitative estimation of various physico-chemical parameters such as Total Hardness (TH), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Chlorides (Cl), Alkalinity, Bicarbonates (HCO_3), Dissolved Oxygen (DO), Sulphate (SO_4), Phosphate (PO_4), Nitrate (NO_3) and Heavy metals were carried out using the methodology for water quality followed by Standard methods for examination of water and waste water (APHA, 2012).

Table 3.1. Details of the sampling locations

Sample	Location	Lattitude	Longitude	Sample	Location	Lattitude	Longitude
S1	Konthilampadam	N10º22'56.0"	E 076º14'29.9"	S17	Pullazhi	N10º 31' 18.8"	E 076º 09' 45.2"
S2	Madavakkara	N10º26' 17.9"	E 076º15' 24.1"	S18	Chettupuzha	N10º30'07.7"	E 076º09'53.8"
S3	Kecheri	N10º36' 45.0"	E 076º 06' 57.0"	S19	Parakkad	N10º34' 41.9"	E 076º05' 16.8"
S4	Adatt	N10º32' 26.1"	E 076º 10' 41.4"	S20	Elavally	N10º33' 58.4"	E 076º05' 53.4"
S5	Kanimangalam	N10º 28' 42.6"	E 076º 13' 05.1"	S21	Vaka	N10º34' 07.8"	E 076º06' 20.3"
S6	Pullu	N10º 27' 3.1"	E 076º 10'23.1"	S22	Parappur	N10º33' 46.9"	E 076º08' 09.4"
S7	Thannyam(vendra)	N10º 24' 30.5"	E 076º 09'16.8"	S23	Annakara	N10º33' 00.7"	E 076º06' 37.5"
S8	Cherppu(church)	N10º 25' 55"	E 076º 12'26.1"	S24	Manalipadavu	N10º32' 15.5"	E 076º06'06.8"
S9	Karanchira(vellani)	N10º 23' 50.4"	E 076º 10'1.6"	S25	Venkitangue	N10º31' 24.4"	E 076º06' 14.4"
S10	Karalam(chemmanda)	N10º 24' 4.2"	E 076º 10' 58.4"	S26	Padoor	N10º31' 43.8"	E 076º04' 48.8"
S11	Aloor (Eranampadam)	N10º 19' 44.8"	E 076º 16' 02.2"	S27	Manalur	N10º29' 41.9"	E 076º06' 53.4"
S12	Muriyaadu(Vallakunnu)	N10º 21' 06.4"	E 076º 15' 47.1"	S28	Perumbuzha	N10º29' 21.8"	E 076º08' 05.9"
S13	Thomanna	N10º 20' 04.9"	E 076º 15' 16.5"	S29	Kaippilly	N10º29' 08.8"	E 076º08' 19.1"
S14	Anthikkad	N10º 27' 38.7"	E 076º 07' 49.3"	S30	Puthanthodu	N10º23' 22.8"	E 076º 13' 32.4"
S15	Veluthur	N10º 28' 08.5"	E 076º 08' 59.7"	S31	Thelappilly	N10º23' 11.5"	E 076º 12' 46.4"
S16	Aranattukara	N10º 30' 10.9"	E 076º 11' 18.5"	S32	Vallyapalam	N10º23' 46.4"	E 076º 13' 46.4"

3.4. Physico-chemical analysis of water sample

In the present study, the quantitative estimation of various physico chemical parameters was carried out. The pH of the samples was measured using Eutech instruments digital pH meter. The calibration done by using pH 4, 7 and 9.2 buffer solutions. Electrical conductivity and TDS were measured by Eutech instruments con510 conductivity/TDS/^{0}C/^{0}F Meter. Elico CL 52 D was used to measure turbidity, by standardizing with Hydrazine sulphate and Hexamethylene tetramine.

Spectroscopic analysis was carried out for estimating sulphate, phosphate, nitrate, fluoride and iron by using Thermo Fisher Scientific model G10s UV-V. Sulphate concentrations of the samples were determined using spectrophotometry analysis at 420nm. Sulphate ion was precipitated in an acid medium with barium chloride to form barium sulphate. The absorbance reading of barium sulphate suspension gave the sulphate ion concentration. The estimation of Phosphate was done by spectrophotometry method using Ammonium molybdate. Ammonium molybdate was made to react with Phosphate-P in the water sample to form molybdo phosphoric acid, which was then reduced to a blue coloured complex ' *Molybdenum blue'* by the addition of stannous chloride was made at 690nm. A standard curve was plotted using known standards of 0.2, 0.4, 0.8 and 1.0 mg per litre of phosphorous. The instrument directly calculates the concentration in the sample and reported as mg/l of phosphate-P. The nitrate was analysed by Phenol disulphonic acid method. The nitrate reacts with phenol disulphonic acid (PDA) to produce a nitro derivative, which in alkaline solution – Potassium hydroxide developed a yellow colour. The absorbance was reading at 220 nm. In the SPADNS (trisodium2- parasulfophenylazo-1, 8- dihydroxy-3, 6- naphthalene disulfonate) method, zirconium acid reacts with SPADNS to form a red coloured complex measured using a spectrophotometer at 570 nm. Solutions containing ions of iron are colourless, but upon addition of Ortho-phenanthroline, the iron (II) ions in the sample react immediately to produce a complex ion, which is orange in colour. For the estimation of Iron, 10% hydroxyl amine hydrochloride and 0.25% Ortho-phenanthroline solution were used for colour formation and absorbance read at 400 nm.

The total hardness, Alkalinity, Chloride, Bicarbonate and Dissolved Oxygen were estimated by titration. A solution of the substance was prepared and the appropriate reagent was added to the substance until the amount added was equivalent to the amount of substance to be determined. Total hardness, Calcium and Magnesium were estimated by using EDTA titration and Erichrome black T as indicator in the presence of buffer pH 10. The alkalinity was analysed by titrated against 0.1N sulphuric acid using methyl orange as indicator. Dissolved oxygen was analysed by Winkler method. Argentometric titration was adopted for the estimation of chloride in the water sample using potassium chromate indicator was titrated against 0.1 N. $AgNO_3$solution.

The alkaline metals like Sodium and Potassium were estimated using flame photometry. Heavy metal analysis done by using ICP/MS. 0.25g to 0.5 g sample was weighed accurately in to MDS digestion tube. Added 5.0 ml conc. HNO_3 (extra pure), 0.5 ml conc. HCl (extra pure), and 1.0 ml H_2O_2 (extra pure), and allowed 15 min. self-digestion in the MDS tube. After digestion transferred the contents in to 50 ml tube and make up to 50 ml using extra pure water.

Element (ug/L) = Concentration from calibration graph (ug/L) x dilution factor

Tri linear Piper's diagram, Salinity hazard ratio, Percent sodium (%Na), Wilcox, Sodium Absorption Ratio (SAR), U.S. salinity laboratory diagram (USSL), Permeability Index (PI), Magnesium hazard (MH) and Kelly's ratio were used to evaluate the water quality for irrigation purpose.

Kriging or Gaussian process regression was a method of interpolation for which the interpolated values are modeled by prior covariances. Under suitable assumptions on the priors, Kriging gave the best linear unbiased prediction of the intermediate values. Interpolating methods based on other criteria such as smoothness (e.g., smoothing spline) may not yield the most likely intermediate values. The method was widely used in the domain of spatial analysis and computer experiments. The technique was also known as Wiener–Kolmogorov prediction, after Norbert Wiener and Andrey Kolmogorov.

The Kriging tool fit a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. The predicted values were derived from the measure of relationship in samples using sophisticated weighted average technique. It used a search radius that can be fixed or variable.

The general formula for both interpolators was formed as a weighted sum of the data:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)$$

Where, $\boldsymbol{Z(s_i)}$ = the measured value at the i^{th} location, $\boldsymbol{\lambda_i}$ = an unknown weight for the measured value at the ith location, $\boldsymbol{s_0}$ = the prediction location and $\boldsymbol{N}$ = the number of measured values. ARC GIS 10.1 was used for spatial interpolation and generating prediction maps. Briefly the steps followed were; In ARC MAP → Arc Tool box

→Spatial Analysis Tools → Interpolation→ IDW/Spline/ Kriging→ Input point feature value field → Output raster → OK.

3.5. RESULT AND DISCUSSION

3.5.1 Physico- chemical characteristics of surface water

The result of the physical and chemical characteristics of surface samples (n=32) for the two seasons are given in the table (3.2 (a) and (b), 3.3(a) and (b), in the figures 3.2 to 3.7 and Plate 3.1. The ranges in the values of different parameters are listed in table 3.4.

Table 3.4 Concentration range for water quality parameters

Parameters	Pre monsoon		Post monsoon	
	Maximum	Minimum	Maximum	Minimum
pH	7.90	4.00	7.30	4.07
EC (µs)	633.84	233.80	4637.99	347.86
TDS (ppm)	412.00	151.97	3014.70	226.11
Turbidity (NTU)	41.60	4.25	63.10	1.00
Sodium (ppm)	75.60	9.60	15.10	1.00
Potassium(ppm)	36.00	0.94	2568.00	5.70
Chloride(mg/l)	196.40	85.74	248.15	35.45
TH (mg/l as $CaCO_3$)	156.56	6.65	172.64	47.54
Calcium(ppm)	40.00	2.00	41.40	11.40
Magnesium (ppm)	18.30	0.40	16.80	4.63
Alkalinity (mg/l as $CaCO_3$)	124.92	3.34	237.38	99.84
Bicarbonate(mg/l as $CaCO_3$)	152.40	4.07	289.60	121.80
DO (ppm)	6.10	2.90	9.00	4.00
Fluride(ppm)	0.05	0.00	0.18	0.00
Iron (ppm)	9.60	0.00	5.89	0.00
Phosphate(ppm)	8.05	0.00	1.89	0.00
Nitrate (ppm)	9.50	0.00	4.58	0.00
Sulphate (ppm)	8.92	0.00	25.00	0.00

Table 3.2 (a) Physico chemical characteristics of Surface water (pre monsoon)

sample sites	pH	EC (µs)	TDS (ppm)	Turbidity (NTU)	Na^{2+} (ppm)	K^{2+} (ppm)	Cl^{-} (mg/L)	TH (mg/L) as $CaCO_3$	Ca^{2+} ppm	Mg^{2+} ppm	Alkalinity (mg/L) as $CaCO_3$	HCO_3^{-} (mg/L) as $CaCO_3$	DO mg/l	F^{-} ppm	Fe^{2+} ppm	PO_4^{3-} (ppm)	$N0_3^{-}$ (ppm)	SO_4^{2-} (ppm)
S1	5.10	585.69	380.70	17.00	45.90	2.80	168.50	128.81	40.00	7.00	93.03	113.50	4.04	0.00	0.87	6.40	5.01	3.00
S2	6.14	432.46	281.10	18.90	30.80	5.60	107.00	113.06	23.00	13.50	80.90	98.70	6.10	0.01	0.07	0.00	3.00	2.50
S3	4.80	460.20	299.13	16.00	75.60	11.70	138.09	63.52	18.00	4.50	41.31	50.40	3.00	0.00	1.08	3.47	1.04	0.84
S4	5.50	506.37	329.14	4.25	56.90	23.10	196.40	36.85	9.80	3.00	31.89	38.90	4.80	0.05	9.60	0.96	7.01	1.04
S5	6.00	354.46	230.40	5.00	21.00	9.00	98.04	72.31	17.40	7.00	58.66	71.56	5.04	0.02	2.00	7.02	0.00	6.40
S6	5.90	263.29	171.14	26.00	19.30	4.08	114.08	22.57	5.90	1.90	15.49	18.90	5.50	0.00	0.94	1.75	5.08	6.98
S7	6.37	329.55	214.21	32.00	9.60	1.21	124.90	62.56	13.50	7.00	47.54	58.00	4.90	0.00	0.73	0.58	6.00	0.00
S8	5.09	408.74	265.68	18.00	21.50	16.80	142.50	60.79	17.60	4.08	51.80	63.20	3.80	0.00	0.00	6.50	9.50	0.00
S9	5.20	341.75	222.14	23.90	41.50	20.30	111.54	35.20	9.80	2.60	29.84	36.40	4.90	0.00	0.00	0.00	1.40	0.00
S10	6.00	330.73	214.97	13.80	13.40	5.07	118.50	55.91	14.30	4.90	47.87	58.40	5.01	0.00	7.20	0.72	6.04	0.40
S11	7.90	356.07	231.45	24.00	25.70	1.01	103.24	77.54	19.00	7.30	61.64	75.20	4.00	0.00	0.00	0.97	8.07	0.01
S12	5.00	416.87	270.96	18.50	31.00	3.90	85.74	115.42	25.10	12.80	84.84	103.50	4.03	0.00	4.07	4.08	3.68	8.92
S13	6.07	492.74	320.28	9.58	48.30	0.94	177.91	69.69	18.00	6.00	53.36	65.10	4.70	0.00	6.00	1.71	0.00	4.03
S14	4.60	435.65	283.17	31.00	52.96	15.60	154.30	43.99	12.00	3.40	35.48	43.28	5.80	0.00	1.07	8.05	6.90	1.63
S15	6.00	503.85	327.50	18.60	46.40	17.00	168.50	96.94	21.00	10.80	52.30	63.80	4.62	0.00	3.88	0.95	3.06	0.00
S16	8.00	440.45	286.29	8.50	62.40	12.90	147.00	51.15	11.90	5.20	38.36	46.80	3.52	0.01	2.40	0.00	1.01	0.09

Table 3.2 (b) Physico chemical characteristics of Surface water (pre monsoon)

sample sites	pH	EC (µs)	TDS (ppm)	Turbidity (NTU)	Na^{2+} (ppm)	K^{2+} (ppm)	Cl^{-} (mg/L)	TH (mg/L) as $CaCo_3$	Ca^{2+} ppm	Mg^{2+} ppm	Alkalinity (mg/L) as $CaCO_3$	HCO_3^{-} (mg/L) as $CaCO_3$	DO mg/l	F^{-} ppm	Fe^{2+} ppm	PO_4^{3-} (ppm)	$N0_3^{-}$ (ppm)	SO_4^{2-} (ppm)
S17	7.10	376.46	244.70	24.80	30.00	2.40	113.50	149.91	30.50	17.90	41.31	50.40	5.30	0.00	1.01	0.86	2.00	0.00
S18	5.00	452.77	294.30	30.50	35.70	3.00	108.10	105.62	22.00	12.30	89.84	109.60	2.90	0.00	5.90	1.07	0.91	3.60
S19	4.71	281.54	183.00	24.00	55.00	6.80	90.50	68.75	16.80	6.50	6.07	7.40	4.08	0.00	0.00	0.08	0.58	0.00
S20	4.90	318.14	206.79	19.60	42.90	7.20	107.60	43.29	14.70	1.59	26.89	32.80	3.70	0.00	0.00	0.00	0.79	0.00
S21	5.70	403.92	262.55	18.00	39.80	6.00	98.50	106.25	26.40	9.78	65.57	80.00	4.60	0.01	0.00	0.00	1.00	2.07
S22	4.40	278.31	180.90	21.00	28.10	19.50	103.50	22.10	6.70	1.30	17.87	21.80	5.00	0.01	4.60	2.04	6.40	0.00
S23	5.30	484.77	315.10	14.00	40.17	18.00	124.20	106.15	23.20	11.70	78.71	96.03	4.62	0.00	3.90	5.07	1.04	1.80
S24	6.00	314.31	204.30	36.00	34.00	4.80	136.40	21.70	7.00	1.02	16.39	20.00	4.60	0.00	1.01	0.00	1.30	1.08
S25	5.70	499.18	324.47	13.50	61.01	28.70	157.00	57.59	18.00	3.06	45.90	56.00	5.70	0.00	0.75	3.04	0.96	0.70
S26	5.01	483.56	314.31	27.00	30.00	3.70	198.10	62.67	15.70	5.69	50.07	61.08	5.40	0.00	0.01	1.40	1.01	0.04
S27	5.80	350.74	227.98	20.00	22.40	11.00	107.80	62.49	19.40	3.40	51.70	63.08	5.02	0.00	1.84	0.00	1.04	0.90
S28	6.00	310.56	201.87	15.80	36.20	6.60	89.50	57.79	16.40	4.08	40.23	49.08	5.90	0.00	0.00	0.00	0.00	0.01
S29	4.00	233.80	151.97	18.90	34.00	11.00	100.50	6.65	2.00	0.40	3.34	4.07	5.70	0.00	2.00	7.01	2.07	0.00
S30	5.50	320.92	208.60	30.40	47.30	22.90	90.40	35.76	12.00	1.40	28.36	34.60	4.70	0.00	6.38	4.90	3.90	0.00
S31	5.30	452.46	294.10	29.40	60.00	36.00	121.30	54.99	16.40	3.40	45.57	55.60	5.09	0.00	3.40	0.05	1.80	1.40
S32	5.26	633.85	412.00	41.60	39.00	4.60	165.20	156.56	32.50	18.30	124.92	152.40	5.10	0.00	7.04	0.00	0.98	0.00

Table 3.3 (a) Physico chemical characteristics of Surface water (Post monsoon)

Sample sites	pH	EC (µs)	TDS (ppm)	Turbidity (NTU)	Na^+ (ppm)	K^+ (ppm)	Cl^- (mg/L)	TH (mg/L) as $CaCO_3$	Ca^{2+} ppm	Mg^{2+} ppm	Alkalinity (mg/L) as $CaCO_3$	HCO_3^- (mg/L) as $CaCO_3$	DO mg/l	F^- ppm	Fe^{2+} ppm	PO_4^{3-} (ppm)	$N0_3^-$ (ppm)	SO_4^{2-} (ppm)
S1	6.41	503.79	327.46	4.10	3.70	12.70	141.80	90.07	21.34	8.92	113.93	139.00	6.01	0.09	0.90	0.08	0.43	0.00
S2	6.84	492.15	319.90	14.50	5.10	41.00	70.90	115.09	27.60	11.20	134.51	164.10	7.13	0.00	0.89	0.20	0.32	0.00
S3	6.30	489.04	317.88	5.40	4.00	16.50	70.90	125.10	30.00	12.17	151.07	184.30	9.00	0.02	3.90	0.08	0.20	0.00
S4	6.45	383.79	249.46	8.50	3.90	15.00	70.90	72.56	17.40	7.06	105.41	128.60	8.02	0.01	5.70	1.89	0.27	6.60
S5	6.91	696.54	452.75	23.70	4.20	16.20	70.90	172.64	41.40	16.80	232.79	284.00	6.14	0.00	0.65	0.95	5.62	19.25
S6	6.55	644.17	418.71	7.70	6.70	30.80	70.90	150.12	36.00	14.61	193.85	236.50	4.00	0.02	1.30	0.00	1.29	23.20
S7	6.65	469.69	305.30	33.80	7.80	39.70	70.90	57.55	13.80	5.60	116.80	142.50	7.90	0.00	2.56	1.80	1.20	25.00
S8	5.95	406.99	264.54	4.10	5.70	8.90	70.90	117.59	28.20	11.44	111.89	136.50	6.17	0.00	1.56	0.96	1.36	2.90
S9	6.00	464.69	302.05	5.70	6.30	25.60	70.90	77.56	18.60	7.55	136.48	166.50	6.84	0.00	1.00	0.66	0.98	6.60
S10	6.99	461.83	300.19	34.70	4.10	6.80	70.90	80.06	19.20	7.79	138.69	169.20	6.02	0.00	0.90	0.10	4.58	22.20
S11	6.20	378.40	245.96	5.50	2.40	13.90	70.90	72.56	17.40	7.06	106.15	129.50	6.56	0.00	0.01	0.32	0.51	4.80
S12	6.80	496.07	322.44	8.20	2.50	5.70	70.90	117.59	28.20	11.44	165.16	201.50	6.45	0.00	0.36	0.03	0.31	2.20
S13	6.50	820.40	533.26	42.93	15.10	113.70	70.90	112.59	27.00	10.96	237.38	289.60	6.25	0.01	0.70	0.93	0.78	6.00
S14	4.07	570.38	370.75	7.20	3.90	35.90	106.35	97.58	23.40	9.50	153.28	187.00	7.03	0.00	1.89	0.01	1.60	4.70
S15	5.96	601.14	390.74	6.80	3.00	21.00	141.80	100.08	24.00	9.74	146.72	179.00	6.18	0.00	1.56	0.85	0.22	12.20
S16	6.45	638.18	414.82	6.20	5.20	25.60	141.80	127.60	30.60	12.42	160.66	196.00	7.00	0.00	2.90	0.70	0.00	3.20

Table 3.3 (b) Physico chemical characteristics of Surface water (Post monsoon)

Sample sites	pH	EC (µs)	TDS (ppm)	Turbidity (NTU)	Na^+ (ppm)	K^+ (ppm)	Cl^- (mg/L)	TH (mg/L) as $CaCO_3$	Ca^{2+} ppm	Mg^{2+} ppm	Alkalinity (mg/L) as $CaCO_3$	HCO_3^- (mg/L) as $CaCO_3$	DO mg/l	F^- ppm	Fe^{2+} ppm	PO_43^- (ppm)	$N0_3^-$ (ppm)	SO_4^{2-} (ppm)
S17	6.15	413.75	268.94	6.00	3.70	25.80	70.90	70.06	16.80	6.82	111.49	136.02	6.90	0.00	1.89	0.04	0.61	8.90
S18	5.79	647.73	421.02	53.90	4.90	10.50	177.25	125.10	30.00	12.17	151.64	185.00	5.89	0.09	0.98	0.59	0.66	1.20
S19	6.64	691.82	449.68	31.00	4.50	135.20	106.35	117.59	28.20	11.44	134.34	163.90	6.50	0.12	2.80	0.40	2.54	0.09
S20	5.00	422.00	274.30	28.00	3.50	5.80	70.90	85.07	20.40	8.28	135.33	165.10	4.89	0.01	1.00	0.07	0.72	0.32
S21	7.30	1241.30	806.85	15.00	3.60	330.60	248.15	97.58	23.40	9.50	152.87	186.50	8.00	0.00	0.97	0.42	0.90	5.10
S22	4.07	595.85	387.30	59.00	3.30	29.40	70.90	145.12	34.80	14.12	189.82	231.58	6.15	0.18	0.80	0.97	0.28	3.20
S23	6.00	4637.99	3014.70	12.00	4.30	2568.00	212.70	97.58	23.40	9.50	157.46	192.10	7.02	0.01	1.78	0.03	0.12	4.70
S24	6.23	445.52	289.59	63.10	4.00	18.40	35.45	100.08	24.00	9.74	160.66	196.00	6.30	0.00	3.90	0.45	0.50	2.00
S25	3.88	822.06	534.34	23.00	5.80	116.50	106.35	115.09	27.60	11.20	217.21	265.00	4.90	0.00	2.80	0.99	0.37	1.89
S26	6.00	519.69	337.80	1.50	7.60	68.50	70.90	92.57	22.20	9.01	129.58	158.09	5.80	0.00	3.78	0.66	0.89	1.50
S27	6.45	450.87	293.07	3.00	6.20	14.00	106.35	70.06	16.80	6.82	117.13	142.90	5.60	0.00	5.89	1.01	0.08	0.00
S28	6.20	347.86	226.11	3.60	1.00	15.50	70.90	47.54	11.40	4.63	99.84	121.80	4.90	0.00	2.13	0.62	0.36	0.88
S29	4.26	625.19	406.38	5.30	6.00	66.40	106.35	105.08	25.20	10.23	155.33	189.50	4.78	0.00	1.57	0.99	0.34	2.70
S30	6.00	424.20	275.73	7.00	5.00	17.10	70.90	77.56	18.60	7.55	127.61	155.68	5.74	0.00	4.60	0.50	0.59	0.90
S31	6.01	428.94	278.81	1.00	4.50	30.30	35.45	87.57	21.00	8.52	143.48	175.04	5.68	0.00	2.89	0.88	0.36	4.00
S32	5.50	578.29	375.89	6.00	6.40	58.60	70.90	105.08	25.20	10.23	162.34	198.06	5.23	0.00	3.60	0.00	0.26	6.50

3.5.1.1. pH

The pH of surface water responds to variations in dissolved carbon dioxide concentrations and alkalinity. In the study area pH values ranged from 4 (S29) to 8 (S16). According to BIS, the acceptance limit is within 6.50 to 8.50. However, water remains acidic throughout the year at S22 and S29. The lowest pH observed during pre-monsoon was 4.00 (S29) (Table 3.2 (b)) and post monsoon (Table.3.3 a and b) was 4.07(S 14 and S22) (Table.3.2.a and Fig.3.2 a). In other locations pH values fall between 5.00 and 8.00. The fresh water pH depends on weather pattern, human activity and natural process. The change in the pH was an indicator for chemical pollution (Swenson et al.,1965). The solubility and biological availability of nutrients and heavy metals depend on pH. The natural and anthropogenic factors directly affect the pH of water. The high and low pH of water detrimental to everyday life.

3.5.1.2. Electrical Conductivity

Conductivity reflects the mineral salt content of the water. Electrical Conductivity of the surface water samples varied from 233.80 µs (S29) to 4637.99 µs (S23) (Table 3.2. a,b and 3.3.a and b). During pre-monsoon season, the electrical conductivity was found to be 233.80 µs (S29) to 633.84µs (S32) (Table 3.2(b)). The highest conductivity showed at post monsoon was 4637.99µs (S23) and minimum 347.85 µs (S28) (Table 3.3(b)). The high value of EC at S23 can be attributed to the presence of fertilizer residues in water (Fig.3.2 b). The conductivity of the water was affected by the presence of chloride, nitrate, sulphate, and phosphate or Na, Mg, Ca, Fe and Al (USEPA, 2012). Conductivity in the water body was primarily affected by the geology of the area through which the water flows. The streams that run through the clay soils tends to have higher conductivity because of the presence of materials that ionize when washed into the water (www.therivermile.org).

3.5.1.3. Total dissolved solids (TDS)

Total dissolved solids comprise inorganic salts such as calcium, magnesium, potassium, sodium, bicarbonates, chlorides, sulfates and some small amounts of organic matter that are dissolved in water. The TDS ranged from 151.97ppm (S29) to 3014.70 ppm (S23). During pre-monsoon, TDS was found to be minimum in S29 (151.97 ppm) and maximum S32 (412 ppm). During the post monsoon season, the value reaches a maximum value of 3014.70 ppm (S23) and minimum of 226.11 ppm (S28). According to BIS standards, the acceptance limit is 500 ppm to 2000 ppm (Table 3.2.a and b,3.3.a and b and Fig.3.2. c). The high value of TDS at S23 may be due to the increase of runoff from the fringe areas. The amount of TDS can be used to determine changes in the water at different times of the year and its physiological effects on plants and animals (www.therivermile.org).

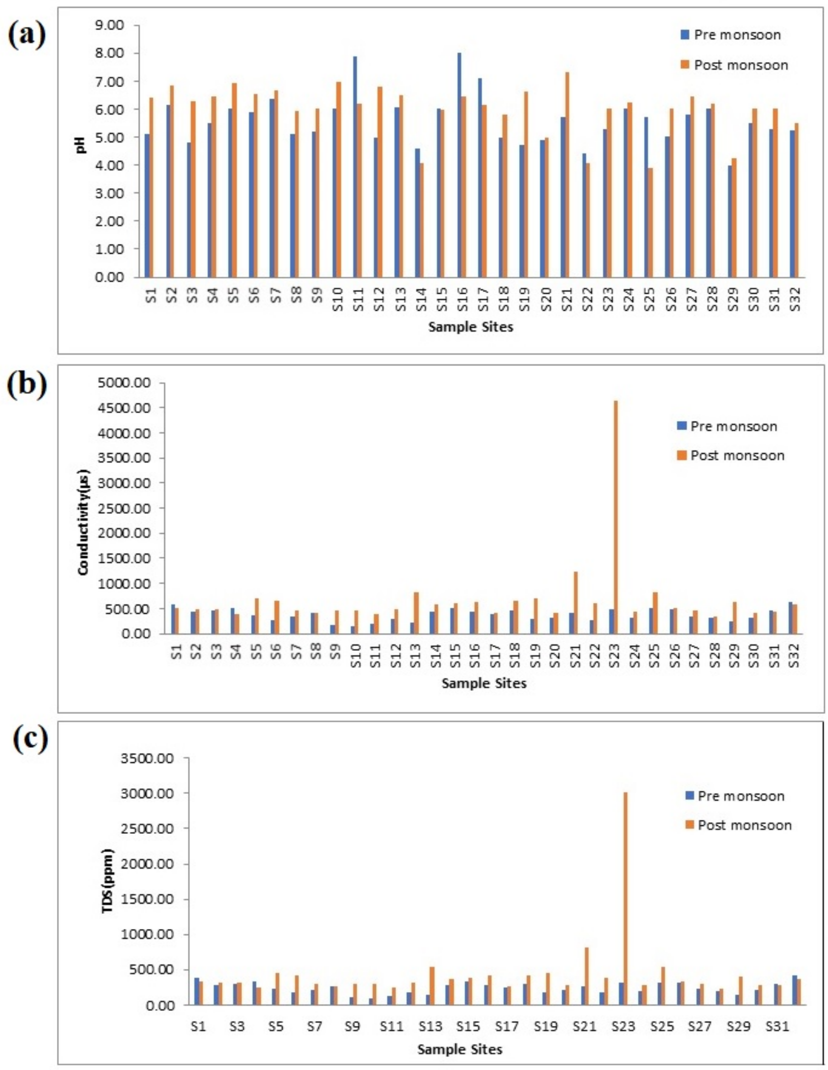


Fig.3.2. Seasonal variation of different parameters of surface water **a)** pH, **b)** conductivity, **c)** TDS

3.5.1.4. Turbidity

Turbidity measures the amount of suspended particles in water. The turbidity was found to range from 1.00 NTU (S31) to 63.10 NTU (S24). During pre-monsoon season turbidity showed a minimum value of 4.25 NTU (S4) and a maximum of 41.60 NTU (S32). During post monsoon season the value of turbidity ranged from 63.10NTU (S24) to 1.00 NTU (S31) (Table 3.2. a, b and 3.3.a, b and Fig.3.3.d). The maximum turbidity was recorded in post monsoon and minimum during pre-monsoon. Higher turbidity values in post monsoon season are mainly due to greater run off or erosion from catchment areas. The highest concentration of particulate matter decreases the light penetration and affect the electrical conductivity, productivity, recreational values and habitat quality. Turbidity increased the rate of sedimentation and siltation that is harmful to aquatic life. The toxic metals and harmful bacteria were concentrated on the surface of the particles and turbidity is considered as one of the important potential water pollution indicators (www.usgs.gov).

3.5.1.5. Sodium

The sodium ion was ubiquitous in water. Most water supplies contain less than 20 mg of sodium per liter, but in some countries, levels can exceed 250 mg/l. Saline intrusion, mineral deposits, seawater spray, sewage effluents, and salt used in road de-icing can all contribute significant quantities of sodium to water. No health-based guideline value is therefore proposed. Sodium concentration in surface water ranges from 9.60 ppm (S7) to 75.60ppm (S3) during pre-monsoon and 1.00 ppm (S28) to 15.10 ppm (S13) during post monsoon season (Table 3.2.a,b and 3.3.a,b and fig.3.3 e). Relatively higher concentration of sodium during pre-monsoon period was a result of dissolution of the soil salts stored by evaporation and anthropogenic activities (Subba Rao, 2002). According to BIS standards the acceptance limit for water samples was 20 ppm. The sodium concentration indicated the intrusion of saline water into the freshwater wetlands.

3.5.1.6. Potassium

Potassium is an essential element in humans and also found in drinking water at levels that could be a concern for healthy humans. It occurred widely in the environment, including all-natural waters (WHO, 2009). The amount of K content is increased widely due to the unscientific use of fertilizers. Potassium play an important role in plant growth and sometimes limiting factor. K concentration in surface water ranges from 0.94 ppm (S13) to 36.00 ppm (S31) during the pre-monsoon and 5.70 ppm (S12) to 2568.00 ppm (S23) during post monsoon season. (Table 3.2.a,b and 3.3.a,b and fig.3.3.f). Potassium could be used as an indicator for potential sources of contamination, by the unscientific agricultural land use management and discharge of wastewater (Hongmei et al., 2010) and also the saline intrusion.

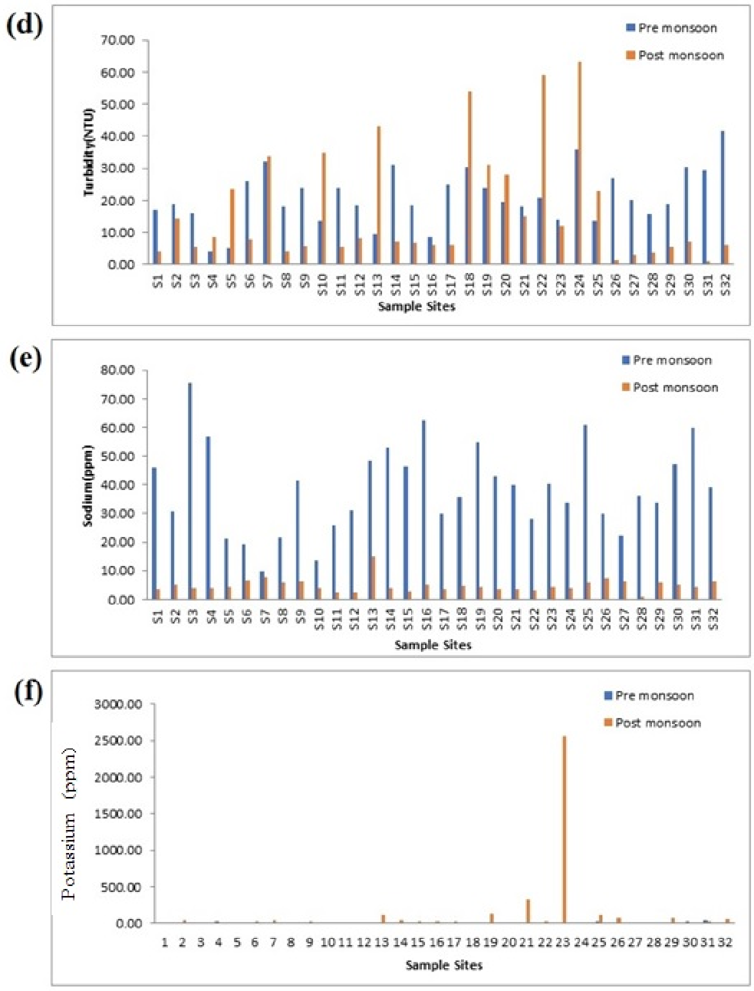


Fig.3.3. Seasonal variation of different parameters of surface water **d)** Turbidity, **e)** sodium and **f)** potassium

3.5.1.7. Chloride

Chloride existed in natural waters, the concentration varying widely and reaching a maximum in the sea water up to 35,000mg/cl. Chloride did not pose a health hazard to humans and the principal consideration was in relation to palatability. At levels 250 mg/l water became salty and increasingly objectionable as the concentration rises further. High chloride levels may render fresh water unsuitable for agricultural irrigation. The chloride value ranges between 85.74mg/l (S12) and 196.40 mg/l (S4) during pre-monsoon season. During post monsoon, the chloride content ranged from 248.15 mg/l (S21) to 35.45 mg/l (S31 and S24), (Table 3.2.a, b and 3.3.a, b and Fig.3.4.h). The high content of chloride in S18, S21 and S23 was due to leaching of lime and salt mixture applied to coconut plantation nearby area.

3.5.1.8. Total hardness

Hard water consisted of high concentration of calcium and magnesium ions. Hardness formed by several other dissolved metals such as aluminum, barium, strontium, iron, zinc, and manganese. These were significant etiological factors around the globe causing many diseases such as cardiovascular problems, diabetes, reproductive failure, neural diseases, and renal dysfunction. Hard water had no known adverse health effect (WHO,2011). Hardness is most commonly expressed as milligrams of calcium carbonate equivalent per liter. Water containing calcium carbonate at concentrations below 60 mg/l is generally considered as soft; 60–120 mg/l, moderately hard; 120–180 mg/l, hard; and more than 180 mg/l, very hard (McGowan, 2000). In the surface water of the study area, total hardness vary from 6.65 mg/l (S29) to 156.56 mg/l (S32) during pre-monsoon season, 172.64mg/l (S5) to 47.54 mg/l (S28) during post monsoon season (Table 3.2.a,b and 3.3.a,b and Fig.3.4 g).

3.5.1.9. Calcium

During pre-monsoon calcium varied from 2.00 ppm (S29) to 40.00 ppm (S1) and 41.40 ppm (S6) to 11.40 ppm (S28) during post monsoon season(Table 3.2.a,b and 3.3.a,b and Fig.3.4 i).Calcium occurs abundant in nature in rocks, bones, shells etc. The water rich in calcium are very hard and are very palatable in nature. The ratio of calcium and magnesium in water is also a critical factor indicating the hardness and in the causation of several hard water health problems. The most common sources of hardness are limestone and dolomite. Since, hardness enters the water in this manner groundwater generally has a greater hardness than surface water (Prepas et al., 2001). Calcium and magnesium ions in the feldspar in granitic rocks can contribute these ions to ground water.

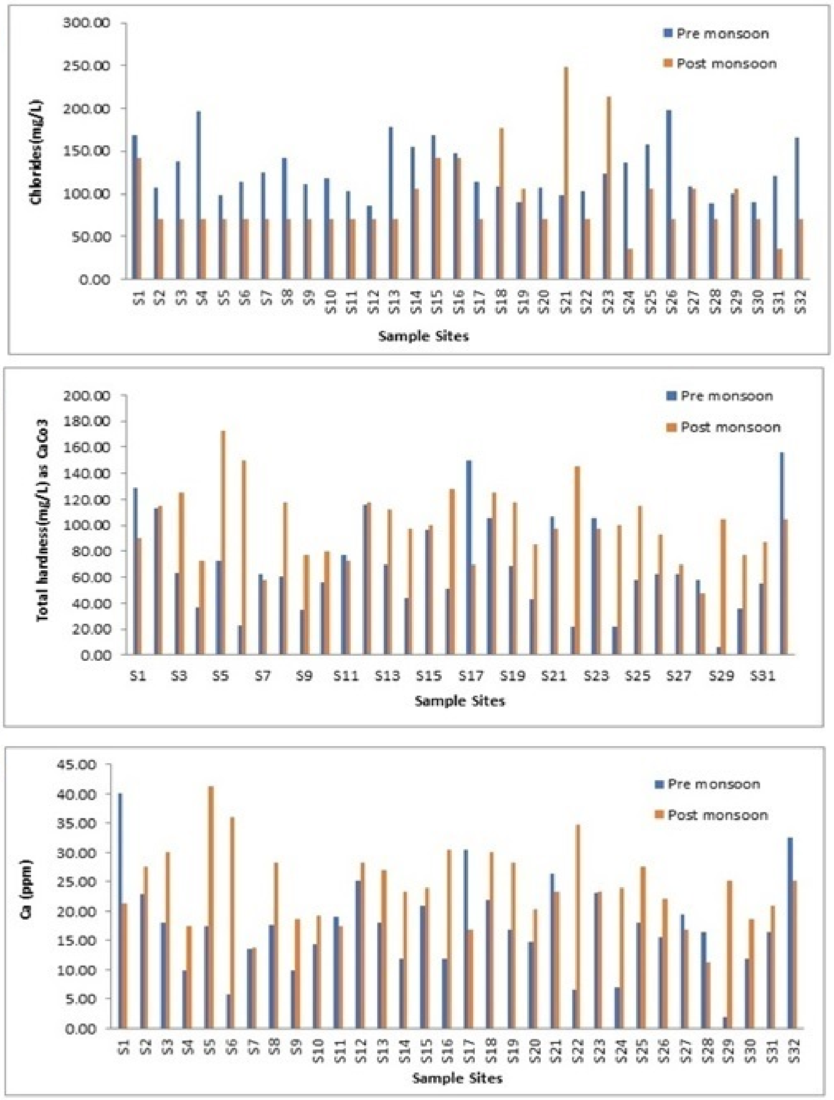


Fig.3.4 Seasonal variation of different parameters of surface water **g)** total hardness, **h)** chloride and **i)** calcium

3.5.1.10. Magnesium

Magnesium also associated with total hardness and Ca in drinking water and also affects the value of water for public and industrial uses. Magnesium value vary from 18.30 ppm (S32) to 0.40 ppm (S29) during pre-monsoon season. The post monsoon season showed a maximum value of Magnesium 16.80 ppm (S5) and a minimum of 4.63 ppm (S28) (Table 3.2.a,b and 3.3.a,b and Fig.3.5 j).

3.5.1.11. Alkalinity

The alkalinity of natural water indicates the presence of bicarbonates formed in the reactions in the soils through which the water percolates. Alkalinity is a chemical measurement of water's ability to neutralize acids or a measure of water's buffering capacity or its ability to resist changes in pH upon the addition of acids or bases. According to BIS standards, the acceptable limit of alkalinity is within 200 - 600 mg/l. The alkalinity of surface water ranges from 3.34 mg/l (S29) to 124.92 mg/l (S32) during pre-monsoon period and 99.84 mg/l (S28) to 237.38 mg/l (S13) during post monsoon (Table 3.2.a, b and 3.3.a, b and Fig.3.5 k).

3.5.1.12. Bicarbonates

Bicarbonates represent the major form of alkalinity in natural waters and its source being the partitioning of CO2 from the atmosphere and the weathering of carbonate minerals in rocks and soil. Other salts of weak acids, such as borate, silicates, ammonia, phosphates, and organic bases from natural organic matter, may be present in small amounts. During pre-monsoon, the bicarbonates ranged between 4.07 mg/l (S29) to 152.40 mg/l (S32). And during post monsoon season the value vary from 289.60 mg/l (S13) to 121.80 mg/l (S28) (Table 3.2.a, b and 3.3.a, b and Fig.3.5 l).

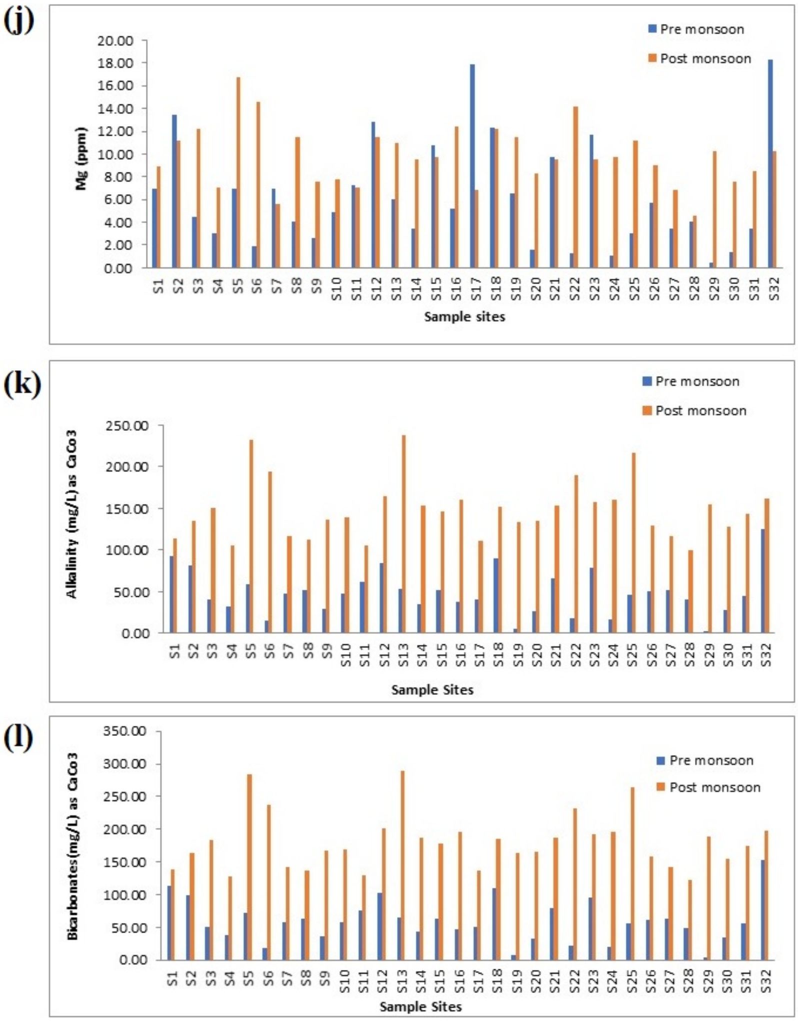


Fig.3.5. Seasonal variation of different parameters of surface water **j)** magnesium, **k)** alkalinity and **l)** bicarbonates

3.5.1.13. Dissolved oxygen

Dissolved oxygen was the amount of gaseous oxygen dissolved in an aqueous solution. Oxygen got into water by diffusion from the surrounding air, by aeration and byproduct of photosynthesis. When the total dissolved solids concentration in water exceed above 13-14 mg/l, it can be harmful to aquatic life (table 3.5). Fish in waters containing excessive dissolved gases may suffer from "gas bubble disease". Adequate dissolved oxygen was necessary for good water quality (Manoj and Avinash, 2012). The DO content in pre monsoon season varied from 2.90 ppm (S3) to 6.10 ppm (S2). During post monsoon the DO content was maximum with 9.00 ppm (S3) and minimum of 4.00 ppm (S6) (Table 3.2.a, b and 3.3.a, b and Fig.3.6 m). The DO content at sites S3 and S18 goes less than 3 during pre-monsoon period and it was not favorable for the survival of fish (USEPA, 2006).

Table 3.5. Significance of DO levels

Effect on living organisms	DO (mg)
Support plant and animal growth	< 5
Stress to living organisms	3-5
Not support all living organisms especially fish	<3
Death of any organisms	<0.5

Source: Volunteer estuary monitoring manual, USEPA 2006.

3.5.1.14. Fluoride

Fluorine was physiologically very active and widespread in nature. Fluoride salts were in abundance in the earth's crust. Fluoride was probably the first inorganic ion which underlines its toxic effect and its contamination in drinking water recognized as a global problem. Fluoride concentration in drinking water above 0.60 ppm leads to the reduction in tooth decay in growing children and up to 1.00 ppm was beneficial for the human body. The maximum value of fluoride was found to be 0.05 ppm (S4) in pre monsoon season and during post monsoon the fluoride content was 0.18 ppm (S22) (Table 3.2.a, b and 3.3.a, b and Fig3.6 n).

3.5.1.15. Iron

Iron was most commonly found in nature in the form of its oxides. Aeration of iron-containing layers in the soil can affect the quality of both groundwater and surface water if the groundwater table is lowered or nitrate leaching takes place. Dissolution of iron can occur as a result of oxidation and decrease in pH. Laundry and sanitary ware will stain at iron concentrations above 0.30 ppm (WHO, 2009). During pre monsoon iron content was maximum with 9.60 ppm (S4) and in post monsoon, the maximum value of 5.89 ppm (S27) (Table 3.2. a, b and 3.3. a,b and Fig.3.6 o).The surface water at the location S4 was stagnant and enriched with algal growth .This anaerobic environment favoured the growth of iron reducing bacteria(Sawyer et al.,2017).

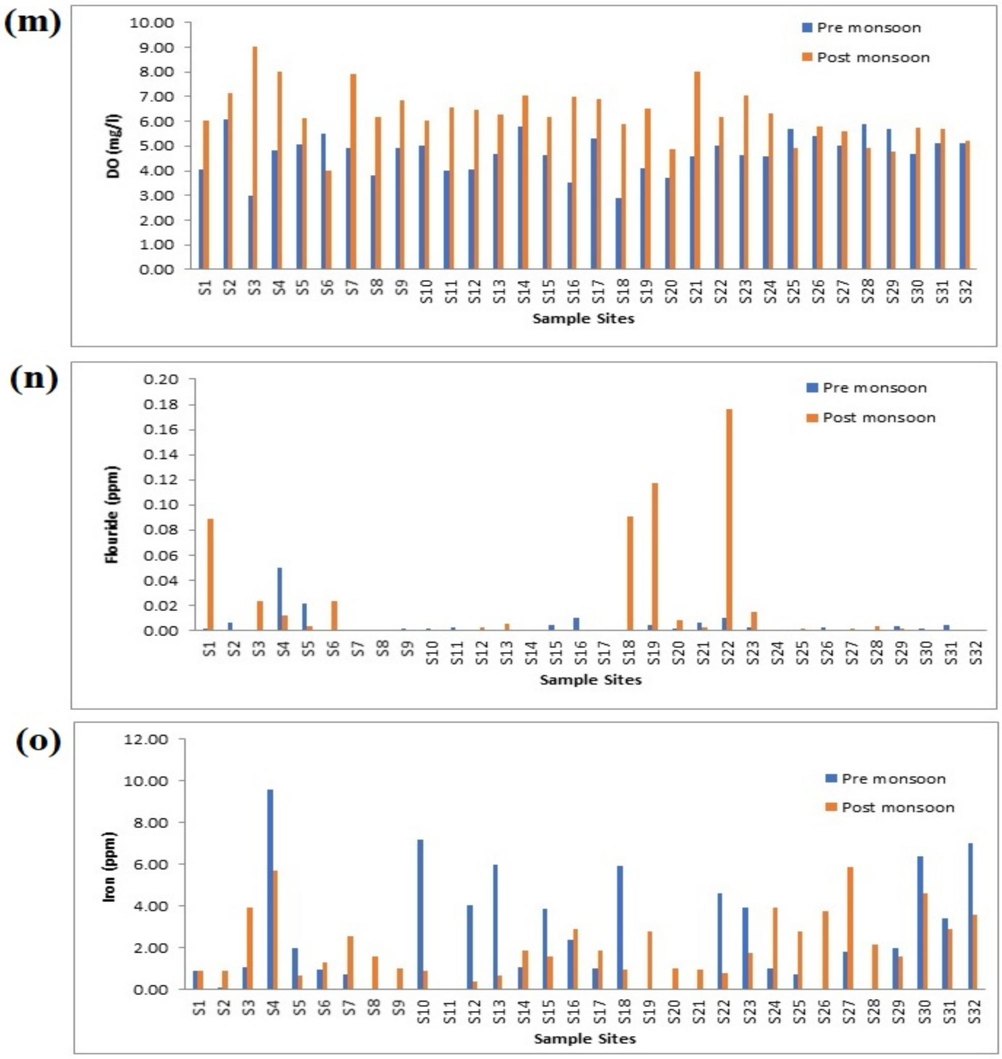


Fig.3.6. Seasonal variation of different parameters of surface water **m)** DO, **n)** fluoride **o)**iron

3.5.1.16. Phosphate

Phosphorus was a common constituent of agricultural fertilizers, manure, and organic wastes in sewage and industrial effluent. It was an essential element for plant life however it could speed up eutrophication (a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients) of rivers and lakes. Phosphorus was one of the key elements necessary for the growth of plants and animals and in lake ecosystems it tends to be the growth-limiting nutrient. Phosphates are not toxic to people or animals unless they were present in very high levels. But as the phosphate loading continues and there is a build-up of phosphate in the lake or surface water ecosystem, the aging process of lake or surface water ecosystem will be accelerated. Phosphate occurred in runoff from fields treated with phosphate-containing fertilizers, runoff from livestock and poultry-feeding operations, fertilized lawns and golf-courses, pet wastes, food-processing wastes, wastewater from the pulp and paper industry, and partially treated or untreated sewage (WHO,2009). The maximum value of phosphate during pre-monsoon season was 8.05 ppm (S14) and there were locations that lack phosphates. During post monsoon the maximum value recorded was 1.89 ppm (S4) and in some locations the value falls beyond the detectable limit (Table 3.2.a, b and 3.3.a, b and Fig.3.7 p).

3.5.1.17. Nitrate

The sources of nitrate contamination of water occurred from various sources such as leaching from geological formations, precipitation, human and animal wastes, cultivation practices like fallowing and the use of fertilizers. The climatic factors like precipitation, temperature and evapotranspiration, the characteristics of soils and nitrate content were also affecting the nitrate leaching. The cropping pattern, irrigation pattern and the fertilizer application also contribute the nitrogen leachate to the water bodies. During pre-monsoon the nitrate content attained a maximum value of 9.50 ppm (S8) where as in the post moon soon season the value hiked up to 4.58 ppm (S5) (Table 3.2.a,b and 3.3.a,b and Fig.3.7 q).

3.5.1.18. Sulphate

Sulphates occurred naturally in numerous minerals, including barite ($BaSO_4$), epsomite ($MgSO_4 \cdot 7H_2O$) and gypsum ($CaSO_4 \cdot 2H_2O$). These minerals are found dissolved in many drinking-waters. The existing data do not identify a level of sulfate in drinking-water that was likely to cause adverse human health effects and complaints arising from a noticeable taste as concentrations in water increase above 500 mg/l (WHO, 2009). During pre monsoon season the sulphate content reached a maximum value of 8.92 ppm (S12) and in post monsoon season the value reached up to 25 ppm (S7) (Table 3.2.a,b and 3.3.a,b and Fig.3.7 r).

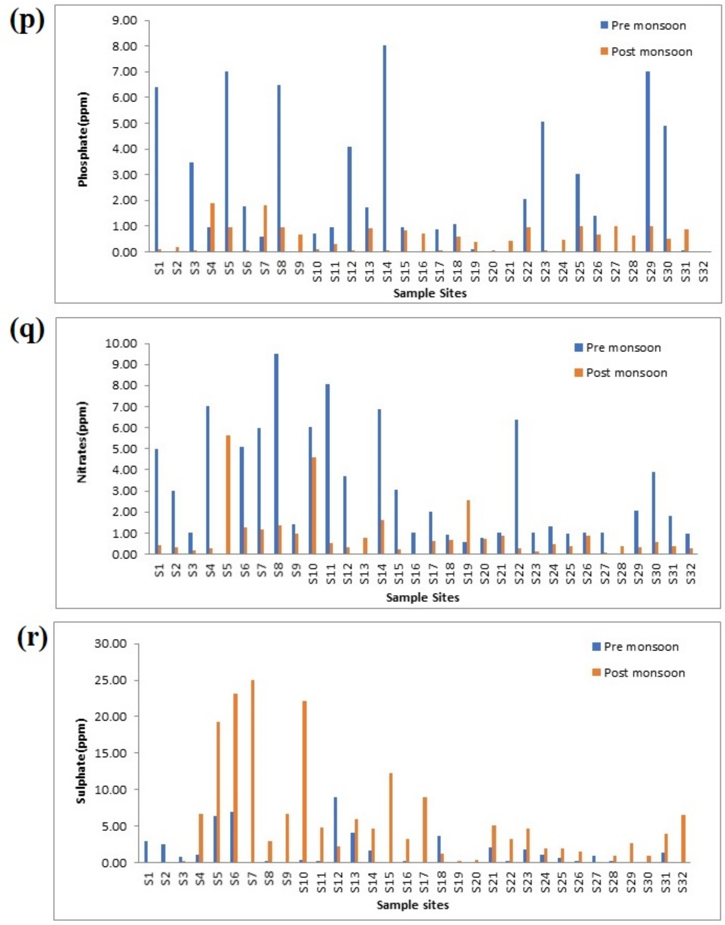


Fig.3.7. Seasonal variation of different parameters of surface water **p)** phosphate, **q)** nitrate, **r)** sulphate

3.5.2. Comparative evaluation of hydro chemical parameters.

The various Physico- chemical parameters of the surface water of wetland is compared with BIS 2012 and are given in the Table 3.6. It has been found that all the water quality attributes of the surface water listed below fall well within the permissible limit as suggested by BIS 2012. However, pH, Turbidity and Iron values exceeds the limit at all the time. Based on the drinking water standards, the surface water could not be used as drinking water.

Table 3.6 Comparative evaluation of hydro chemical parameters of wetland surface water quality with quality standards.

Sl No.	Parameters	Acceptable limit	Permissible Limit	Average values of water samples
1	pH	6.5 – 7.5	No relaxation	5.82
2	EC (µs)	100	2000	337.78
3	TDS(ppm)	500	2000	219.55
4	Turbidity(NTU)	1	5	18.86
5	Sodium (ppm)	20	500	21.81
6	Potassium (ppm)	-	-	66.92
7	Chloride (mg/l)	250	1000	110.65
8	TH (mg/l as $CaCO_3$)	200	600	85.15
9	Calcium (ppm)	75	200	20.77
10	Magnesium (ppm)	30	100	8.07
11	Alkalinity (mg/l as $CaCO_3$)	200	600	98.56
12	Bicarbonate (mg/l as $CaCO_3$)	-	-	120.25
13	DO (ppm)	-	-	5.50
14	Fluoride (ppm)	1.0	1.5	0.01
15	Iron (ppm)	0.3	No relaxation	2.29
16	Phosphate (ppm)	-	-	1.36
17	Nitrate (ppm)	45	No relaxation	8.99
18	Sulphate(ppm)	200	400	3.60

3.5.3. Heavy metals

The heavy metal contamination mainly occurred from the effluent discharges, distribution pipes or geological functions. The mercury, cadmium, lead, nickel etc were analyzed by ICP/MS. Heavy metals are considered as environmental monitoring factors, and induce toxicity in humans, animals, and plants (An *et al.*, 2010). Heavy metals are formed from chemical leaching of bedrock, runoff from banks, water drainage and discharge of urban industrial and rural agricultural wastewaters, (Xiao *et al.*, 2013). The heavy metal concentration in water is below detectable limit.

3.5.4. Irrigational quality status of surface water

The classification of surface water in the study area was based on the chemical composition of water sample. Hydro chemical facies could be classified on the basis of dominant ions using the Piper's Trilinear Diagram. The other parameters used for the characterization of the surface water are Salinity Hazard Ratio, Percent Sodium, Wilcox diagram , Sodium Absorption Ratio, U.S. Salinity Laboratory Diagram, Permeability Index, Magnesium Hazard and Kelly's Ratio (table 3.7 and 3.8).

Table 3.7. Irrigation parameter of the surface water sample during Pre monsoon.

	% Na	SAR	PI	MH	KELLI		% Na	SAR	PI	MH	KELLI
S1	44.54	1.76	73.53	22.29	0.78	**S17**	31.34	1.07	51.51	49.03	0.44
S2	39.65	1.26	72.62	49.04	0.59	**S18**	43.59	1.51	79.02	47.82	0.74
S3	73.87	4.13	92.10	29.07	2.59	**S19**	65.14	2.89	72.78	38.81	1.74
S4	80.64	4.08	101.95	33.42	3.36	**S20**	70.31	2.84	95.16	15.06	2.16
S5	44.19	1.07	84.70	39.74	0.63	**S21**	47.03	1.68	74.65	37.78	0.82
S6	67.67	1.77	108.21	34.55	1.86	**S22**	79.58	2.60	109.39	24.13	2.77
S7	26.42	0.53	83.57	45.95	0.33	**S23**	51.02	1.70	77.64	45.26	0.82
S8	52.91	1.20	90.85	27.54	0.77	**S24**	78.69	3.17	107.27	19.28	3.41
S9	76.77	3.04	102.77	30.31	2.57	**S25**	74.64	3.50	94.93	21.79	2.30
S10	38.95	0.78	91.87	35.97	0.52	**S26**	52.78	1.65	90.19	37.27	1.04
S11	42.47	1.27	83.57	38.64	0.72	**S27**	50.13	1.23	89.57	22.32	0.78
S12	38.58	1.26	72.57	45.53	0.58	**S28**	60.15	2.07	90.56	28.97	1.36
S13	60.41	2.52	89.73	35.34	1.51	**S29**	92.98	5.74	107.79	24.69	11.13
S14	75.46	3.47	98.86	31.72	2.62	**S30**	78.71	3.44	101.38	16.06	2.88
S15	55.89	2.05	76.91	45.74	1.04	**S31**	76.26	3.52	96.12	25.37	2.37
S16	74.87	3.80	96.11	41.74	2.66	**S32**	36.72	1.36	67.96	48.00	0.54

Table 3.8. Irrigation parameter of the surface water sample during Post monsoon.

	% Na	SAR	PI	MH	KELLI		SAR	% Na	PI	MH	KELLI
S1	21.26	2.36	85.26	40.67	0.09	**S17**	18.36	36.98	106.06	39.95	0.12
S2	35.60	3.36	73.89	39.95	0.10	**S18**	19.36	16.16	72.10	39.95	0.09
S3	19.26	4.36	71.57	39.95	0.07	**S19**	20.36	60.88	72.13	39.95	0.08
S4	27.63	5.36	100.20	39.95	0.12	**S20**	21.36	15.03	97.11	39.95	0.09
S5	14.76	6.36	64.48	39.95	0.05	**S21**	22.36	81.55	90.51	39.95	0.08
S6	26.47	7.36	68.73	39.95	0.10	**S22**	23.36	23.61	68.79	39.95	0.05
S7	54.10	8.36	125.49	39.95	0.30	**S23**	24.36	97.13	91.86	39.95	0.10
S8	16.84	9.36	67.17	39.95	0.11	**S24**	25.36	24.39	90.53	39.95	0.09
S9	37.49	10.36	105.67	39.95	0.18	**S25**	26.36	58.44	91.62	39.95	0.11
S10	18.05	11.36	103.76	39.95	0.11	**S26**	27.36	52.98	89.05	39.95	0.18
S11	24.09	12.36	100.53	39.95	0.07	**S27**	28.36	30.97	107.90	39.95	0.19
S12	9.78	13.36	78.41	39.95	0.05	**S28**	29.36	31.67	146.73	39.95	0.05
S13	61.32	14.36	97.62	39.95	0.29	**S29**	30.36	48.29	85.77	39.95	0.12
S14	35.83	15.36	90.68	39.95	0.09	**S30**	31.36	29.71	102.77	39.95	0.14
S15	25.04	16.36	86.60	39.95	0.07	**S31**	32.36	35.70	97.19	39.95	0.11
S16	25.69	17.36	72.77	39.95	0.09	**S32**	33.36	45.86	87.53	39.95	0.13

3.5.4.1. Hydrochemistry of surface water using Piper Trilinear diagram

The concentrations of major ionic constituents of surface water samples were plotted in the Piper Trilinear diagram to determine the water type (Piper, 1953). The classification for cation and anion facies, in terms of major-ion percentages and water types, was according to the domain in which they occur on the diagram segments (Back, 1966). In order to gain better insight into the hydro chemical processes operating in the groundwater system of the area, the Piper diagram (Piper, 1953) was used.

Piper (1953) has developed a form of Tri linear diagram, which was an effective tool in segregating analysis data with respect to sources of the dissolved constituents in groundwater, modifications in the character of water as it passes through an area and related geochemical problems. The diagram was useful in presenting graphically a group of analysis on the same plot.

The major parameters which regulate the water quality are HCO_3, Ca^{2+} and Mg^{2+}. All those three ions control the precipitation or solution of carbonate phase. These facts decide whether it was suitable for drinking or not. Being the major constituents in most fresh water, HCO_3 held the key to the level of a number of other ions such as Ca and Mg as well as other ions such as Fe, Mn, Cu, Pb, Zn, and Cd (Subramanian, 2000).

The plot of the chemical data on diamond shaped tri linear diagram reveals that the majority of the water samples fall in the fields of 1,3 and 5 suggesting that the alkaline exceeds alkalies, weak acids exceed strong acids and carbonate hardness (secondary alkalinity) exceeds 50% respectively (Table 3.9). From the data plot, the hydrochemical facies dominated by weak acids exceeds strong acids and alkaline earths exceeds alkalies during pre-monsoon (Fig.3.8) whereas during post monsoon the strong acids exceed weak acids, alkalies exceeds alkaline earths and alkaline earths exceeds alkalies (Fig.3.9). The pre monsoon surface water samples fall into class 2 and 4 indicating alkalies exceeds alkaline earths and strong acids exceeds weak acids. Some samples fall in the class mixed water where having none of the cation- anion pair exceeds 50%. During post monsoon 53.13% fall in the non-carbonate alkali group and 75% in carbonate hardness in pre monsoon. 87% of the samples fall in anionic bicarbonate facies, 46.88% cationic Ca facies. This indicates the presence of secondary hardness in water bodies. During pre-monsoon period, samples fall in noncarbonate alkali class (primary salinity) and in chloride anionic facies. During post monsoon 53.13% of the samples falls in noncarbonate alkali class (primary salinity) and also 75% of the water sample of post monsoon season fallen within the anionic chloride facies. It was attributed to the addition of lime and salt during the ground preparation for paddy cultivation. The effect of addition lime and salt is well reflected in the chemistry of S21 and S23 (Table 3.10).

From the cationic and anionic triangular fields of Piper diagram, it is observed that during pre-monsoon 46.88% of the surface water samples fall in the Ca type, 25% in sodium /potassium type and 28.13% in cation facies, where as in post monsoon season 46.88% fall into sodium/ potassium type, 9% in Ca facies and 43.75% in non-dominant cation facies. It was also found that during pre-monsoon 87.5% fall in bicarbonates and 12.5% in chlorides of anion facies. During post monsoon season, the surface water samples fall into 75% in chlorides and 25% in non-dominant anion facies (Table 3.10).

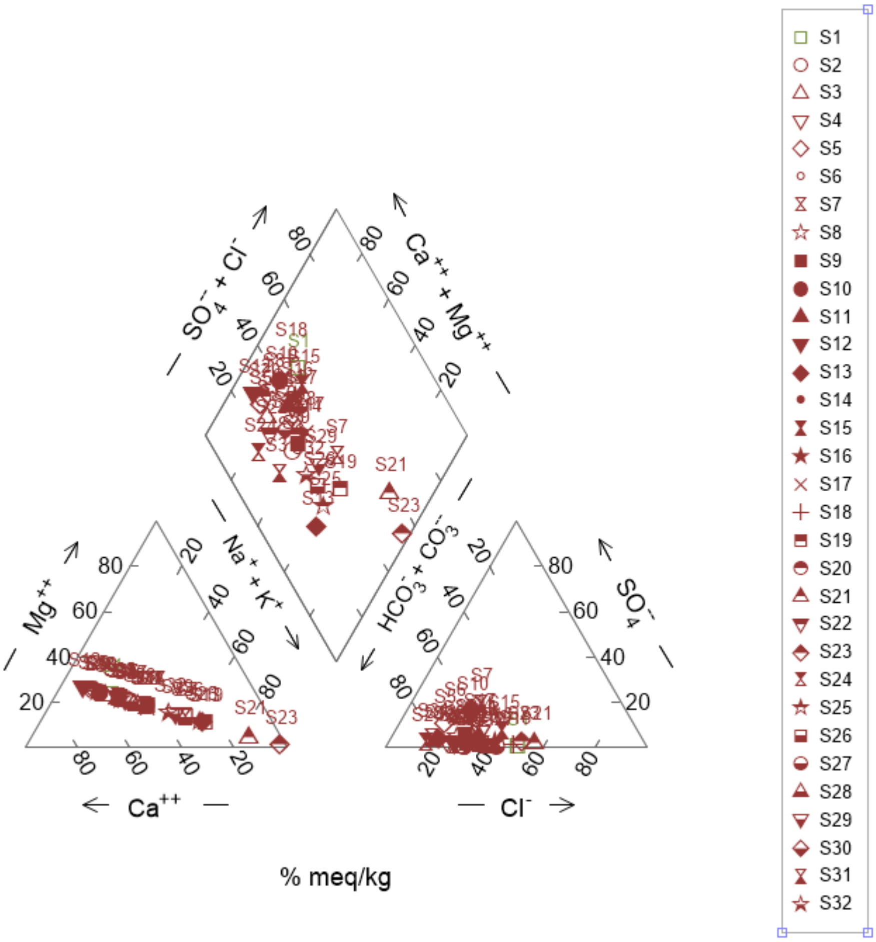


Fig.3.8. Piper plot for Pre monsoon season

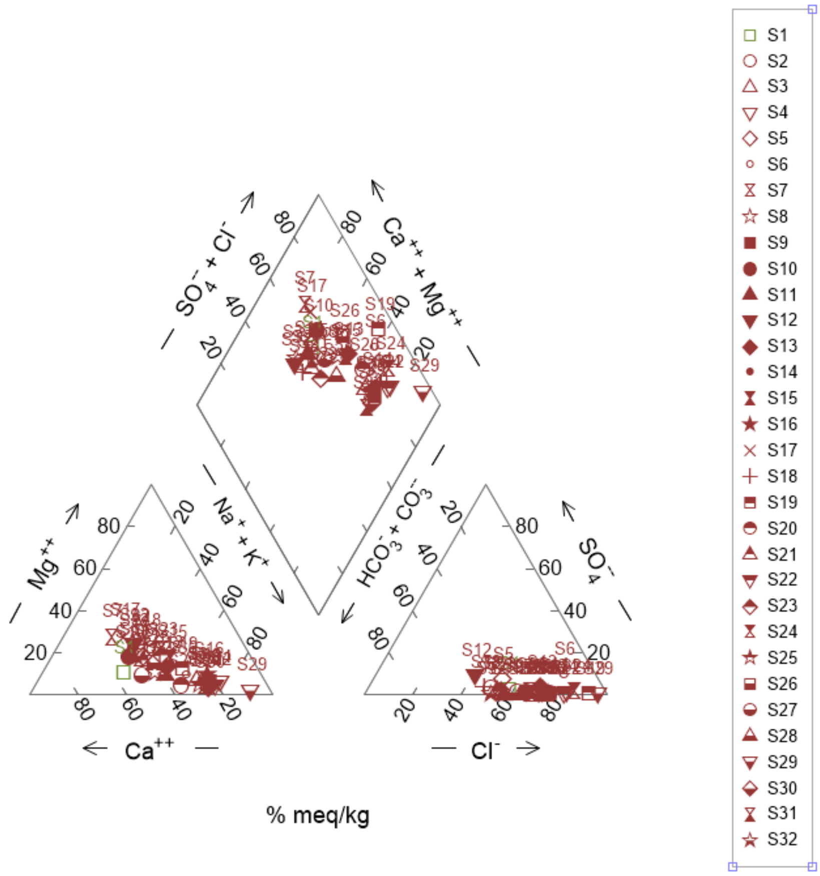


Fig.3.9. Piper plot for Post monsoon season

Table.3.9 Characterization of surface water on the basis of Piper tri linear diagram for the pre-monsoon samples.

Subdivision of the diamond	Characteristics of corresponding subdivisions of diamond shaped fields	Number of samples	
		Pre monsoon	Post monsoon
1	Alkaline earth (Ca+ Mg) exceeds alkalies (Na +K)	24	15
2	Alkalies exceeds alkaline earths	6	17
3	Weak acids (CO_3+HCO_3) exceeds strong acids (SO_4 + Cl)	30	-
4	Strong acids exceeds weak acids	2	32
5	Carbonate hardness (secondary alkalinity) exceeds 50%	24	-
6	Non carbonate hardness (secondary salinity) exceeds 50%	-	-
7	Non carbonate alkali (primary salinity) exceeds 50%	2	17
8	Carbonate alkali (primary alkalinity) exceeds 50%	-	-
9	None of the cation-anion pairs exceeds 50%	6	15

Table 3.10. Geo chemical classification of the surface water

Sl. No	Water type	Sample	
		Pre monsoon	Post monsoon
Cation Facies			
A	Magnesium	-	-
B	Calcium	15	3
C	Sodium or Potassium	8	15
D	No dominant	9	14
Anion Facies			
E	Sulphate	-	-
F	Bicarbonate	28	-
G	Chloride	4	24
H	No dominant	-	8

3.5.4.2. Salinity Hazard Ratio

The electrical conductivity and salinity are the two important parameters which determine the nature of irrigation water. The usage of water with high salt content for irrigation increase the salinity in the soil and also affected the salt intake capacity of the plants through their roots (Janardhanaraju et al., 2009). During pre-monsoon season, 3.13% of the samples fall in excellent category and 96.88 % in good category. During the post monsoon season, 3.13% fall in high salinity category (poor quality water) and 6.25% in medium salinity category and remaining 90.63% in excellent category (Table 3.11). The sample S23 fall in poor/bad quality water in post monsoon and is assigned due to the unscientific agricultural practices.

Table 3.11. Irrigation water quality classification (after Richards, 1954)

Sl. No.	Water class	Electrical conductivity	Number of samples	
			Pre monsoon	Post monsoon
1	Excellent	Up to 250	S30	-
2	Good	250-750	S1 to S29 S31, S32	S1 to S12 S14 to S22 S24, S26 toS32
3	Fair/ Medium	750-2250	-	S13, S25
4	Poor /Bad	>2250	-	S23

3.5.4.3. Percent Sodium

Sodium concentration was important in classification of the irrigation water because sodium react with soil to reduce its permeability. The assessment of Na concentration is very important for the consideration of suitability of irrigation water. In natural water, the percent sodium content was a parameter to evaluate its suitability for agriculture purpose (Wilcox, 1948).

$$\% \, Na = \frac{Na^{+} + K^{+} \times 100}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}}$$

Where, the concentrations are expressed in meq/l.

In pre monsoon season majority of the samples falls under the doubtful category (43.75%). The samples S4, S29 are unsuitable during pre monsoon period (6.13 %). In post monsoon period majority of the samples turn out to be good category (50 %) followed by excellent category (21.87%). 12.50 % of the samples fallen under doubtful and unsuitable category (Table 3.12). The samples S4 and S29 (pre monsoon), S21 and S23 (post monsoon) fall within unsuitable category.

Table 3.12. Surface water quality based on the percentage of sodium

Sl.No	Sodium (%)	Water Class	Seasons	
			Pre monsoon	Post monsoon
1	<20	Excellent	Nil	S3,S5,S8,S10,S12,S18, S20
2	20-40	Good	S2, S7, S10, S12, S17, S32	S1,S2, S4, S6, S9,S11,S14 S15, S16, S17, 22,S24,S27, S28,S30, S31
3	40-60	Permissible	S1, S5, S8, S11, S15, S18, S21, S23,S26, S27	S7, S25, S26, S29, S32
4	60-80	Doubtful	S3, S6, S9, S13, S14, S16, S19, S20, S22, S24, S25, S28, S30, S31	S13,S19
5	>80	Unsuitable	S4, S29	S21,S23

3.5.4.4. Wilcox Diagram.

Wilcox (1948) classified groundwater for irrigation purposes on the basis of the percentage of soluble sodium and electrical conductivity. Eaton (1950) recommended the concentration of residual sodium carbonate for determining the suitability of water for irrigation purposes. According to US Salinity Laboratory method Richards (1954), electrical conductivity and Sodium Adsorption Ratios were considered in determining the suitability of water quality for irrigation.

Table.3.13. Rating of surface water samples based on Wilcox diagram

Sl No	Class	Sample	
		Pre monsoon	Post monsoon
1	Very good to good	S1 to S21, S23 to S32	S1 to S21, S23 to S32
2	Good to permissible	S22	S22
3	Permissible to doubtful	Nil	Nil
4	Good to permissible	Nil	Nil
5	Doubtful to unsuitable	Nil	Nil
6	Unsuitable	Nil	Nil

As per Richards classification, 96.88% (31 samples) fall into the field of very good to good category and only one sample in good to permissible field, irrespective of seasons (Table 3.13 and figures 3.10 (a) and (b)).

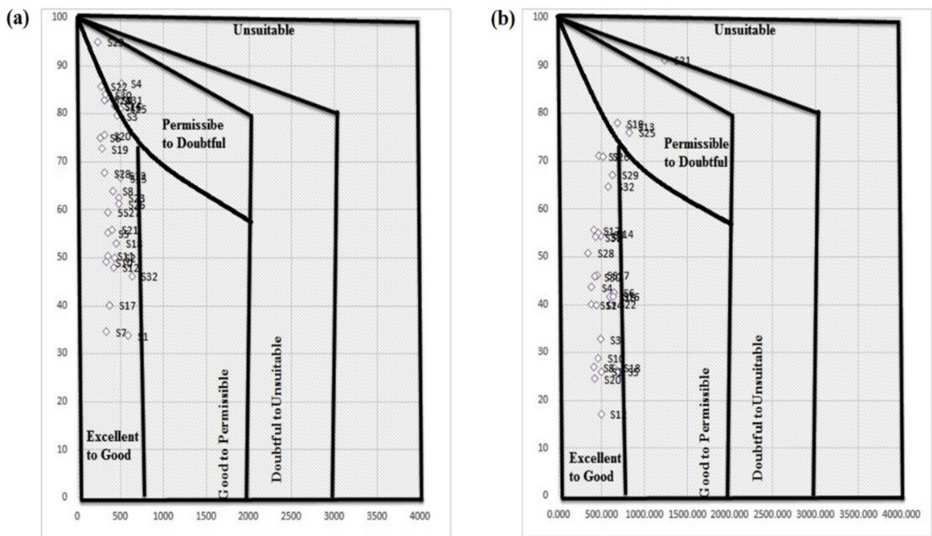


Fig. 3.10. Qualification of water quality for irrigation during **a)** pre-monsoon (after Wilcox, 1948) and **b)** post monsoon (after Wilcox, 1948)

3.5.4.5. Sodium Adsorption Ratio (SAR)

The U.S. Salinity Laboratory (Richards, 1954) proposed a diagram for studying the suitability of groundwater for irrigation purposes based on Sodium Adsorption Ratio (SAR) and electrical conductivity (EC). SAR is a measure of the suitability of water for use in agricultural irrigation because sodium concentration can reduce the soil permeability and soil structure (Todd, 1980). SAR measures the alkali/sodium hazard for crops. SAR can be estimated by taking individual values of Na^+, Ca^{2+} and Mg^{2+} in meq/l and substituting in the expression given below.

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Table 3.14. Surface water quality based on sodium / alkalinity hazard

Sl.No	SAR	Water class	Samples	
			Pre monsoon	Post monsoon
1	< 10	Excellent	S1 to S32	S1 to S8
2	10-18	Good		S9 to S16
3	18 – 26	Doubtful		S17 to S24
4	> 26	Unsuitable		S25 toS32

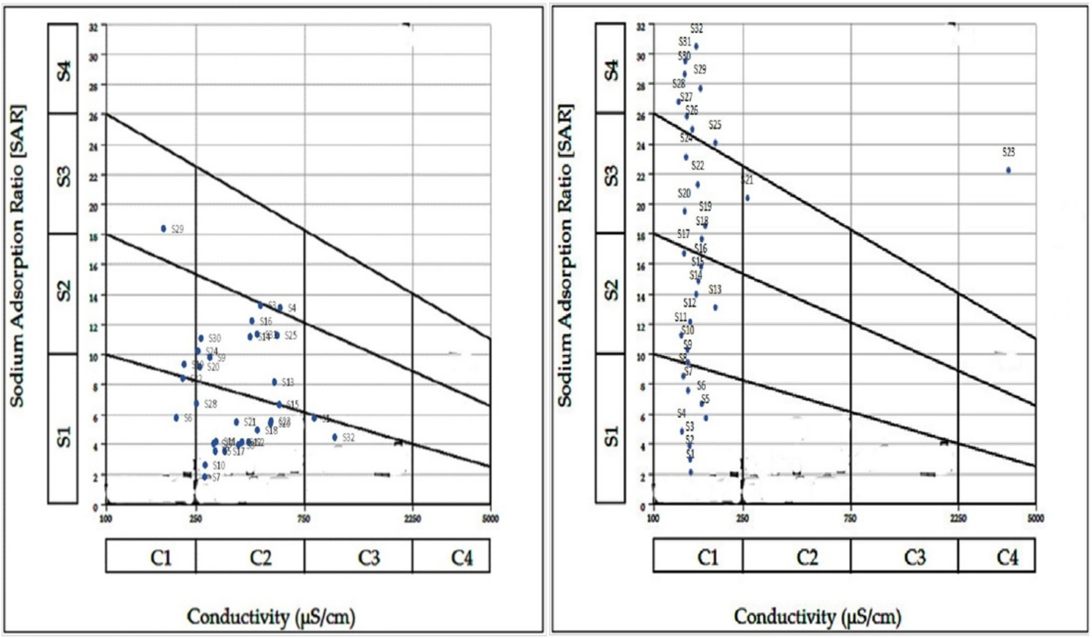
There is a significant relationship between sodium adsorption ratio of irrigation water and the extent to which sodium is absorbed by the soils. In the pre monsoon season, based on the SAR values all the samples are categorized under excellent class. However, during the post monsoon season, 25% of the sample remained under each category (Table 3.14). Excess salinity reduced the osmotic activity of plants and interferes with the absorption of water and nutrients from the soil (Saleh et al., 1999). During post monsoon, sample locations S25 to S32 not suitable for irrigation purposes.

3.5.4.6. U.S. Salinity Laboratory Diagram

Based on USSL, all samples fall into good category (Table 3.15). During pre-monsoon 43.75% of the samples fall into the C2 S1, 28% in C2 S1 and 34.375% in C2 S2 and 6.25% in C3 S1 (Fig 3.11a). In post monsoon,25% of the samples fall in C1S1 and C1S4,28.125% in C1 S2 and 15.625% in C1S3.The other samples 3.125% in C2 S3(S1 and S32) and C4 S3(S23). (Fig 3.11b and plate 3.2).

Table 3.15. Surface water quality based on USSL classification

Sl. no	USSL Classification	Water class	Seasons	
			Pre monsoon	Post monsoon
1	C1-S1	Good	S6, S22	S1,S2,S3 S4,S5,S6,S7,S8
	C1-S2		S19	S9,S10,S11,S12, S13,S14,S15,S16,S 17
	C1-S3		S29	S18,S19,S20,S22, S24
	C1-S4		-	S25, S26, S27,S28, S29,S30,S31,S32
2	C2-S1	Moderate	S2,S5,S7,S8,S10,S1 1,S12,S17, S18,S21,S23,S26,S 27,S28	-
	C2-S2		S3,S9,S13, S14,S15,S16,S20, S24,S25,S30,S31	-
	C2-S3		S4	S21
	C2-S4			-
3	C3-S1	Bad	S1, S32	-
	C3-S2			-
	C3-S3			-
	C3-S4			-
	C4-S1			-
	C4-S2			-
	C4-S3			S23
	C4-S4			-



(a) **(b)**

Fig.3.11. Rating of surface water samples in relation to salinity hazard and Sodium hazard during **a)** pre-monsoon season and **b)** post monsoon season (after Richards, 1954)

3.5.4.7. Permeability Index

The permeability of the soil is affected by long-term irrigation influenced by Na, Ca, Mg and HCO_3 contents of the soil. The permeability index (PI) values also indicate the suitability of surface water for irrigation. Permeability index (Doneen, 1964) is calculated as follows (where, the concentrations are expressed in meq/l).

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100$$

Based on PI value water is classified into class I, Class II and Class III orders (Table 3.16). During pre-monsoon season, the 78.13% fall in excellent category and 21.88% in good category. In post monsoon season, 71.88% comes under excellent category and 28 % in good category. According to this parameter, the surface water was considered as suitable for irrigation.

Table 3.16. Surface water quality based on Permeability Index

Class	Permeability	Usage Quality	Sample	
			Pre monsoon	Post monsoon
ClassI	>75%	Excellent for irrigation	S3 to S11, S13 to S16, S18, S20, S22 to S31	S1, S4, S7, S9 to S15, S17, S20, S21, S23 to S32
ClassII	75% - 25%	Good for irrigation	S11, S12, S17, S19, S21, S32	S2,S3,S5,S6,S8,S16,S18, S19S22
Class III	< 25%	Unsuitable for irrigation	-	-

3.5.4.8. Magnesium Hazard (MH)

Szabolcs and Darab (1964) proposed MH value for irrigation water as given by the following formula (where the concentrations are expressed in meq/l):

$$MH = \frac{Mg^{2+} x\ 100}{Ca^{2+} + Mg^{2+}}$$

MH values >50 were considered harmful and unsuitable for irrigation purposes. Based on MH analysis, all the 32 samples were found suitable for irrigation during pre-monsoon season and post monsoon (Table 3.17).

Table 3.17. Surface water quality based on MH

Sl. No	Class	MH	Sample	
			Pre monsoon	Post monsoon
1	Suitable	<50	S1 to S32	S1 to S32
2	Unsuitable	>50		

3.5.4.9. Kelly's Ratio

Based on Kelly's ratio, water is classified for irrigation purposes. Sodium measured against Ca^{2+} and Mg^{2+} was considered by Kelly (1957) to calculate this parameter (where, all the concentration in this equation is expressed in meq/l.)

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}}$$

Kelly's ratio of more than 1 indicates an excess level of Na^{+} in water (Table 3.18). on the basis of Kelly's ratio values of water samples 43% fall in the suitable category and

18.75% in permissible and 37.50 % in unsuitable. Moreover, all the samples were found suitable for irrigation during post monsoon.

Table 3.18. Surface water quality based on Kelly's Ratio

Sl. No	Class	Kelly's ratio	Sample	
			Pre monsoon	Post monsoon
1	Suitable	<1	S1,S2,S5,S7,S8,S10,S11,S12,S17, S18,S21,S23,S27,S32	S1 to S32
2	Permissible	1-2	S6,S13,S15,S19,S26,S28	-
3	Unsuitable	>2	S3,S4,S9,S14,S16,S20,S22,S24,S25,S29,S30,S31	-

3.6. Linear Regression analysis by Scatter diagram

Correlation analysis measures the closeness of the relationship between chosen independent and dependent variables. If the correlation coefficient is nearer to +1 or -1, it shows the probability of linear relationship between the variables x and y. The correlation between parameters characterized into different types tabulated in Table 3.19 (Achuthan et al, 2005). In this study, the interrelationship of hydro chemical attributes was determined by calculating Karl Pearson's correlation coefficient (R) using scatter diagram on Excel.

Table3.19. R Value and its characterization

Absolute value of R	**Strength of relation**
+1	Perfect +ve correlation
-1	Perfect –ve correlation
R > 0.7	Strong
0.5 < R < 0.7	Moderate
0.3 < R <0.5	Weak
R < 0.3	None or very weak

Source: www.westga.edu

By using the formula

$$R = \frac{\sum (X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum (X-\bar{X})^2 \sum (Y-\bar{Y})^2}}$$

Where, x (x=values of x-variable x, x value x) and y (y = values of y-variable, y= average values of y) represents two different water quality parameters. If the values of correlation coefficient R between two variables X and Y are fairly large, it implies that these two variables are highly correlated (Jothivenkatachalam et al., 2010).

To determine the straight linear regression, the following equation of the straight line can be used

$$Y = a + bX,$$

where y and x are the dependent and independent variable respectively, a is the slope of the line and b is the intercept on y axis (Sonawane and Khole, 2010).

The value of empirical parameters a and b are calculated with the help of the following equation

$$b = \frac{\sum XY - \overline{X} \sum Y}{\sum X^2 - \overline{X} \sum Y}$$

$$a = \overline{Y} - b\overline{X}$$

In statistics, correlation was a broad class of statistical relationship between two or more variables. Correlation was used for the measurement of the strength and the statistical significance of the relation between two or more water quality parameters (Mehta, 2010). The systemic calculation of correlation coefficient between water quality variables and regression analysis provides indirect means for rapid monitoring of water quality. The correlation coefficient measures the degree of association that exists between two variables, one taken as dependent variable. The greater the value of regression coefficient, the better is the fit and more useful the regression variables (Sami et al., 2011). The regression equation was used as a mathematical tool to calculate different dependent characteristics of water quality by substituting the values for the independent parameters in the equations.

The concentration range of major ions during pre-monsoon and post monsoon were summarized in the Table.3.4. With the help of scatter diagram and linear regression line, the correlation between the total anions and total cations were determined. A strong positive correlation exists between anions and cations during pre-monsoon and post monsoon attesting the cation-anion balance (Fig 3.12 (a) and (b) and Table 3.20).

Table 3.20 Linear correlation coefficient (R) and regression equation for total cation and total anion.

Seasonal representation	R^2value	R value	Regression equation
Pre monsoon	**0.521**	**0.7218**	Total anion = 2.55 (total cation) - 27.93
Post monsoon	**0.513**	**0.7162**	Total anion = 8.02 (total cation) - 1841.00

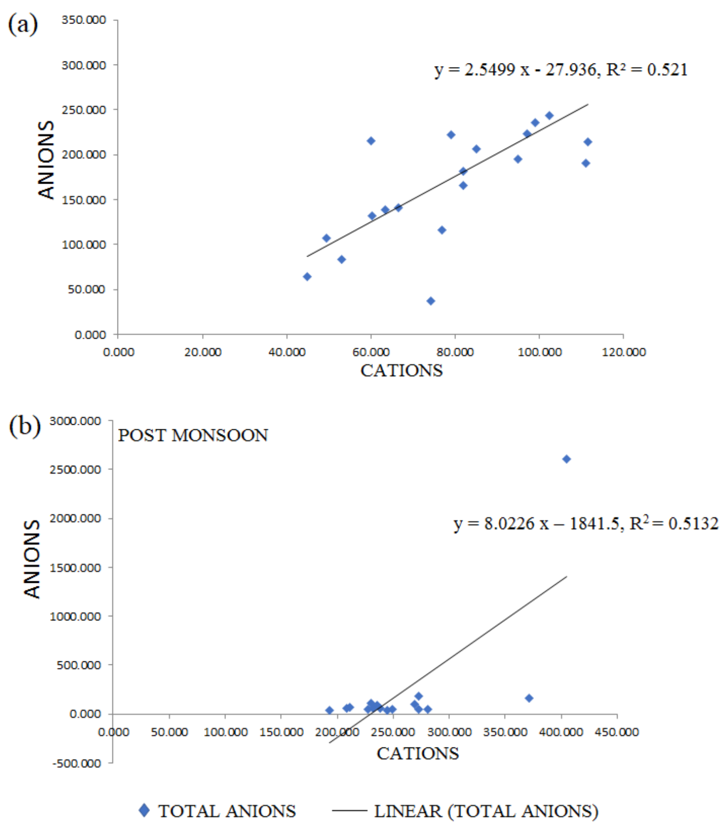


Fig 3.12. The relationship between anions and cations with total anions **a)** pre-monsoon, **b)** post monsoon.

The regression analyses carried out for the water quality parameters during the pre monsoon season found to have better and higher level of significance in their correlation coefficient (Table 3.21 and 3.22 and Fig. 3.13).

During pre-monsoon time, perfect relationship existed between EC-TDS only. The strong positive correlation was found to exist between parameters EC- Alkalinity and EC- Bicarbonate (R=0.7320), EC-Cl(R=0.7170), TH-Ca (R= 0.9420), TH-Mg (R=0.9390), TH- Alkalinity(R=0.8320) and Ca-Mg(R=0.7690). The parameter EC-TH (R=0.6150) showed a moderate relationship among them.

The parameters EC-Na^+(R=0.4230), EC-K^+ (R=0.1000), EC-SO_4^{2-} (R=0.0508), TH-SO_4^{2-} (R=0.184), Ca^{2+}-Cl^- (R=0.1200), Ca^{2+}- SO_4^{2-} (R=0.1610), Mg^{2+}- SO_4^{2-} (R=0.1860), Mg^{2+}- Cl^- (R=0.0140), Turbidity- Fe^{2+} (R=0.1020), PO_4^{3-} -NO_3^- (R=0.2940), PO_4^{3-} - SO_4^{2-} (R=0.2790), NO_3^--SO_4^{2-} (R=0.0620) showed very weak relationship among them.

The linear regression analyses have been carried out for the water quality parameters which were found to have higher level significance in their correlation coefficient (R>0.50). The different dependent characteristics of water quality were calculated using the regression equation and by substituting the values for the independent parameters in the equations. In this study the distribution of EC-TDS, EC-TH, EC-Alkalinity, EC- HCO_3^-, EC-Cl^-, TH-Ca^{2+}, TH-Mg^{2+}, TH- Alkalinity, Ca^{2+}-Mg^{2+} and EC-TH were significantly correlated (<0.80).

Table 3.21: Linear correlation coefficient R and regression equation for certain pairs of parameters (Pre monsoon)

Paramters	Equation	R²	R	Strength of Relationship
EC – TDS	TDS = 0.65(EC) + 2E-12	1.000	1.000	Perfect
EC – TH	TH = 0.2406(EC) - 27.143	0.378	0.615	Moderate
EC – Alkalinity	Alkalinity = 0.2062(EC) - 34.181	0.536	0.732	Strong
EC - HCO_3^-	HCO_3^- = 0.2516(EC) - 41.701	0.536	0.732	Strong
EC – Na^+	Na^+ = 0.0683(EC) + 11.254	0.179	0.423	Weak
EC – K^+	K^+ = 0.0093(EC) + 6.9845	0.010	0.100	Very Weak
EC - SO_4^{2-}	SO_4^{2-} = 0.0014(EC) + 0.924	0.003	0.058	Very Weak
EC – Cl^-	Cl^- = 0.2393(EC)+ 31.02	0.513	0.717	Strong
TH - SO_4^{2-}	SO_4^{2-} = 0.0112(TH) + 0.701	0.034	0.184	Very Weak
TH – Ca^{2+}	Ca^{2+} = 0.2025(TH) + 3.2972	0.887	0.942	Strong
TH – Mg^{2+}	Mg^{2+} = 0.12(TH) - 2.0031	0.882	0.939	Strong
TH – Alkalinity	Alkalinity = 0.5987(TH)+ 7.0358	0.692	0.832	Strong
Ca^{2+}-Mg^{2+}	Mg^{2+} = 0.4569(Ca) - 1.6003	0.591	0.769	Strong
Ca^{2+}-Cl^-	Cl^- = 0.478(Ca) + 118.83	0.015	0.120	Very Weak
Ca^{2+}-SO_4^{2-}	SO_4^{2-} = 0.0457(Ca) + 0.6884	0.026	0.161	Very Weak
Mg^{2+}-SO_4^{2-}	SO_4^{2-} = 0.0887(Ca) + 0.9203	0.035	0.186	Very Weak
Mg^{2+}-Cl^-	Cl^- = 0.0864(Ca) + 126.59	0.000	0.014	Very Weak
Turbidity – Fe^{2+}	Fe^{2+} = -0.0314(Turbidity) + 3.0868	0.010	0.102	Very Weak
PO_4^{3-} - NO_3^-	NO_3^- = 0.3062(PO_4^{3-}) + 2.2357	0.087	0.294	Very Weak
PO_4^{3-} - SO_4^{2-}	SO_4^{2-} = 0.2466(PO_4^{3-}) + 0.9532	0.078	0.279	Very Weak
NO_3^- - SO_4^{2-}	SO_4^{2-} = -0.0527(NO_3^-) + 1.635	0.004	0.062	Very Weak

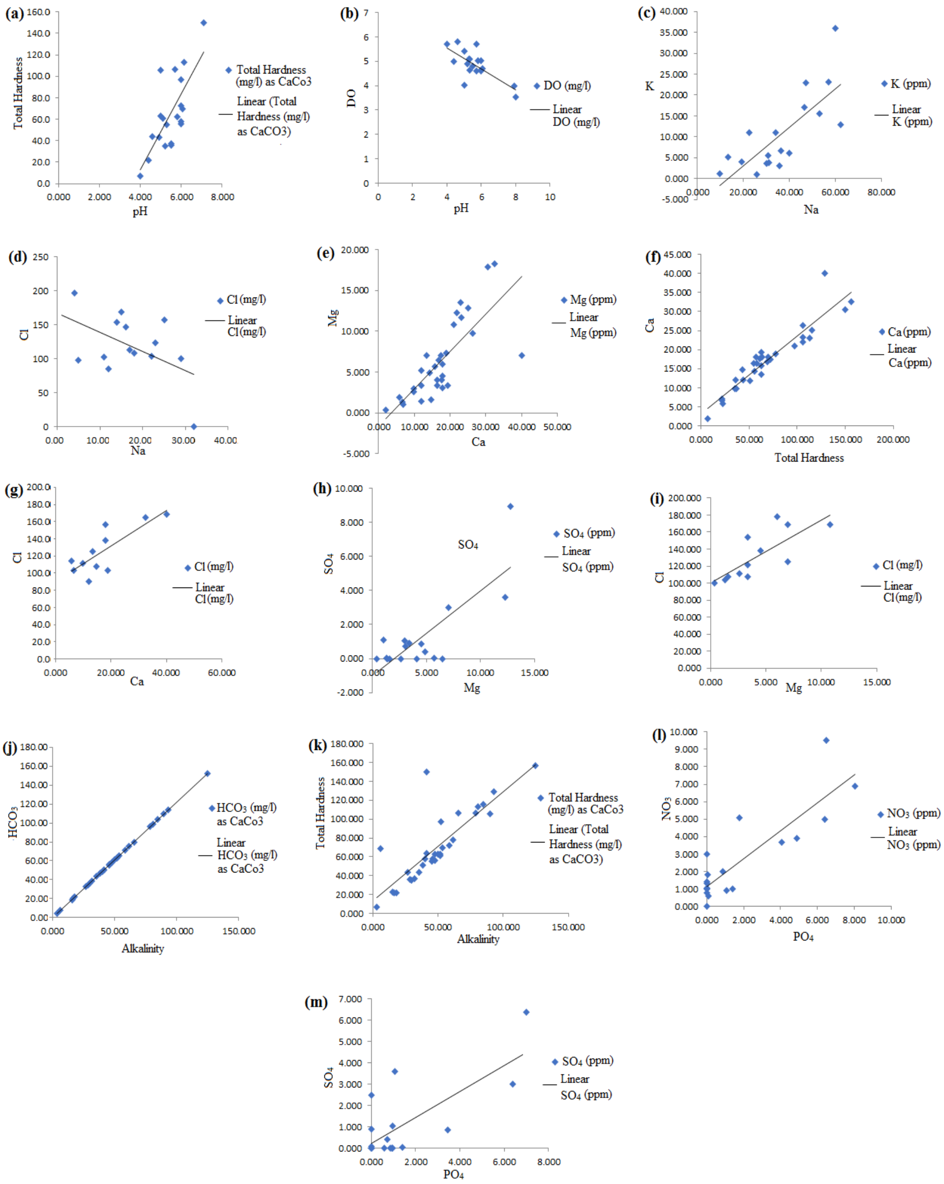


Fig 3.13. The relationship between various parameters (pre-monsoon). **a)** pH-TH **b)** pH-DO, **c)** Na^{+}– K^{+}, **d)** Na^{+}- Cl^{-}, **e)** Ca^{2+} – Mg^{2+}, **f)** Ca^{2+} – TH, **g)** Ca^{2+} – Cl^{-}, **h)** Mg^{2+} – SO_4^{2-}, **i)** Mg – Cl^{-}, **j)** Alkalinity – HCO_3^{-}, **k)** Alkalinity – TH, **l)** PO_4^{3-} – NO_3^{-}, **m)**PO_4^{3-} – SO_4^{2-} .

During post monsoon season, the perfect relation among the parameters EC-TDS and TH-Ca (R=1) (Table 3.22 and Fig. 3.14). The strong positive correlation observed between seven parameters. The parameters were EC - TH(R=0.8034),EC- Alkalinity and EC-HCO_3^{-} (R=0.8298),EC-K^{+}(R=0.9907),TH-Mg^{2+}(R=0.9999), TH-Alkalinity

(R=0.7445) and Ca^{2+}-Mg^{2+} (R=0.9998).The moderate relationship exist between EC-Na^{+} (R=0.5058) , EC-Na^{+} (R=0.5910) and NO_3^{-} - SO_4^{2-} (R=0.5747). There were some parameters showed very weak relationship among them like EC- SO_4^{2-} (R=0.0686), Ca^{2+}-Cl^{-}(R=0.0812),Ca^{2+}-SO_4^{2-}(R=0.0889),Mg-SO_4^{2-}(R=0.0866),Mg^{2+}-Cl^{-} (R=0.0819), Turbidity -Fe^{2+}(R=0.1924), PO_4^{2-}-NO_3^{-}(R=0.0200),PO_4^{3-}-SO_4^{2-} (R=0.1732). Very weak correlation exists between Ca and Cl^{-}. Similar trend is noticed in the water quality assessment at Virudhunagar district, Tamil nadu (Muthulakshmi., et al,2013). In this study the distribution of EC-TH, EC-Alkalinity, EC- HCO_3^{-}, EC-K^{+}, TH- Alkalinity, TH-Mg^{2+} and Ca^{2+}-Mg^{2+} were significantly correlated (<0.80).

Table 3.22 Linear correlation coefficient (R) and regression equation for certain pairs of parameters (Post monsoon).

Parameters	Equation	R^2	R	Strength of Relationship
EC – TDS	TDS = 0.65(EC) + 1E-13	1.0000	1.0000	Perfect
EC – TH	TH = 0.2594(EC) – 29.59	0.6454	0.8034	Strong
EC – Alkalinity	Alkalinity = 0.2395 (EC) + 20.839	0.6887	0.8298	Strong
EC - HCO_3^{-}	HCO_3^{-} = 0.2922 (EC) + 25.423	0.6887	0.8298	Strong
EC – Na^{+}	Na^{+} = 0.0099(EC) - 0.2639	0.2558	0.5058	Moderate
EC – K^{+}	K^{+} = 0.6007(EC) + 6.9845	0.9814	0.9907	Strong
EC - SO_4^{2-}	SO_4^{2-} = 0.0028 (EC)+ 4.3216	0.0047	0.0686	Very Weak
EC – Cl^{-}	Cl^{-} = 0.0376 (EC)+ 68.505	0.3493	0.5910	Moderate
TH - SO_4^{2-}	SO_4^{2-} = 0.0225(TH)+ 3.4212	0.0076	0.0872	Very Weak
TH – Ca^{2+}	Ca^{2+} = 0.2399(TH) - 0.0201	1.0000	1.0000	Perfect
TH – Mg^{2+}	Mg^{2+} = 0.0972(TH) + 0.0122	0.9999	0.9999	Strong
TH – Alkalinity	Alkalinity = 0.9521(TH)+ 52.513	0.5543	0.7445	Strong
Ca^{2+}-Mg^{2+}	Mg^{2+} = 0.4053(Ca^{2+}) + 0.0216	0.9997	0.9998	Strong
Ca^{2+}-Cl^{-}	Cl^{-} = 0.5841(Ca^{2+}) + 80.823	0.0066	0.0812	Very Weak
Ca^{2+}-SO_4^{2-}	SO_4^{2-} = 0.0954(Ca^{2+}) + 3.4066	0.0079	0.0889	Very Weak

Mg^{2+}-SO_4^{2-}	$SO_4^{2-} = 0.2287(Ca^{2+}) + 3.466$	0.0075	0.0866	Very Weak
Mg^{2+}-Cl^-	$Cl^- = 1.4524(Ca^{2+}) + 79.912$	0.0067	0.0819	Very Weak
Turbidity – Fe^{2+}	$Fe^{2+} = -0.0166(Turbidity) + 2.4095$	0.0370	0.1924	Very Weak
PO_4^{3-} - NO_3^-	$NO_3^- = -0.0499(PO_4^{3-}) + 0.9418$	0.0004	0.0200	Very Weak
PO_4^{3-} - SO_4^{2-}	$SO_4^{2-} = 2.4553(PO_4^{3-}) + 4.3192$	0.0300	0.1732	Very Weak
NO_3^- - SO_4^{2-}	$SO_4^{2-} = 3.3103(NO_3^-) + 2.6863$	0.3303	0.5747	Moderate

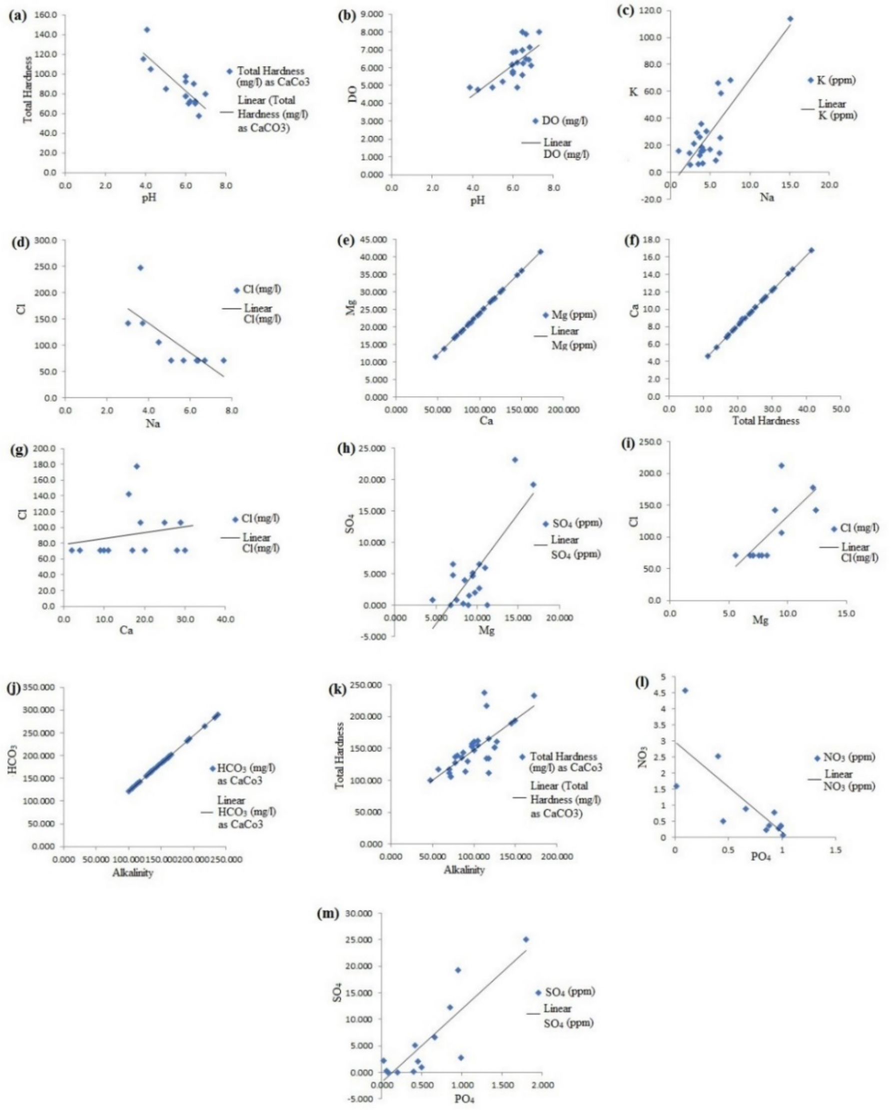


Fig 3.14. The relationship between various parameters (post-monsoon), **a)** pH-TH **b)** pH-DO, **c)** $Na^+ – K^+$, **d)** Na^+- Cl^-, **e)** $Ca^{2+}– Mg^{2+}$, **f)** Ca^{2+} – TH, **g)** $Ca^{2+}– Cl^-$, **h)** $Mg^{2+}– SO_4^{2-}$,i) $Mg^{2+} – Cl^-$, **j)** Alkalinity – HCO_3^-, **k)** Alkalinity – TH, **l)** $PO_4^{3-} – NO_3^-$, **m)** $PO_4^{3-} – SO_4^{2-}$

3.7. Univariate Statistical Analysis

3.7.1. Karl Pearson's Correlation matrix

The seasonal correlation matrix of the water quality parameters obtained from the Univariate correlation analysis by PAST 3.0. The Karl Pearson's correlation coefficient values for the assessed physiochemical parameters -pH, EC, TDS, Turbidity, Na^{+}, K^{+}, Cl^{-}, TH, Ca^{2+}, Mg^{2+}, Alkalinity, DO, HCO_3^{-}, F^{-}, Fe^{2+}, PO_4^{3-}, $NO3^{-}$ and SO_4^{2-} for pre monsoon and post monsoon seasons(Table 3.23 and 3.24).

The correlation coefficient for pre monsoon season is presented in table 3.23. The correlation coefficient values of EC with Cl^{-}, TH, Ca^{2+}, Mg^{2+}, alkalinity and Fe^{2+} are 0.72, 0.61, 0.66, 0.50, 0.73 and 0.31 respectively. The TDS show correlation with Na^{+}, Cl^{-}, TH, Ca^{2+}, Mg^{2+}, alkalinity, HCO_3^{-} and Fe^{2+} with values 0.72, 0.61, 0.66, 0.5, 0.73, 0.73, 0.31respectively. The Na^{+} moderately correlated with K^{+} and Cl^{-} with values 0.49 and 0.33. The TH strongly correlated with Ca^{2+}, Mg^{2+}, alkalinity, HCO_3^{-} and showed values 0.94, 0.94, 0.83 and 0.83 respectively. Ca^{2+} showed strong correlation with Mg^{2+}, alkalinity and HCO_3^{-} with correlation coefficient values 0.77, 0.81 0.81 respectively. The F^{-} has a moderate positive correlation with Fe^{2+} with a value of 0.43. The Karl Pearson's correlation matrix for post monsoon season was tabulated in table 3.24. The pH showed a moderate correlation (0.36) with DO. The EC and TDS showed strong correlation (0.99) with K^{+} and moderate (0.59) with Cl^{-}. The turbidity shows moderate correlation with alkalinity, HCO_3^{-} and Fe^{2+} with values 0.40,0.40, and 0.49 respectively. The correlation values showed that there was a weak relationship (0.43) with Na^{+} and alkalinity.TH was in perfect correlation with Ca^{2+} and Mg^{2+}. The TH was correlated to alkalinity, HCO_3^{-}, F^{-} and NO_3^{-} with values 0.74,0.74,0.35 and 0.30 respectively. The Ca^{2+} showed perfect correlation with Mg^{2+} alkalinity and HCO_3^{-}.The Fe^{2+} and PO_4^{-} has a correlation value of 0.34 , while nitrate and sulphate had a value 0.57.

Table 3.23 Correlation of the water quality parameters of the surface water during pre monsoon

	pH	EC	TDS	Turbidity	Na^+	K^+	Cl^-	TH	Ca^{2+}	Mg^{2+}	Alkalinity	DO	HCO_3^-	F^-	Fe	PO_4^{3-}	NO_3^-	SO_4^{2-}
pH	1.00																	
EC	0.02	1.00																
TDS	0.02	1.00	1.00															
Turbidity	-0.16	-0.06	-0.06	1.00														
Na^+	-0.16	0.42	**0.42**	-0.17	1.00													
K^+	-0.25	0.10	0.10	-0.13	**0.49**	1.00												
Cl^-	0.01	**0.72**	**0.72**	-0.10	**0.33**	0.11	1.00											
TH	0.20	**0.61**	**0.61**	0.09	-0.04	-0.37	0.07	1.00										
Ca^{2+}	0.13	**0.66**	**0.66**	0.02	0.05	-0.30	0.12	**0.94**	1.00									
Mg^{2+}	0.24	**0.50**	**0.50**	0.15	-0.13	-0.40	0.01	**0.94**	**0.77**	1.00								
Alkalinity	0.11	**0.73**	**0.73**	0.08	-0.10	-0.26	0.18	**0.83**	**0.81**	0.75	1.00							
DO	-0.02	-0.15	-0.15	0.08	-0.26	0.15	0.02	-0.14	-0.20	-0.07	-0.16	1.00						
HCO_3^-	0.11	**0.73**	**0.73**	0.08	-0.10	-0.26	0.18	**0.83**	**0.81**	0.75	1.00	-0.16	1.00					
F^-	0.05	0.12	0.12	-0.51	0.17	0.28	0.27	-0.17	-0.20	-0.12	-0.12	0.04	-0.12	1.00				
Fe^{2+}	-0.09	**0.31**	**0.31**	-0.10	0.10	0.20	0.25	0.06	-0.02	0.13	0.22	-0.09	0.22	**0.43**	1.00			
PO_4^{3-}	-0.40	0.06	0.06	-0.19	0.02	0.15	0.04	-0.08	0.00	-0.16	0.02	0.03	0.02	-0.01	-0.02	1.00		
NO_3^-	0.03	-0.09	-0.09	0.05	-0.32	0.07	0.11	-0.17	-0.15	-0.17	-0.07	0.00	-0.07	0.18	0.11	0.29	1.00	
SO_4^{2-}	-0.06	0.06	0.06	-0.20	-0.18	-0.25	-0.17	0.18	0.16	0.19	0.29	-0.05	0.29	0.05	0.10	0.28	-0.06	1.00

Table.3.24. Correlation of the water quality parameters of the surface water during post monsoon

	pH	EC	TDS	Turbidity	Na^+	K^+	Cl^-	TH	Ca^{2+}	Mg^{2+}	Alkalinity	DO	HCO_3^-	F^-	Fe^{2+}	PO_4^{3-}	NO_3^-	SO_4^{2-}
pH	1.00																	
EC	0.00																	
TDS	0.00	1.00																
Turbidity	-0.10	0.00	0.00	1.00														
Na^+	0.04	0.02	0.02	0.17	1.00													
K^+	0.01	**0.99**	**0.99**	-0.04	-0.02	1.00												
Cl^-	0.06	**0.59**	**0.59**	-0.04	-0.12	**0.53**	1.00											
TH	-0.08	0.08	0.08	0.28	0.13	-0.01	0.08	1.00										
Ca^{2+}	-0.08	0.08	0.08	0.28	0.13	-0.01	0.08	**1.00**	1.00									
Mg^{2+}	-0.08	0.08	0.08	0.27	0.13	-0.01	0.08	**1.00**	**1.00**	1.00								
Alkalinity	-0.20	0.18	0.18	**0.40**	**0.43**	0.08	0.03	**0.74**	**0.75**	**0.74**	1.00							
DO	**0.36**	0.14	0.14	0.00	-0.08	0.15	0.21	-0.10	-0.10	-0.10	-0.21	1.00						
HCO_3^-	-0.20	0.18	0.18	**0.40**	0.43	0.08	0.03	**0.74**	**0.75**	**0.74**	1.00	-0.21	1.00					
F^-	-0.21	0.02	0.02	**0.49**	-0.14	-0.01	0.16	**0.35**	**0.35**	**0.36**	0.09	-0.02	0.09	1.00				
Fe^{2+}	0.00	-0.10	-0.10	-0.19	0.07	-0.05	-0.17	-0.30	-0.29	-0.30	-0.27	0.11	-0.27	-0.17	1.00			
PO_4^{3-}	-0.05	-0.19	-0.19	0.14	0.28	-0.19	-0.13	-0.13	-0.13	-0.13	-0.01	0.13	-0.01	-0.01	**0.34**	1.00		
NO_3^-	0.28	-0.09	-0.09	0.22	0.00	-0.12	-0.14	**0.30**	**0.30**	**0.30**	0.27	-0.04	0.27	-0.01	-0.28	-0.02	1.00	
SO_4^{2-}	0.29	-0.01	-0.01	0.11	0.16	-0.04	-0.13	0.09	0.09	0.09	0.21	-0.01	0.21	-0.20	-0.22	0.17	**0.57**	1.00

3.7.2. ANOVA

The most common method of detecting a discrete water quality changes due to the land treatment changes are the T -test analysis of variance or ANOVA .The results are interpreted by using the p value (Gary et al., 1998).The one way ANOVA was conducted for analysing the significant differences in the water quality parameters of the surface water in Thrissur Kole Wetlands. The significance level 95% used for indicating the level of significance in the result. ANOVA performed on R: A language and environment for statistical computing (R core team, 2018).

Table 3.25. The water quality parameters of Thrissur Kole wetlands (n = 32) and 18 parameters during the pre-monsoon and post monsoon seasons.

	Df	SS	MS	F	Significance F
Premonsoon					
Treatment	17	2983727	175513	71.09	<2e-16 ***
Residuals	558	1377614	2469		
Post monsoon					
Treatment	17	17723902	1042582	18.72	<2e-16 ***
Residuals	558	31081377	55701		
Sign if. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1					

The results of One-way ANOVA (Table 3.25) suggested that there was significant difference in the means of the parameters [$F_{(17,558)}$ =71.09, p =<2e$^{-16]}$ valuated in the surface water samples that was collected from 32 locations during the pre-monsoon season period.

The results of One-way ANOVA suggested that there was significant difference in the means of the parameters [$F_{(17,558)}$ =373.8, p =<2e^{-16}] valuated in the surface water samples.

The results of One-way ANOVA suggested that there was significant difference in the means of the parameters [$F_{(17,558)}$ =18.72, p =<2e^{-16}] valuated in the surface water samples that was collected from 32 fields in the post-monsoon season.

The result of One-way ANOVA indicated that there was significant difference in the parameters of surface water in two seasons –pre monsoon and post monsoon of Thrissur Kole wetlands. The ANOVA results are consistent with the hydrological and hydro chemical parameters of the samples collected from 32 locations.

3.8. Multivariate Statistical Analysis

Multivariate statistical methods are statistical methods for the simultaneous analysis of data on number of variables. Data for multivariate analysis is the chemical quality of water, which depends on factors like slope of ground, composition of the host rock, movement of water, etc. The chemical characteristics of water play a vital role in agricultural and industrial purposes. Statistics can assist in generating hypothesis for the interpretation of hydro-chemical processes. The objective of the study is to identify the quality of groundwater by using multivariate analysis of the geochemical data sets. The Correlation analysis and Principal Component Analysis (PCA), Multivariate techniques helps to simplify and organize. Large data sets is essential to make useful generalizations, which can lead to meaningful insight (Laaksoharju et al.,1999).

Multivariate statistical analyses such as principal component analysis (PCA) and cluster analysis (CA) provide a reliable alternative approach for understanding and interpreting the complex system of water quality with the capability of analyzing large amounts of data (Feryal et al., 2011) and distinguishing complex relationships among many variables (Jalali, 2006).

Many studies have been conducted using Principal Component Analysis (PCA) in the interpretation of water quality parameters. PCA is a multivariate statistical procedure designed to classify variables based on their correlations with each other. The goal of PCA and other factor analysis procedures is to consolidate a large number of observed variables into a smaller number of factors that can be more readily interpreted. In the case of groundwater, concentrations of different constituents may be correlated based on underlying physical and chemical processes such as dissociation, ionic substitution or carbonate equilibrium reactions.

Multivariate statistical method encompassing factor analysis, principal component analysis, cluster analysis and discriminate analysis have been successfully used in hydro geochemistry for many years. The data were prepared and processed in PAST 3.04 Software.

3.8.1. Principal Component Analysis

In Principal component analysis, eigenvalues are normally used to determine the number of the principal components (PCs) that can be retained for further study. Scree plot for the eigenvalues obtained in this study shows a pronounced change of slope after the third eigenvalue (Fig. 3.15). According to Vega et al., (1998) all of the PCs up to and including the first one after the brake can be used for further analysis. In this study, the first four PCs are used for analysis .These four PCs have eigenvalues greater than or close to unity and explain 85.63%, and 99.13%, of the total variances of information contained in the original dataset, for pre monsoon and post monsoon respectively. The component loadings are the linear combinations for each principal component, and express the correlation between the original variables and the newly formed components. The component loadings can be used to determine the relative importance of a variable (or parameter in this study) as compared to other variables in a PC and do not reflect the importance of the component itself (Ouyang et al.,2006).

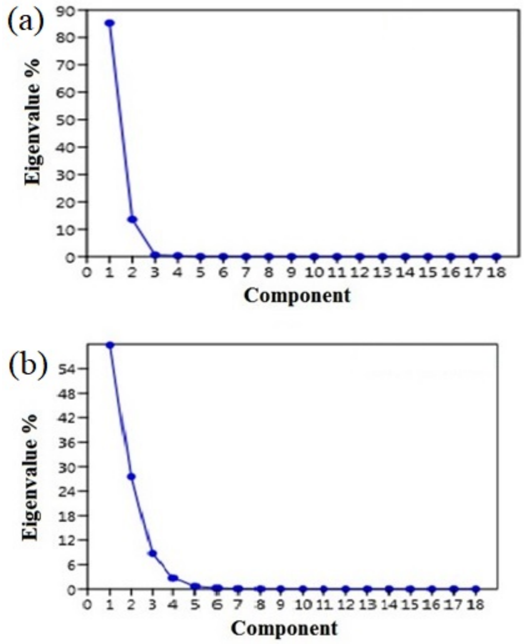


Fig 3.15. Scree plot for the eigenvalues obtained in this study **a)** pre monsoon, **b)** post monsoon

During pre-monsoon (Table 3.26), the PC1 explained 85.63 % of total variance parameters was positively and strongly contributed by EC and moderately by TDS and poorly loaded by Na^+, Cl^-, TH, Ca^{2+}, Mg^{2+}, Alkalinity, HCO_3^- and Fe^{2+}. The PC2 was moderately loaded by mineral related parameters such as TH (0.59), alkalinity (0.36) and HCO_3^- (0.44). The poor loading carried out by inorganic parameters such as turbidity, Ca and Mg and organic parameter SO_4^{2-} by anthropogenic sources. PC3 showed only one moderately positive loading by Na (0.64). In PC4, the Cl^- and TH moderately positive loaded with 0.45 and 0.69 respectively. The organic parameters such as nitrate and phosphate showed negative loading in PC2 and PC3.This may be due to the natural cleaning and detoxification mechanism of the wetland system. Therefore, this component seems to measure the preponderance of physical and organic-related water quality parameters over the mineral and inorganic nutrient-related water quality parameters. This component also reveals that the water pH and turbidity were less important in accounting for surface water quality variations in pre monsoon since the loading (eigenvector) coefficients were zero for these two parameters of the total variance and was negatively contributed by organic-related PCs. The result indicated the changes in the surface quality of the water with respect to the seasonal fluctuations.

Table 3.26. Principal Component Analysis for pre-monsoon season

PC	Eigenvalue	% variance	PC 1	PC 2	PC 3	PC 4
pH	15054.40	**85.63**	0.00	0.00	-0.01	0.01
EC	1799.94	**10.24**	**0.77**	-0.17	0.11	-0.08
TDS	312.79	**1.78**	**0.50**	-0.11	0.07	-0.05
Turbidity	264.25	**1.50**	0.00	0.04	-0.06	0.03
Na^+	71.79	0.41	0.05	-0.18	**0.64**	-0.08
K^+	45.48	0.26	0.00	-0.10	0.22	-0.23
Cl^-	11.11	0.06	0.18	-0.47	-0.55	**0.45**
TH	7.38	0.04	0.20	**0.59**	0.23	**0.69**
Ca^{2+}	5.28	0.03	0.05	0.11	0.07	0.11
Mg^{2+}	4.06	0.02	0.02	0.08	0.02	0.10
Alkalinity	2.96	0.02	0.17	**0.36**	-0.25	-0.31
DO	0.47	0.00	0.00	0.00	-0.01	0.00
HCO_3^-	0.43	0.00	0.21	**0.44**	-0.31	-0.37
F^-	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{2+}	0.00	0.00	0.01	-0.01	-0.01	-0.04
PO_4^{3-}	0.00	0.00	0.00	-0.01	0.00	-0.03
NO_3^-	0.00	0.00	0.00	-0.01	-0.06	-0.01
SO_4^{2-}	0.00	0.00	0.00	0.02	-0.01	-0.03

The principal component analysis for post monsoon season (Table 3.27) showed that a total variance of 99.13%, in which the PC1 showed a strong positive loading of 0.75 with EC and moderately loaded by TDS and K. The mineral related parameters and the potassium in water samples were introduced by anthropogenic sources of fertilizers at the time of crop cultivation. The PC2 showed moderate positive loading with alkalinity and bicarbonates and also mineral related parameters and EC, TDS, Turbidity and Cl. The positive loading is an indication of saline intrusion into the wetlands. The K and Fe are negatively loaded with PC2. The PC3 showed positive loading with alkalinity and bicarbonates and negatively loaded with mineral related parameters (EC, TDS, Cl and DO). In PC4 only TH showed significant positive loading with and Ca and Mg. Majority of PC4 components loaded negatively and indicated the alteration in the running water with season and locations.

Table 3.27. Principal Component Analysis for post monsoon season

PC	Eigenvalue	% variance	PC 1	PC 2	PC 3	PC 4
pH	985403.00	**99.13**	0.00	0.00	0.00	0.00
EC	5966.37	**0.60**	**0.75**	0.25	-0.11	-0.02
TDS	2039.15	**0.21**	**0.49**	0.16	-0.07	-0.01
Turbidity	308.50	0.03	0.00	0.09	0.07	-0.42
Na^+	245.35	0.02	0.00	0.01	0.01	-0.04
K^+	61.83	0.01	**0.45**	-0.62	0.29	0.05
Cl^-	5.23	0.00	0.03	0.16	-0.81	-0.04
TH	1.89	0.00	0.00	0.28	0.12	**0.84**
Ca^{2+}	1.10	0.00	0.00	0.07	0.03	0.20
Mg^{2+}	0.85	0.00	0.00	0.03	0.01	0.08
Alkalinity	0.44	0.00	0.01	**0.41**	**0.30**	-0.17
DO	0.16	0.00	0.00	0.00	-0.01	0.00
HCO_3^-	0.00	0.00	0.01	**0.50**	**0.36**	-0.21
F^-	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{2+}	0.00	0.00	0.00	-0.01	0.00	0.00
PO_4^{3-}	0.00	0.00	0.00	0.00	0.00	-0.01
NO_3^-	0.00	0.00	0.00	0.00	0.00	0.00
SO_4^{2-}	0.00	0.00	0.00	0.02	0.03	-0.06

3.9. Water quality analysis using Kriging

The spatial modelling of selected chemical parameters under the study were carried out using interpolation method, a technique adopted in GIS. The use of spatial interpolation helps in providing a spatial information. Geospatial interpolation technique (kriging) utilizes the statistical properties of the measured points. It quantifies the spatial auto correlation among measured points and account for the spatial configuration of the sample points around the prediction location. pH, iron, sodium and the percent sodium (irrigational parameter) were selected for kriging.

3.9.1.pH

During pre monsoon, centres of relatively low pH has recorded in the NW-SW segment of the wetland system. In the post monsoon period, the water remains acidic only on the NW segment of the study area (Fig.3.16.).

3.9.1.2.Iron

The spatial distribution of iron is presented in Figure 3.17 (a) and (b). The majority of the area falls under the category above the permissible limit.It is due to the lateritic soil , which releases iron to the water by leaching. The figure explains the gradual increase in the iron concentration from SE-NW part of the wetland during post monson. During pre monsoon period the conncentration of iron in selected areas reaches a maximum value of 9.60 ppm.

3.9.1.3.Sodium

The spatial distibution of Sodium concentration is shown in Fig.3.18 (a) and (b).A larger area falls above the BIS acceptance limit of drinking water.However during post monsoon , the water in the entire wetlands falls within BIS acceptance limit.

3.9.1.4. Percentage sodium

Total area wise distribution based on sodium % during different seasons is provided in Table 3.28.Variation of %Na (Fig3.19) is comparatively higher in NW stretch of segment of the study area(365.51 sq. km) during premonsoon period and is classified under doubtful category. An area of 164.81 sq.km falls under permissible category. However , based on the sodium % content quality become good category in the NW segment(164.81 sq.km) and in other parts(365.51sq.km) it become permissible category during post monsoon.

Table 3.28. Area (sq.km) wise variation in surface water quality(%Na)

Percentage sodium	Area (during pre monsoon)	Percentage sodium	Area (during post monsoon)
Excellent	-	Excellent	-
Good	-	Good	164.81
Permissible	164.81	Permissible	365.51
Doubtful	365.51	Doubtful	-
Unsuitable	-	Unsuitable	-

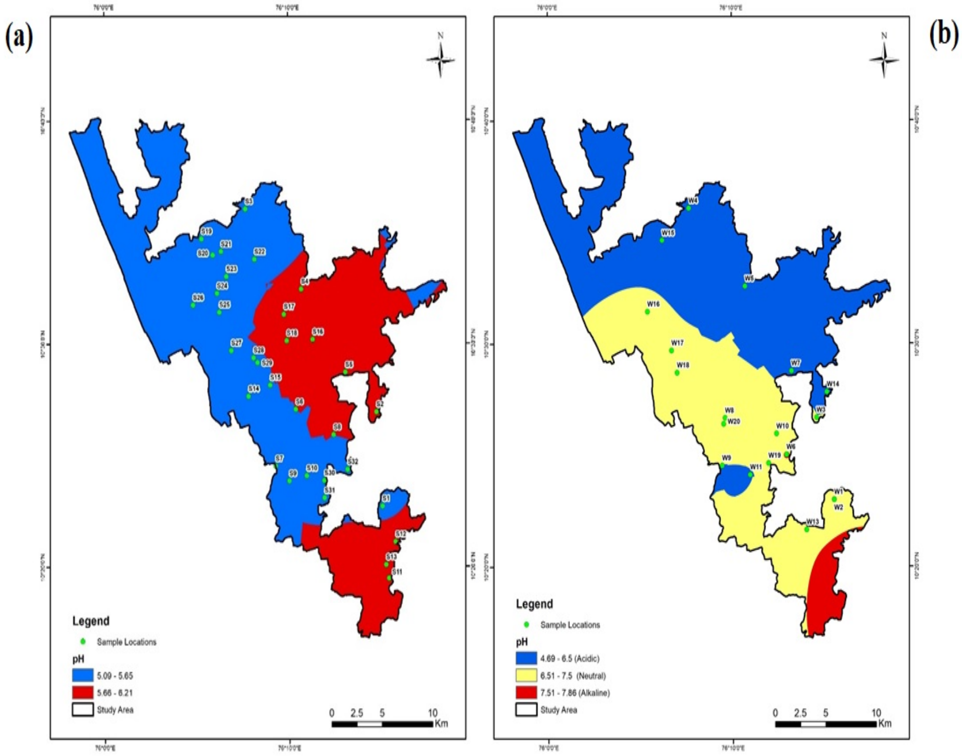


Fig.3.16. Map of pH by Kriging method during **a)** pre monsoon, **b)** post monsoon

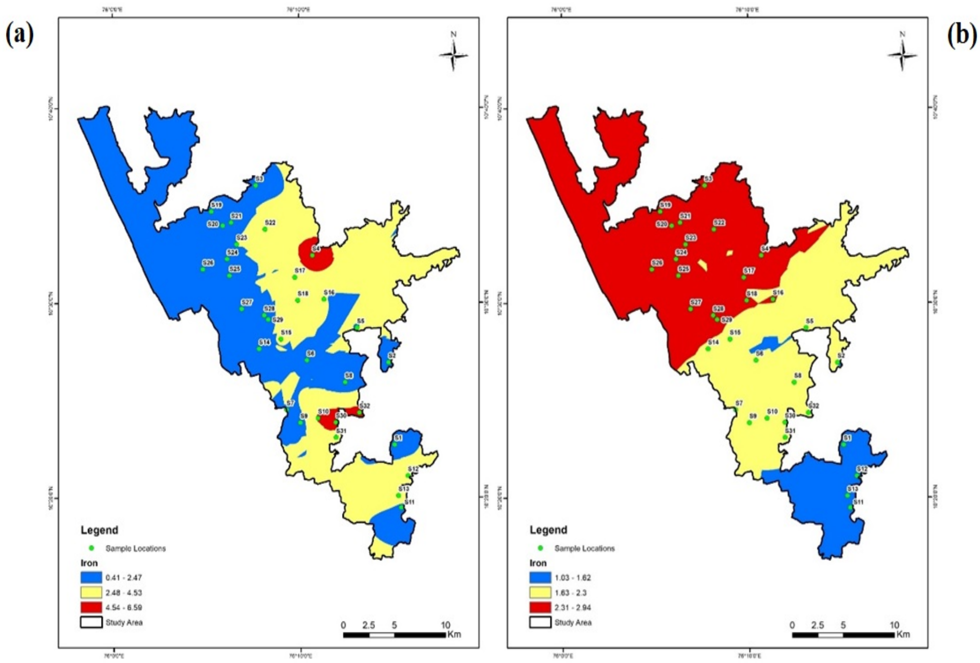


Fig.3.17. Map of Iron by Kriging method during **a)** pre monsoon, **b)** post monsson

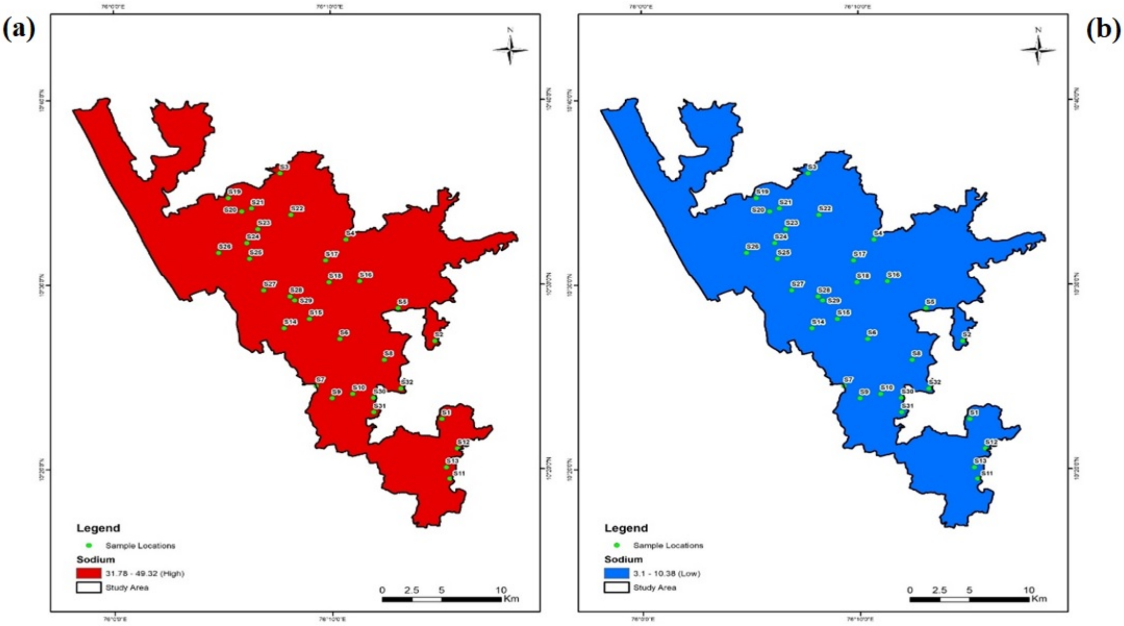


Fig.3.18. Map of sodium by Kriging method during **a)** pre monsoon **b)** post monsoon

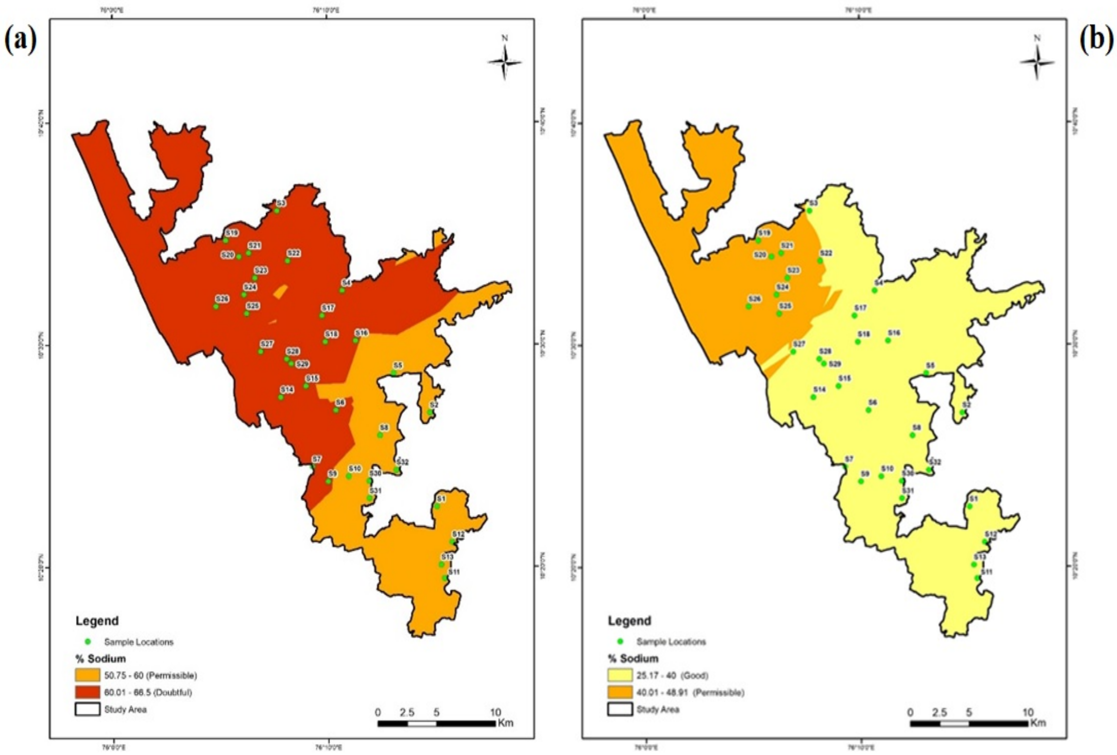


Fig.3.19.Map of percentage sodium by Kriging method during **a)** pre monsoon **b)** post monsoon

3.10.Conclusion

During premonsoon, 90% of the samples were acidic in nature and only two samples (S11 and S16) were alkaline in nature. Duirng postmonsoon ,71% of the water sample were acidic in nature. The electrical conductivity of all the surface water samples were above the acceptance limit in the pre monsoon. The sample S23 was an exception and it showed high electrical conduictivity during post monsoon. During pre monsoon,TDS of all the surface water samples were within the acceptance limit and during postmonsoon season showed four samples were exceeded the permissible limit.

The value of 90% of the water sample exceeded the permissible limit with regard to the sodium during pre monsoon and the sodium concentration of all the water samples remained within the permissible limit during post monsoon . The iron content was below the detectable limit in 21% of the samples in the pre monsoon , however, 96% of the samples are above the permissible limit duirng post monsoon. The presence of high turbidity is due to the presence of dissolved salts like iron and other suspended solids.Where as high value of EC and pottasium content was an indication of saline intrusion into the surface water.

The classification of cation and anion facies in triangular fields of piper plot showed that majority of the surface water samples fall into Ca type in cationic and HCO_3 type in anionic during pre-monsoon. Ca>Na or K >Mg in cationic and HCO_3 > Cl>SO_4 in anionic facies. During post monsoon Na/K> Ca>Mg in cationic and Cl>HCO_3>SO_4 in anionic facies. The tri linear plot in the piper diagram suggests that the alkaline earth exceeds the alkalies, alkalies exceeds alkaline earths, weak acids exceed strong acids, strong acids exceed weak acids, secondary hardness exceeds 50%, primary salinity exceeds 50% and mixed type during pre-monsoon. The post monsoon studies showed that alkalies exceeds alkaline earth, alkaline earth exceeds alkalies, strong acids exceed weak acids, non-carbonate alkali (primary salinity) and none of the cation or anion exceeds 50%.

The water quality characterisation based on irrigation parameters such as salinity hazard, % Na and USSL diagram, the results revealed that the water samples collected from Annakara are not suitable for irrigation during post-monsoon period. The high content of the chloride in S23 was due to the leaching of lime and salt mixture applied to coconut plantation nearby areas and also indicating the presence of salinity intrusion into the Kole wetlands. From USSL diagram the samples S1 and S32 categorized in bad water quality type in pre- monsoon. The sample from S4 and S29 during pre-monsoon are not suitable for irrigation. The system, which received pollutants from the agricultural catchment, influenced the Ca^{2+} and Mg^{2+} concentrations of the water. Based on SAR values the samples S25 to S32 fall in unsuitable category during post monsoon.

The total hardness was highly correlated with Ca^{2+}, Mg^{2+}, and HCO_3^-. Therefore, the hardness of the water is interpreted as temporary hardness. Temporary hardness was due to the presence of $Ca(HCO_3^-)_2$ (calcium hydrogen carbonate) and $Mg(HCO_3^-)_2$ (magnesium hydrogen carbonate). Both calcium hydrogen carbonate and magnesium hydrogen carbonate decompose when heated or boiled.

It was found that during pre-monsoon time, there existed a perfect relationship existed between EC-TDS only. A strong positive correlation was found to exist between seven pair of parameters such as EC- Alkalinity, EC- HCO_3^-, EC-Cl^-, TH-Ca^{2+}, TH-Mg^{2+}, TH- Alkalinity and Ca^{2+}-Mg^{2+} indicating the saline intrusion during summer season.

During post monsoon season, the perfect relation among the parameters EC-TDS and TH-Ca^{2+}. The strong positive correlation observed between seven parameters. The parameters were EC - TH, EC- Alkalinity and EC-HCO_3^-, EC-K, TH-Mg^{2+}, TH-Alkalinity and Ca^{2+}-Mg^{2+}.

The correlation matrix (pre-monsoon) showed that EC of the water is strongly correlated with Cl^-, HCO_3^-, Alkalinity, TH, Ca^{2+}, and Mg^{2+}. The EC and TDS showed strong correlation value with K^+. The high loading may be due to the contribution from fertilizer component of the catchment area. The high concentrations of these parameters in post monsoon samples were due to leachates. The result of One-way ANOVA indicated that there was significant difference in the parameters of surface water in two seasons – pre monsoon and post monsoon of Thrissur Kole wetlands.

From the above results, it was found that the sample(S4) collected from Puzhakkal kayal, a fresh water zone of Thrissur town, was unsuitable for agricultural purpose during pre-monsoon period. The decrease in fresh water potential has assisted in the intrusion of salt water into the shallow fresh water zone.

The water samples at Vaka and Annakara was not suitable for irrigation purposes throughout the season and is linked to the unscientific excavation of lateritic soil from the adjacent low elevated hillock. The removal of porous and permeable lateritic soil reduces the ground water recharge. Adatt and Kaippili areas which was situated below the mean sea level shows high content of sodium during pre-monsoon time. The Sodium Absorption Ratio is found to be high in regions Venkitangue, Padoor, Manalur, Perumpuzha , Kaippilli, in the North Kole and Puthanthode, Vallya paalam and Thelappilli which is a part of South Kole which was unsuitable for irrigation during post monsoon. All evidences direct towards severe water quality deterioration in the entire Kole wetland system dominated by reclamation, increase in settlements, dominants of waste water discharge and saline water intrusion. The problem was more aggravate in North Kole compared to that of South Kole.

The map prepared using kriging method clearly demarcate that the NW part of the wetland area is under the threat of saline intrusion during pre monsoon period. The proximity to the sea can be identified as the source for salinity. It is found that iron content in surface water is above the permissible limit in both the seasons. The concentration of iron become maximum in post monsoon period at the NW segment of the wetland area.

CHAPTER 4

STATUS OF GROUND WATER CHEMISTRY

STATUS OF GROUND WATER CHEMISTRY

4.1 Introduction

Ground water was the major source of water for drinking, irrigation and industries used in all parts of the world. Ground water quality deterioration has become an issue in different areas due to rapid urbanization and industrialization. Ground water quality in a region is largely determined by natural processes and anthropogenic activities viz. agriculture, industry, urban development and over exploitation of water resources. The ground water contains mineral ions in the form of dissolved solids from the aquifers, from the precipitation water or from the river water that recharges the aquifer. Dissolved solids present as a major constituent, secondary constituents or a trace constituent in ground water. The major constituents were sodium, calcium, magnesium, potassium, iron and strontium. The secondary constituents were carbonates, bicarbonates, sulphates, nitrate, chloride, fluoride, silica and boron. The trace constituents include heavy metals, other metals and phosphates and iodides.

Except for natural organic matter originating from top soils, all of the naturally occurring dissolved solids were inorganic constituents, minerals, nutrients and trace elements. The trace elements in low concentrations do not pose threat to human health as it is essential for metabolism. Human activities can alter the natural composition of ground water through the disposal or dissemination of chemicals and microbial matter at the land surface and through injection of wastes directly into the ground water. In India, most of the freshwater sources are found to be contaminated with soluble inorganic and organic material which makes ground water unsuitable for drinking purpose. Groundwater is polluted mainly by sulphates, chlorides, nitrogen compounds (nitrates, ammonia, and ammonium, petroleum products, phenols, iron compounds, and heavy metals -copper, zinc, lead, cadmium, mercury). Groundwater pollution was a serious danger that limits its practical use, primarily for domestic use and drinking water supply. Lead mining was posing threat to the quality of water resources in the Bandalamottu area of Guntur District of Andhra Pradesh. The high concentration of HCO_3^- and CO_3^- and low Ca^{2+}: Mg^{2+} make the groundwater not suitable for sustainable crop production and soil health (Nagaraju et al., 2014). The study carried out in Mysore (Divya and Belagali, 2012), revealed that ground water was found to be alkaline due to application of chemical fertilizers. Nitrate and phosphate concentrations were found to be higher than the permissible limits of WHO standards, due to leaching and surface run off from agricultural lands.

The United State Environmental Protection Agency (USEPA) defined ground water pollution in terms of both inorganic and organic constituents, microbial matter and other ground water quality factors. The contamination of ground water occurred from natural processes or anthropogenic activities. The human activities including commercial, industrial, residential, municipal and agricultural activities altered the quality of ground water and make it unsuitable for drinking.

The water chemistry had an important role in the hydrological cycle from the initial precipitation stage and it's all successive stages. The chemical characteristics of the ground water determined by the chemical characteristics of the soil zone where precipitation and infiltration occurred. The acidic nature of the ground water contributed by organic compounds seen in the soil zone, where the water rock interaction happened. The ion complexing increased with the increase in the level of anionic carbon species (Deutch, 1997). The carbonic acid present in the ground water acted on the silicates and released major cations like Calcium, Magnesium, Sodium and Potassium and which is a very slow process in the water rock interaction. The formation of carbonates occurred from the dissociation of Carbonic acid. The CO_2 present in the groundwater dissociate the Calcium and Magnesium carbonates (Karanth, 1997).

The increase in NO_3^-, SO_4^{2-}, PO_4^{2-}, Ca^{2+}, Na^+, K^+ and Cl^- in the groundwater is the result of direct dissolution or run off from agricultural areas. The source of NO_3^- is mostly from the nitrate fertilizers such as ammonia and that of SO_4 and Ca is gypsum powder. The Potassium and Phosphates are necessary ingredients of NPK fertilizer and Na and Cl are the impurities in the nitrogen rich fertilizers. Another source which contaminates shallow ground waters are leaching from municipal wastes and industries. The content of NO_3^-, SO_4^{2-}, Cl^- and traces of heavy metals that are hazardous to living organisms as a result contamination (Umar et al., 2010). The study within Nanded City, Mahabharata (Sayyed and Bhosle,2011) revealed that the agricultural activities, geological formation and local environmental conditions control the ground water quality.

It is estimated that approximately 17% of the world's population uses water from the unprotected and remote sources, 32% from some form of protected sources and 51% from some sort of centralized (piped) system to the dwelling or a plot (UNICEF/WHO,2008).The chemical quality of the ground water depends upon the interaction of water with aquifer minerals, land use pattern, physiography, effect of agricultural activities ,the anthropogenic activities, chemical composition of precipitation, evaporation and other climatic variables like flood and drought (Indira and Romit, 2017).

4.2 Methodology

The ground water samples were collected from 20 wells (Table 4.1 and Fig 4.1) located at different places in Thrissur Kole wetland area. The samples were collected during pre-monsoon and post monsoon seasons and analysed in the laboratory. The physicochemical characterization of the ground water was carried out by using the APHA (2012) standard methods for surface water analysis as mentioned in chapter3.Suitability of ground water for irrigation purposes is determined by using different parameters (section 3.3). Using GIS interpolation- Kriging , the spatial distribution of pH, iron, sodium and %Na were delineated.

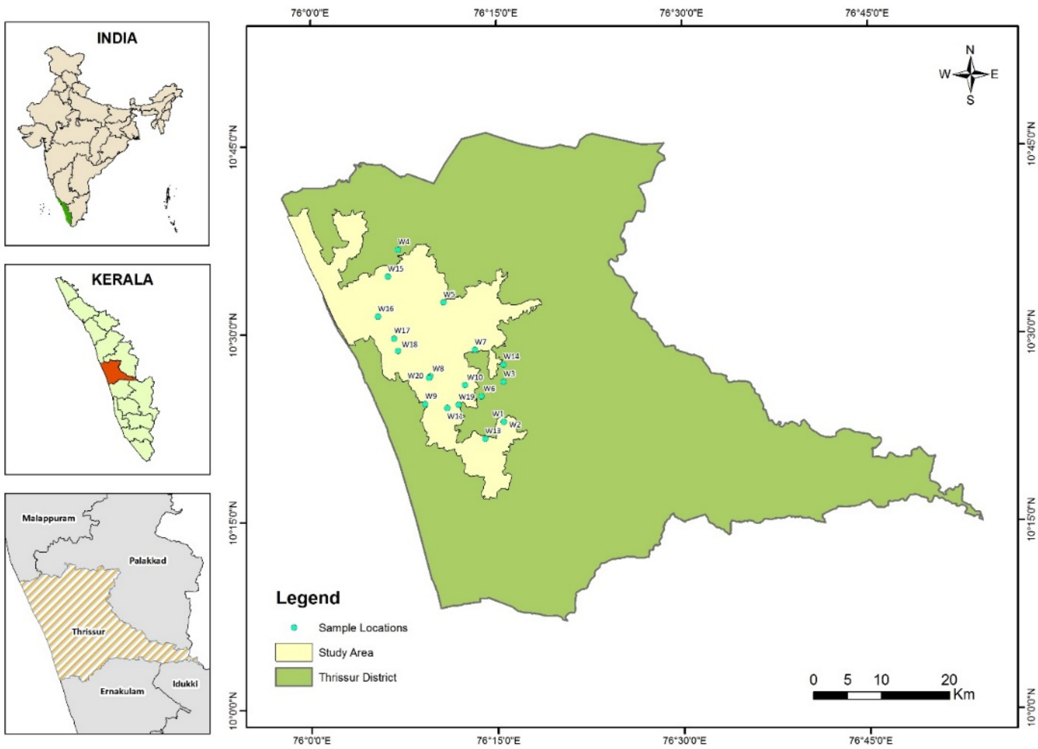


Fig 4.1. The sample locations of ground water from wells

Table.4.1. Sample locations of ground water from wells

Sites	Location	Latitude	Longitude
W1	Konthipulam	N10º23' 0.05"	E 076º15' 31.3"
W2	Nellayi	N10º23' 0.05"	E 076º15' 31.3"
W3	Near manalipuzha	N10º26' 12.3"	E 076º15' 30.9"

W4	Kecheri	N10º36' 47.0"	E 076º07' 01.9"
W5	Adatt	N10º32' 34.1"	E 076º10' 41.9"
W6	Aarattupuzha	N10º25' 02.2"	E 076º13' 43.3"
W7	Kanimangalam	N10º28' 46.3"	E 076º13' 13"
W8	Kundolikadavu	N10º26' 39.8"	E 076º 09' 36.1"
W9	Thannyam	N10º24' 25.8"	E 076º 09' 11.2"
W10	Cherpu church	N10º25' 57.4"	E 076º 12' 23.8"
W11	Karanchira,nearVellani	N10º24' 7.3"	E 076º10' 57.8"
W12	Thommanna,Thuravankad	N10º20' 019"	E 076º15' 13.3"
W13	Muriyaad	N10º21' 39"	E 076º14' 1.3"
W14	Anthikkad	N10º27' 34.3"	E 076º15' 31.3"
W15	Vaka	N10º34' 38.0"	E 076º06' 12.3"
W16	Venkitangue	N10º 31' 26.4"	E 076º05' 24.3"
W17	Manalur	N10º 29' 41.74"	E 076º06' 42.23"
W18	Kanjany	N10º 28' 41.7"	E 076º07' 00.2"
W19	Moorkanaad	N10º 24' 26.78"	E 076º12' 16.31"
W20	Alappatt	N10º 26' 23.56"	E 076º09' 31.28"

4.3 Result and Discussion

4.3.1. Physico chemical characteristics of ground water

Geochemical characteristics of ground water samples collected during the pre-monsoon and post-monsoon were analyzed using standard methods and the suitability for various purposes were examined. The result of the physical and chemical characteristics of ground water samples for the pre monsoon and post monsoon seasons are given in the table (4.2, and 4.3), in the figures 4.2 to 4.7 and the plates 4.1 to 4.3. The ranges in the values of different parameters are listed in table 4.4. The water quality standards are provided in the table 4.5. The groundwater quality was deteriorated by pollution and over exploitation. The rapid growth of industrial and agricultural sector and the non-enforcement of laws led to environmental deterioration.

Table. 4.2: Physico chemical characteristics of ground water (Pre monsoon)

Sample site	pH	EC (µs)	TDS (ppm)	Turbidity (NTU)	Na^+ (ppm)	K^+ (ppm)	Cl^- (mg/L)	TH (mg/L) as $CaCO_3$	Ca^{2+} ppm	Mg^{2+} ppm	Alkalinity (mg/L) as $CaCO_3$	DO mg/l	HCO_3^- (mg/L) as CaCo3	F^- ppm	Fe^{2+} ppm	PO_4^{3-} (ppm)	NO_3^- (ppm)	SO_4^{2-} ppm)
W1	7.18	404.05	262.63	5.00	23.60	6.50	70.90	120.67	39.05	5.60	95.49	6.40	116.50	0.00	0.57	5.36	1.87	0.48
W2	6.14	282.77	183.80	7.00	31.70	7.80	60.80	62.41	16.90	4.90	49.51	6.30	60.40	0.00	0.87	3.47	3.47	1.30
W3	8.54	309.09	200.91	10.00	36.40	4.50	45.60	45.98	12.30	3.70	56.07	7.10	68.40	0.00	0.49	3.80	0.87	0.01
W4	3.56	477.95	310.67	9.00	26.30	3.20	70.90	157.64	48.90	8.60	125.08	3.80	152.60	0.09	0.97	2.70	5.01	0.17
W5	6.94	325.53	211.59	12.00	28.80	8.07	128.06	82.17	25.00	4.78	29.34	4.90	35.80	0.13	1.80	6.70	4.09	0.08
W6	9.16	423.85	275.51	8.70	31.90	9.60	192.36	94.19	19.90	10.80	24.51	5.40	29.90	0.00	0.57	4.30	2.05	0.05
W7	6.23	401.32	260.86	12.60	26.80	9.45	106.35	100.13	25.40	8.90	52.30	5.80	63.80	0.00	0.69	3.40	0.01	0.66
W8	5.90	230.91	150.09	5.00	18.75	6.90	64.04	63.63	16.40	5.50	37.54	6.50	45.80	0.00	0.75	8.07	6.07	1.25
W9	5.32	508.35	330.43	12.00	20.56	7.90	185.63	143.69	28.67	17.50	50.66	5.80	61.80	0.01	0.65	2.65	2.08	2.04
W10	6.52	398.14	258.79	9.00	26.90	10.08	123.56	105.87	23.50	11.45	58.61	5.90	71.50	0.00	1.57	4.05	6.04	4.80
W11	6.56	516.31	335.60	4.80	31.95	12.85	214.60	118.81	31.64	9.65	34.67	6.10	42.30	0.00	2.10	0.80	0.96	1.25
W12	5.71	758.36	492.94	8.90	29.65	23.17	284.60	195.90	43.22	21.35	48.80	5.70	59.54	0.08	1.03	5.08	5.04	0.99
W13	5.62	479.53	311.69	12.00	29.80	19.70	189.30	95.35	22.80	9.32	36.98	6.12	45.11	0.05	1.01	0.76	3.07	1.17
W14	6.39	534.25	347.26	10.90	28.90	13.70	214.60	94.61	23.90	8.47	26.32	6.30	32.11	0.00	0.47	4.60	11.50	0.09
W15	4.90	354.10	230.17	8.00	25.74	14.67	133.50	64.04	10.88	8.96	20.75	5.80	25.32	0.01	0.39	1.08	4.08	0.10
W16	6.99	399.01	259.36	11.00	25.80	12.55	169.30	75.88	13.33	10.34	25.56	5.10	31.19	0.00	0.70	2.06	6.04	0.09
W17	6.75	483.66	314.38	13.40	28.35	14.80	201.60	87.93	19.70	9.40	28.07	6.70	34.25	0.01	0.64	8.04	2.04	0.03
W18	6.30	366.22	238.05	10.90	23.30	13.90	110.60	101.07	26.84	8.25	58.11	5.70	70.90	0.00	0.37	0.47	0.00	0.01
W19	5.74	422.74	274.78	8.00	32.50	4.10	70.90	125.08	33.90	9.80	101.23	5.12	123.50	0.00	1.01	0.64	0.00	0.08
W20	5.32	509.68	331.29	14.00	22.85	9.56	138.60	130.16	32.40	11.95	71.07	6.40	86.70	0.00	0.98	7.89	1.01	0.09

Table .4.3: Physico chemical characteristics of ground water (Post monsoon)

Sample sites	pH	EC (µs)	TDS (ppm)	Turbidity (NTU)	Na^+ (ppm)	K^+ (ppm)	Cl^- (mg/L)	TH (mg/L) as CaCo3	Ca^{2+} ppm	Mg^{2+} ppm	Alkalinity (mg/L) as CaCo3	DO mg/l	HCO_3^- (mg/L) as CaCo3	F^- ppm	Fe^{2+} ppm	PO_4^{3-} (ppm)	NO_3^- (ppm)	SO_4^- ppm)
W1	7.23	169.11	109.92	2.30	8.12	11.90	24.00	27.88	7.20	2.40	33.98	7.90	41.45	0.30	1.45	0.57	5.20	0.00
W2	6.83	194.68	126.54	4.60	7.65	13.80	45.00	40.81	8.85	4.54	35.16	8.00	42.90	0.20	2.35	1.90	1.10	0.80
W3	6.00	177.39	115.30	7.90	1.60	10.80	32.00	86.31	26.62	4.80	36.48	7.60	44.50	1.50	0.98	0.10	3.90	1.98
W4	3.54	134.37	87.34	5.00	1.80	9.90	22.00	65.78	17.59	5.30	29.26	6.90	35.70	0.00	0.04	2.50	2.10	1.05
W5	6.27	174.05	113.13	6.90	3.90	14.30	30.00	35.19	10.95	1.90	31.16	8.70	38.01	0.08	2.30	0.98	16.00	0.07
W6	9.16	192.17	124.91	4.81	3.10	18.80	23.00	43.99	16.00	0.97	51.78	5.00	63.18	0.00	1.30	1.10	9.10	0.04
W7	6.18	114.75	74.59	4.80	4.50	21.09	18.00	22.17	6.40	1.50	27.13	6.80	33.10	0.01	2.60	0.08	4.75	0.00
W8	6.89	100.38	65.25	3.90	6.30	18.56	28.00	20.02	7.20	0.49	6.23	7.18	7.60	0.90	1.40	0.58	5.69	0.10
W9	6.47	243.10	158.02	8.96	6.93	8.73	30.00	34.38	9.80	2.40	32.46	6.90	39.60	0.01	0.87	0.07	23.68	0.56
W10	6.52	190.85	124.05	5.94	5.70	9.36	8.50	29.82	8.90	1.84	46.15	6.78	56.30	0.04	0.51	3.71	25.00	0.45
W11	5.41	157.15	102.15	4.87	4.80	8.09	9.60	28.46	8.26	1.90	39.92	8.60	48.70	0.69	0.08	2.90	1.20	0.80
W12	8.89	220.11	143.07	6.57	9.95	11.89	24.80	82.44	26.56	3.90	53.72	6.18	65.54	0.01	0.93	4.60	45.00	1.07
W13	5.62	149.60	97.24	3.00	4.70	9.66	22.60	31.36	8.13	2.68	26.72	5.90	32.60	0.04	1.89	1.98	1.60	0.87
W14	6.39	132.28	85.98	2.90	5.60	11.08	17.00	35.00	14.00	0.00	29.92	6.00	36.50	0.03	2.90	2.89	1.90	1.80
W15	6.71	84.41	54.87	4.87	3.90	11.33	7.10	23.72	7.84	1.00	35.74	7.13	43.60	0.06	1.97	7.80	16.30	0.10
W16	6.99	164.82	107.13	6.40	4.80	9.09	30.00	43.57	15.80	0.99	29.67	7.50	36.20	0.06	2.70	2.81	5.20	0.25
W17	6.24	176.12	114.48	7.00	4.90	10.89	18.00	84.12	32.00	1.00	47.91	6.14	58.46	0.01	5.60	0.97	4.40	0.79
W18	7.10	227.03	147.57	5.60	1.80	12.90	41.00	70.00	28.00	0.00	44.10	5.60	53.80	0.25	2.70	3.00	5.20	0.07
W19	7.64	121.68	79.09	5.90	2.80	7.09	17.00	41.17	14.00	1.50	28.61	6.14	34.90	0.07	6.40	0.10	4.40	1.80
W20	6.94	136.40	88.66	3.00	1.70	12.90	14.00	41.53	15.00	0.98	36.07	7.15	44.00	0.07	0.90	0.08	1.20	0.08

Table 4.4. Concentration range for different parameters

Parameters	Pre monsoon		Post monsoon	
	Maximum	Minimum	Maximum	Minimum
pH	9.160	3.560	9.160	3.540
EC	758.362	230.908	243.105	84.412
TDS	492.935	150.090	158.018	54.868
Turbidity	14.000	4.800	8.960	2.300
Sodium	36.400	18.750	9.950	1.6
Potassium	23.170	3.200	21.090	7.090
Chloride	284.600	45.600	45.000	7.100
TH	195.898	45.976	86.310	20.016
Calcium	48.900	10.875	32.000	7.2
Magnesium	21.350	3.700	5.300	0.000
Alkalinity	125.082	20.755	53.720	6.220
DO	7.100	3.800	8.700	5.000
Bicarbonates	152.600	25.321	65.540	7.600
Flouride	0.130	0.000	1.500	0.000
Iron	2.100	0.370	2.900	0.040
Phosphate	8.070	0.470	7.800	0.068
Nitrate	11.500	0.000	45.000	1.100
Sulphate	4.8000	0.005	1.980	0.000

4.3.1.1 pH

p^H could be affected by chemicals in the water. The p^H of the ground water in the study region for both seasons was in between 3.56 and 9.16 (Table 4.4 and Fig 4.2(a)). The sample W4 showed acidic nature during both seasons. It’s located on the bank of Kecheeri River and had lateritic parent rock. The low pH of the sample due to the excessive usage of acidic fertilizers and super phosphate of lime as manure for agriculture practices .It is also attributed to the acidic lateritic soil which was porous and permeable (Rajesh et al.,2001) .In W6, the water remained alkaline throughout the year and located very close to bath tubs of Karuvannur river bank. The tendency to be alkaline at this location is attributed to the weathering of alkaline parent material. All other samples were well within the limit of WHO water quality standards.

4.3.1.2 Electrical Conductivity

The Electrical conductivity value of samples ranged from 230.91(W8) to 758.36 µm (W12) in pre monsoon season. The post monsoon season showed a minimum value of 84.412 (W15) and a maximum of 243.105 µm (W12) (Table 4.4 and Fig 4.2(b)).

4.3.1.3 Total Dissolved Solids (TDS)

The Total Dissolved Solids values during pre-monsoon season ranged from 150.09 in (W8) to 492.935 µm (W12) (Table 4.4 and Fig 4.2 (c)). In post monsoon, the value ranged between 54.868 µm (W15) to 158.018 µm(W12). All water samples fall within the permissible limits for both drinking and irrigational purpose in both seasons.

4.3.1.4 Turbidity

The turbidity of ground water samples showed a minimum value of 4.800 NTU at W11 and a maximum of 14.000 NTU at W20 in pre monsoon season. All the samples except W1, W8,W11 exceeds the acceptance limit of drinking water quality according to water quality standards. During post monsoon, the minimum value showed 2.3000NTU (W1) and the maximum value exceeds the acceptance limit, 8.960 NTU (W9) (Table 4.4 and Fig 4.3(d)). During monsoon more silt, sand, clay particles have been discharged in to the well through underground soil pipes.

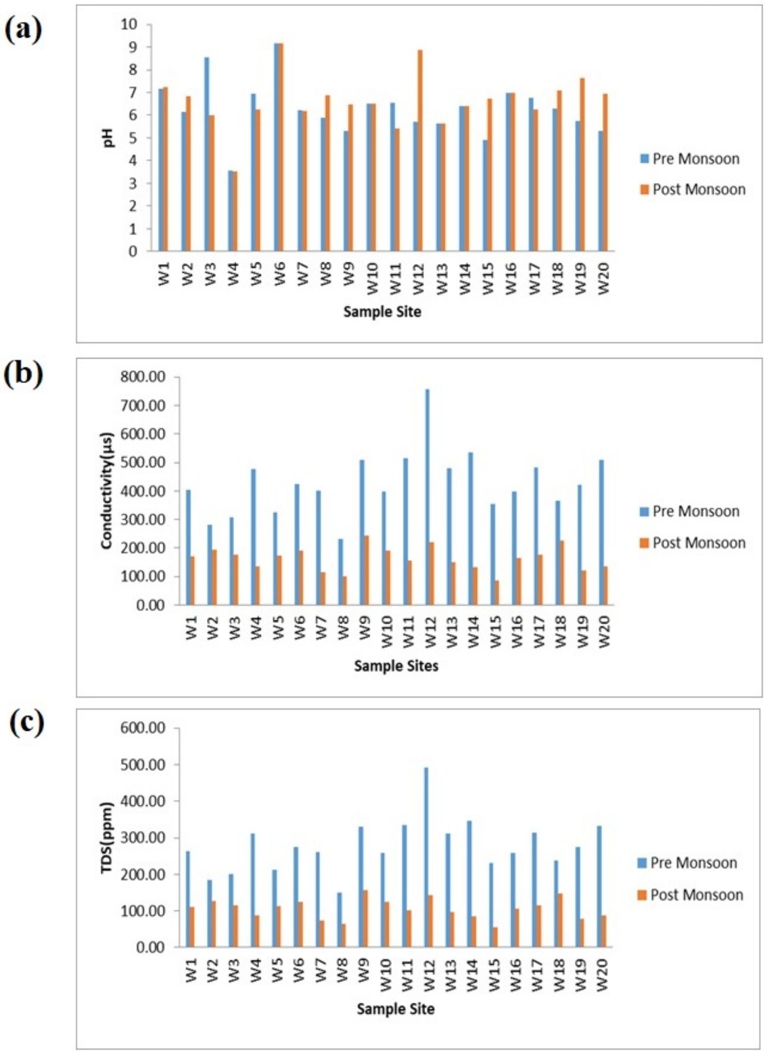


Fig.4.2. Seasonal variations of different parameters **a)** pH, **b)** conductivity, **c)** TDS

4.3.1.5 Sodium

Sodium may affect the taste of drinking-water at levels above about 200 mg/L. (USEPA,1996). The sodium value ranged from 18.750 ppm (W8) to 36.400 ppm (W3) in pre monsoon period. During post monsoon, the minimum value observed was 1.600 (W3) and maximum 9.950 NTU (Table 4.4 and Fig 4.3(e)).

4.3.1.6 Potassium

The potassium value ranged from 3.200 ppm (W4) to 23.170 ppm (W12) for pre monsoon and 7.090 ppm (W19) to 21.090 ppm(W7) for post monsoon season. The higher values of potassium indicate the leaching of the fertilizer residues from the paddy fields (Table 4.4 and Fig 4.3(f)).

(d)
(e)
(f)

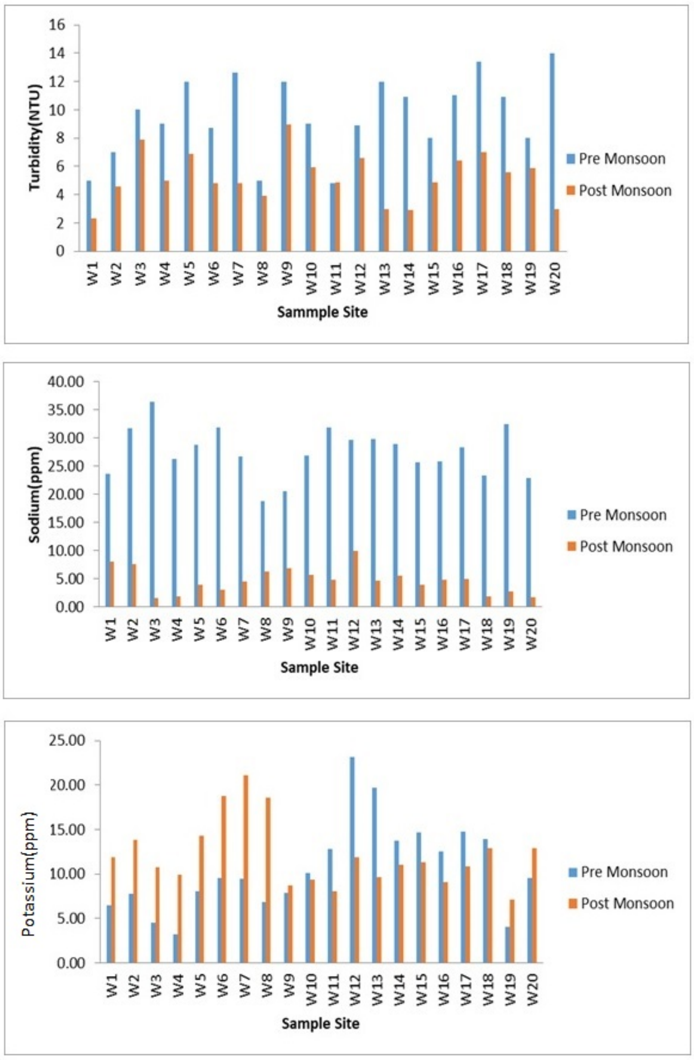


Fig.4.3. Seasonal variations of different parameters **d)** turbidity, **e)** sodium, **f)** potassium

4.3.1.7 Chloride

The concentration of chlorides ranges from 45.600 ppm (W3) to 284.600 ppm (W12) which exceeded the acceptance limit indicating the saline intrusion to the fresh water from the sea during pre-monsoon season (Table 4.4 and Fig 4.4(g)). The value ranged from 7.100 ppm (W15) to 45.000 ppm (W2) during post monsoon season.

4.3.1.8 Total hardness

The total hardness ranged from 41.27 mg/L as $CaCO_3$ (W3) and 187.29 mg/L as $CaCO_3$ in pre monsoon. During post monsoon the minimum value was 20.016 (W8) and the maximum of 86.310 (W3) (Table 4.4 and Fig 4.4(h)).

4.3.1.9 Calcium

The concentration of Calcium in ground water ranges from 10.875 (W15) to 48.900 ppm (W4) during pre-monsoon season. However, during post monsoon season, the Ca ranges from 7.200 ppm (W1 and W8) to 32.000 ppm(W17) (Table 4.4 and Fig 4.4(i)).

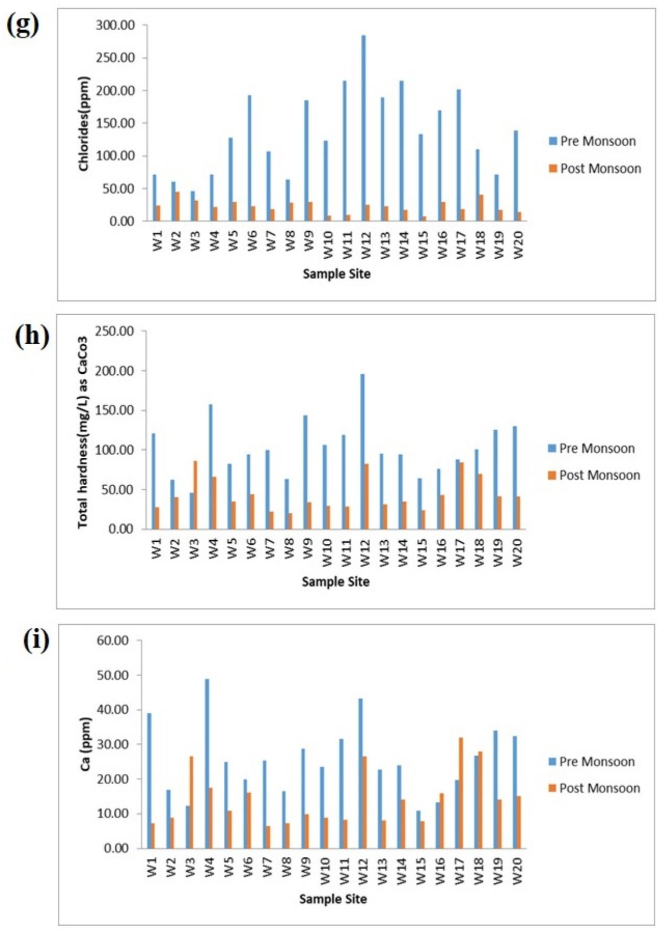


Fig.4.4. Seasonal variations of different parameters **g)** cl, **h)**total hardness, **i)** calcium

4.3.1.10 Magnesium

During pre monsoon season, Mg showed a minimum value of 3.700 ppm (W3) and a maximum of 21.350 ppm (W12). During post monsoon season, the value reached to a maximum of 5.300ppm (W4) (Table 4.4 and Fig 4.5(j)).

4.3.1.11 Alkalinity

The alkalinity of ground water during pre-monsoon season ranged from 20.755 ppm (W15) to 125.082 ppm (W4). During the post monsoon values showed a minimum of 6.229 ppm (W8) and maximum of 53.721) ppm (W12), (Table 4.4 and Fig 4.5(k)).

4.3.1.12. Bicarbonate

The value of bicarbonate in ground water varied between 25.321ppm (W15) and 152.600 ppm(W4) in the pre monsoon season. During post monsoon, it ranged from 7.600 ppm (W8) to 65.540 ppm (W12) (Table 4.4 and Fig 4.5(l)). The primary source of carbonate and bicarbonate ions in water was dissolved CO_2 in rain. Decay of organic matter also contribute to CO_2 enrichment.

4.3.1.13. Dissolved Oxygen

Oxygen was supplied to ground water through recharge and by movement of air through unsaturated material above the water table (Hem, 1985). During pre-monsoon season, the DO showed a minimum value of 3.800 (W4) and a maximum of 7.100ppm (W3). In the post monsoon season values of DO ranged from 5.000 (W6) to 8.700 ppm(W5) (Table 4.4 and Fig 4.6(m)).

4.3.1.14. Fluoride

Fluoride concentrations above 1.5 ppm in drinking water cause dental fluorosis and much higher concentration results skeletal fluorosis. Low concentration (approximately 0.5 ppm) provides protection against dental caries (Manoj and Avinash, 2012). The maximum fluoride concentration in ground water is 0.130 ppm (W5) and 1.500 ppm (W3) in pre monsoon and post monsoon seasons respectively (Table 4.4 and Fig 4.6(n).

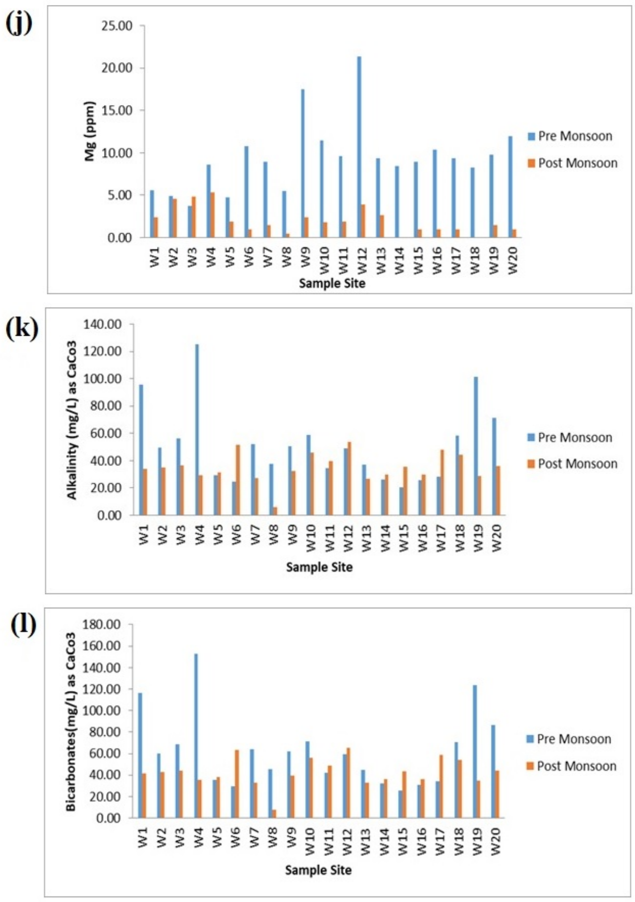


Fig.4.5. Seasonal variations of different parameters **j)** magnesium, **k)** alkalinity, **l)** bicarbonate

4.3.1.15 Iron

The Iron content in ground water in pre- monsoon showed a maximum value of 2.100 ppm (W11) and a minimum of 0.370 ppm (W18). During the post monsoon season, the values ranged between 0.040 ppm (W4) and 2.900ppm(W14) (Table 4.4 and Fig 4.6(o)).

(m)

(n)

(o)

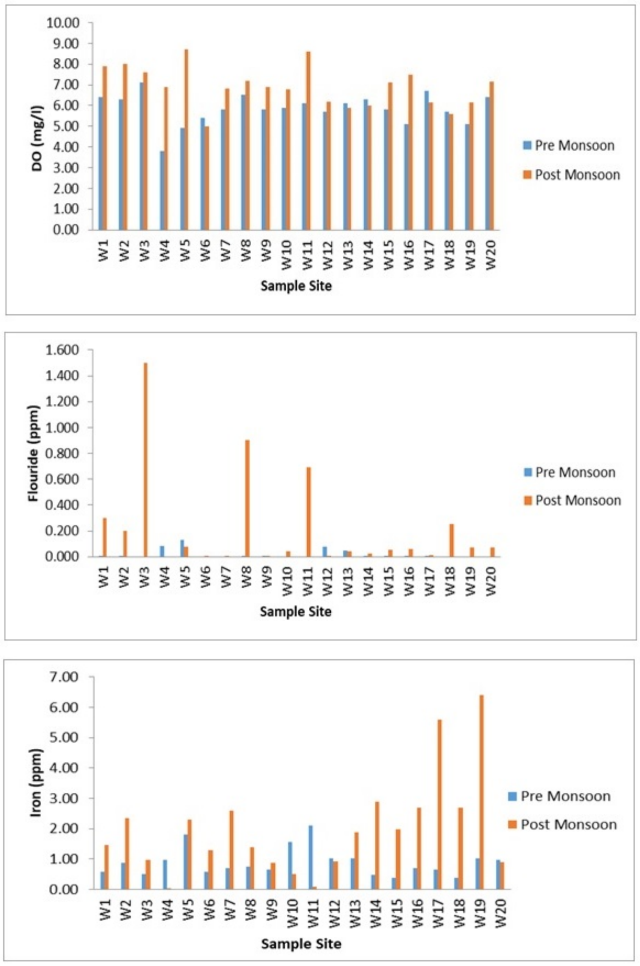


Fig.4.6. Seasonal variations of different parameters **m)** DO, **n)** fluoride, **o)** iron

4.3.1.16 Phosphate

Rainfall can cause varying amounts of phosphates to wash from farm soils into nearby waterways. Phosphates were not toxic to people or animals unless they are present in very high levels. Digestive problem could occur from extremely high level of phosphate. During pre-monsoon season, the phosphate content varied from 8.070 ppm (W8) to 0.470 ppm(W18). The post monsoon season the minimum value was 0.37 ppm (W18) and the maximum value was 1.800 ppm (W5) (Table 4.4 and Fig 4.7(p)).

4.3.1.17. Nitrate

The nitrate content during pre-monsoon seasons showed a maximum value of 11.500 ppm (W14) and the in post monsoon the maximum value was 45.00ppm(W12) and minimum rate of 1.100 ppm(W2) (Table 4.4 and Fig 4.7(q)).

4.3.1.18. Sulphate

There is no proposal for health-based guideline value for sulfate in drinking water. But a noticeable taste felt as concentrations in water increase above 500 mg/L (WHO,1996).The maximum value of sulphate content in the ground water is 4.800ppm (W10) during pre-monsoon and 1.980 (W19) during post monsoon (Table 4.4 and Fig 4.7(r)).

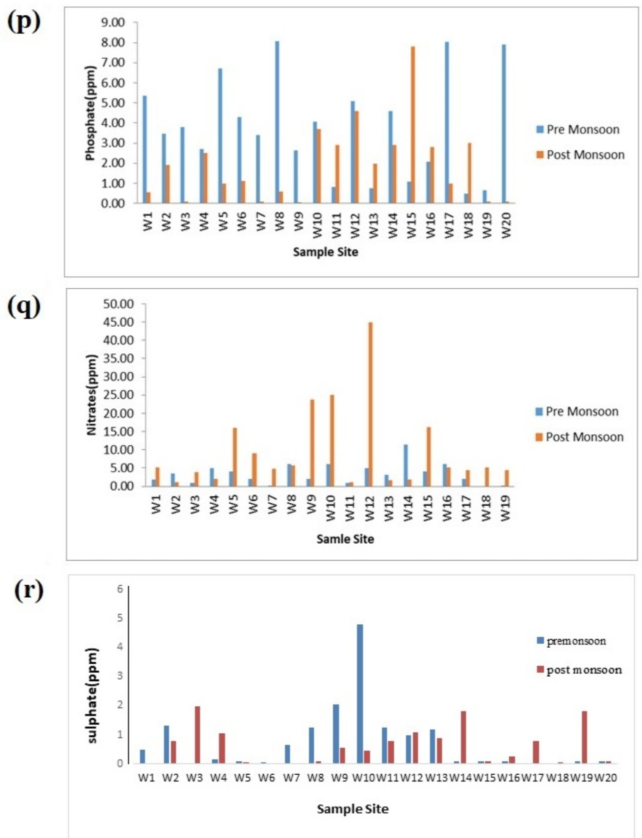


Fig.4.7. Seasonal variations of different parameters **p)** phosphate, **q)** nitrate **r)** sulphate

4.3.2 Comparative evaluation of water quality parameters

The various physico chemical parameters of the groundwater samples was compared with BIS 2012 and given in the table 4.5. It is found that in post monsoon period, ground water at 9 locations were not within the permissible limit of drinking water standards. However, during pre-monsoon season, the ground water at 17 locations was not within the permissible limit of BIS, 2012 of drinking water standards.

Table 4.5 Comparative evaluation of hydro chemical parameters of ground water quality with quality standards.

Sl No.	Parameters	Acceptable limit	Permissible limit	Average values of water samples
1	pH	6.5 – 7.5	No relaxation	6.469
2	EC	100	2000	296.157
3	TDS mg/l	500	2000	192.502
4	Turbidity NTU	1	5	7.436
5	Sodium mg/l	20	500	16.127
6	Potassium mg/l	-	-	11.379
7	Chloride mg/l	250	1000	80.935
8	TH	200	600	73.823
9	Calcium mg/l	75	200	20.093
10	Magnesium mg/l	30	100	5.733
11	Alkalinity	200	600	43.321
12	Bicarbonates	-	-	5.851
13	DO	-	-	6.376
14	Flouride mg/l	1.0	1.5	0.117
15	Iron mg/l	0.3	No relaxation	1.438
16	Phosphates mg/l	-	-	2.866
17	Nitrate mg/l	45	No relaxation	6.206
18	Sulphate mg/l	200	400	1.370

4.3.3 Hydrochemistry of ground water using Piper Tri linear Diagram

The chemical characteristics of water is evaluated by plotting piper trilinear diagram (fig.4.8) to find out the chemical behavior in two seasons. In the pre-monsoon, majority of the water samples fall in the field of 1, 2, 3,4,5,6,7 and 9 ,90% in alkaline earth (Ca+ Mg) exceed alkalies (Na +K),10% in alkalies exceeds alkaline earths, 20% in weak acids (CO_3 + H CO_3) exceed strong acid (SO_4+Cl),80% in Strong acids exceeds weak acids,15% in carbonate hardness (secondary hardness) exceeds 50%, 5% in Non-carbonate alkalinity (primary salinity) and 65% in mixed type (none of the cation or anion pairs exceeds 50%). The post monsoon season samples fall in the field 1, 2, 3,4, 5 and 9, 85% in the alkaline earth exceed alkalies, 15% in alkalies exceeds alkaline earths, 95% in weak acids exceed strong acids, 5% in Strong acids exceeds weak acids, 85% in carbonate hardness (secondary hardness) and 10% in mixed type respectively (Table 4.6).

From the cationic and anionic triangular fields of Piper diagram during pre-monsoon season, it was observed that 40 % of ground water samples fall in the catanionic calcium dominant type and 5% in Na/K type. 55 % in non-dominant, whereas 20% in bicarbonate and 80% in chloride anion facies (Fig. 4.8). In the post monsoon season 65 % of the water samples fall in the calcium ,20% in Na/K and 25% in non-dominant type cationic facies. During the post monsoon season, 95% fall into anionic facies of bicarbonate and 5% in chloride type (Fig 4.9). The sample W8 fall in the category 7- the primary salinity, cationic Na/K and also in chloride of anionic facies. This indicates the saline intrusion during post monsoon season. The sample 7 also fall in the Na/ K type. Majority of the samples ie., 75% fall into the chloride anionic facies of the triangular piper plot. The geochemical classification of the water samples during different seasons with respect to the cation and anion is tabulated in Table 4.7.

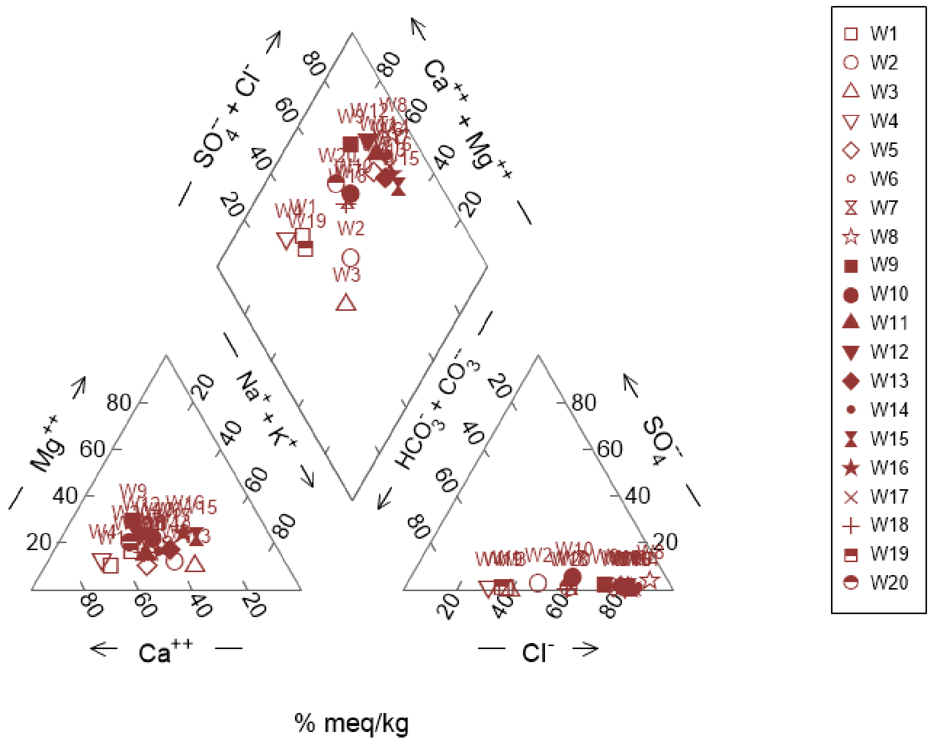


Fig.4.8. Piper plot for Pre monsoon season

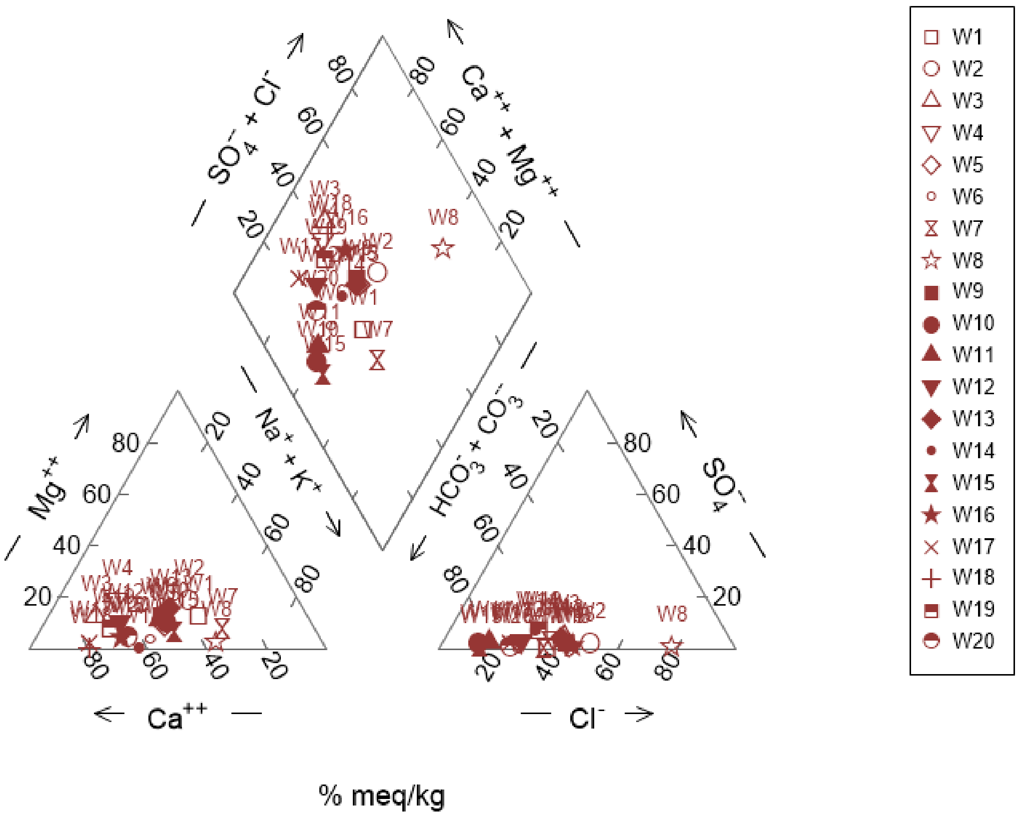


Fig.4.9. Piper plot for Post monsoon season

Table.4.6 Characterization of ground water on the basis of Piper Tri linear diagram

Subdivision of the diamond	Characteristics of corresponding subdivisions of diamond shaped fields	Number of samples	
		Pre monsoon	Post monsoon
1	Alkaline earth (Ca+ Mg) exceed alkalies (Na +K)	18	17
2	Alkalies exceeds alkaline earths	2	3
3	Weak acids (CO_3+HCO_3) exceed strong acids (SO_4 + Cl)	4	19
4	Strong acids exceed weak acids	16	1
5	Carbonate hardness (secondary alkalinity) exceeds 50%	3	17
6	Non carbonate hardness (secondary salinity) exceeds 50%	3	-
7	Non carbonate alkali (primary salinity) exceeds 50%	1	-
8	Carbonate alkali (primary alkalinity) exceeds 50%	-	-
9	None of the cation-anion pairs exceeds 50%	13	2

Table 4.7 Geo chemical classification of the ground water with respect to the cation and anion

Sl.no.	Water type	Sample	
		Pre monsoon	Post monsoon
Cation facies			
A	Magnesium	-	-
B	Calcium	8	13
C	Sodium or Potassium	1	2
D	No dominant	11	5
Anion facies			
E	Sulphate	-	-
F	Bicarbonate	4	19
G	Chloride	16	1
H	No dominant	-	-

4.3.3.1 Irrigational quality status of ground water

The important chemical characteristics considered for the suitability of water for irrigation purposes depend on salinity hazard, Sodium Percentage, Wilcox diagram, Sodium Absorption Ratio (SAR), US Salinity Laboratory Diagram, Permeability Index, Magnesium hazard ratio and Kelly's ratio. The values of each parameter were calculated and given in Table 4.9.

4.3.3.2 Salinity hazard

Richards (1954) classified irrigation water based on the concentration of soluble salt (salinity hazard). On the basis of electrical conductivity and Sodium Absorption Ratio, water has been classified into 4 groups. The EC value ranges from 84.412 to 758.362 µm. During pre-monsoon, 95% falls under Good category and 5% in Excellent. All the post monsoon samples fall into excellent category (Table 4.8).

Table 4.8. Irrigation quality of water (after Richards, 1954)

Sl. No.	Water class	Electrical conductivity	Number of samples	
			Premonsoon	Post monsoon
1	Excellent	Up to 250	W8	W1 to W20
2	Good	250-750	W1,W2,W3,W4,W5,W6,W7,W9,W10,W11,W12,W13,W14,W15,W16,W17,W18,W19, W20	
3	Fair/ Medium	750-2250		
4	Poor /Bad	>2250		

Table 4.9 Irrigation parameters of ground water samples for all seasons

	Pre monsoon					Post monsoon				
	% Na	SAR	PI	MH	Kelly's Ratio	% Na	SAR	PI	MH	Kelly's Ratio
W1	33.110	0.695	70.095	19.120	0.426	54.148	0.522	129.404	35.463	0.634
W2	55.872	1.349	90.422	32.339	1.106	45.685	0.420	102.043	45.819	0.408
W3	64.906	1.809	105.624	33.150	1.724	16.710	0.056	51.514	22.912	0.040
W4	28.026	0.684	63.507	22.476	0.363	20.146	0.075	60.578	33.188	0.060
W5	47.067	1.042	69.767	23.966	0.763	43.237	0.215	109.927	22.242	0.241
W6	46.463	1.157	63.859	47.220	0.737	41.208	0.147	113.759	9.086	0.154
W7	41.305	0.912	69.133	36.613	0.583	62.406	0.317	146.018	27.869	0.442
W8	43.836	0.798	80.617	35.602	0.642	65.197	0.445	93.074	10.087	0.686
W9	27.636	0.610	50.489	50.155	0.312	43.312	0.393	112.068	28.760	0.439
W10	40.304	0.913	68.579	44.543	0.553	45.001	0.344	143.295	25.418	0.416
W11	41.999	0.989	59.066	33.457	0.586	42.238	0.298	141.827	27.499	0.367
W12	32.475	0.740	43.774	44.886	0.330	30.921	0.355	70.678	19.491	0.263
W13	48.587	1.051	67.363	40.258	0.681	41.891	0.285	112.616	35.180	0.326
W14	45.965	1.012	63.006	36.877	0.665	42.993	0.291	107.945	0.000	0.349
W15	53.880	1.173	73.524	57.581	0.875	49.241	0.258	157.825	17.374	0.358
W16	48.770	1.074	69.641	56.116	0.740	33.651	0.229	90.767	9.362	0.240
W17	47.849	1.054	66.311	44.028	0.702	22.646	0.167	62.993	4.899	0.127
W18	40.411	0.782	68.983	33.641	0.502	22.607	0.066	68.948	0.000	0.056
W19	37.805	0.977	72.514	32.275	0.566	26.938	0.140	93.041	15.011	0.148
W20	32.265	0.684	60.833	37.802	0.382	32.751	0.083	102.225	9.723	0.089

4.3.3.3 Percent sodium

Sodium concentration was important in classifying irrigation water because sodium reacts with soil to reduce its permeability. Excess sodium in water produces undesirable effects of changing soil properties and reducing soil permeability

(Kelly,1951). The use of high percentage sodium water for irrigation, stunts the plant growth and reduce permeability of the soil. During pre-monsoon season, 30% of the samples fall into the good water class category, 65% in permissible and 5% in the doubtful category. The post monsoon samples showed that 5% of the samples fall into the Excellent ,35% in Good and 50% in permissible and 10 % in doubtful category (Table 4.10).

Table 4.10. Ground water quality based on the percentage of sodium

Sl.No	Sodium (%)	Water Class	Seasons	
			Pre monsoon	Post monsoon
1	<20	Excellent	-	W3
2	20-40	Good	W1, W4, W9, W12 W19, W20	W4,W12, W16, W17, W18,W19,W20
3	40-60	Permissible	W2, W5, W6, W7 W8,W10,W11,W13W14,W15,W16,W17W18	W1,W2,W5,W6,W9, W10,W11,W13,W14, W15
4	60-80	Doubtful	W3	W7, W8
5	>80	Unsuitable	-	-

4.3.3.4 .Wilcox diagram

The Wilcox diagram relating electrical conductivity and Sodium percentage showed that all the samples of pre monsoon season came under the category of Excellent to Good (Table 4.11 and Fig 4.10(a)). All the samples in the post monsoon also fall in Excellent to Good category (Table 4.7 and Fig 4.10(b)).

Table. 4.11. Rating of surface water samples from Wilcox diagram

Sl No	Class	Sample	
		Pre monsoon	Post monsoon
1	Excellent to good	All samples	All samples
2	Good to permissible		
3	Permissible to doubtful		
4	Good to permissible		
5	Doubtful to unsuitable		
6	Unsuitable		

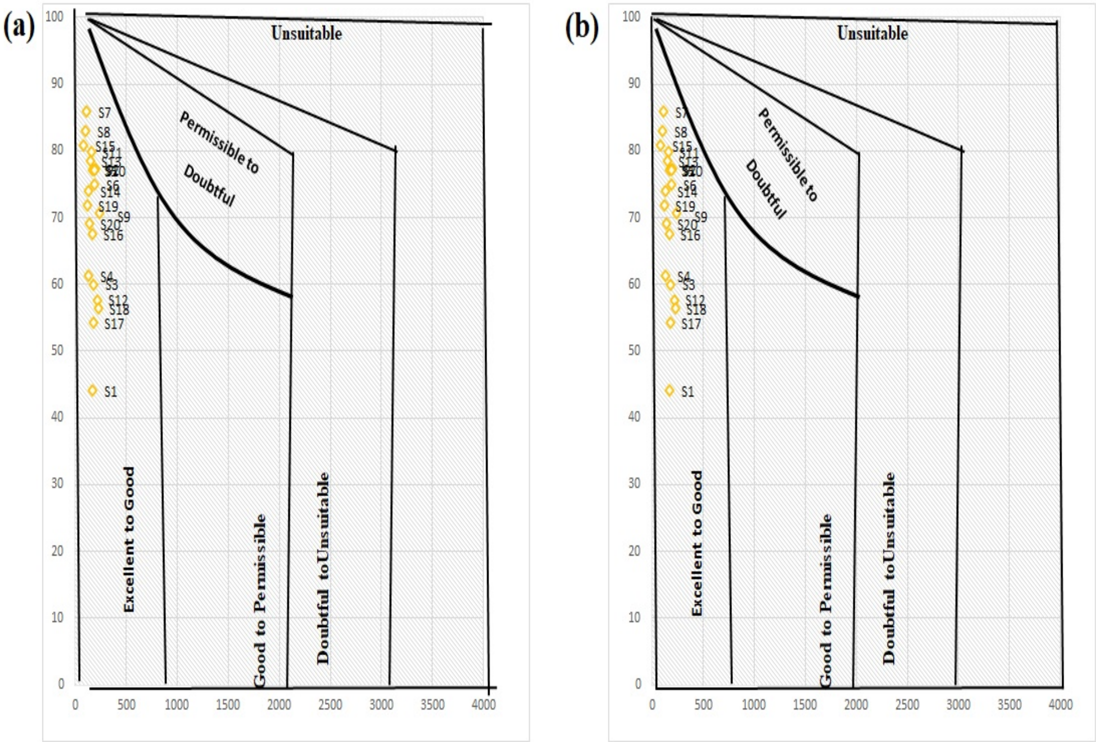


Fig.4.10. Qualification of water quality for irrigation during **a)** pre-monsoon, **b)** post monsoon (after Wilcox, 1948)

4.3.3.5 Sodium Adsorption Ratio (SAR)

Irrigation water containing large amounts of sodium cause sodium hazard, leads to a breakdown in the physical structure of the soil. Sodium is adsorbed and becomes attached to soil particles. The soil then becomes hard and compact when dry and increasingly impervious to water penetration. Fine textured soils, especially those high in clay, are most subject to this action. Certain amendments may be required to maintain soils under high SARs. Calcium and magnesium, if present in the soil in large enough quantities, will counter the effects of the sodium and help maintain good soil properties (Fipps, 2003). All the samples in two seasons- pre monsoon and the post monsoon season showed that 40% in Excellent category,40% in Good and 20% in fair (Table 4.12).

Table 4.12. Ground water quality based on sodium / alkalinity hazard

Sl.No	SAR	Water class	Samples	
			Pre monsoon	Post monsoon
1	< 10	Excellent	All samples	All samples
2	10-18	Good		
3	18 – 26	Doubtful		
4	> 26	Unsuitable		

4.3.3.6 U S Salinity Laboratory Diagram

The US salinity diagram, a plot used to describe the nature of groundwater (Richards 1948), in which the EC is taken as salinity hazard and SAR as alkalinity hazard (Table 4.13). According to USSL Diagram, during the pre-monsoon season (Fig.4.11(a)) 75 % fall under medium salinity-low sodium class (C2-S1) and only 5 % (representing only one sample) of the samples fall within the high-salinity hazard-low sodium hazard class (C3-S1). During the post monsoon season show that the 30% of the samples fall into the low salinity-low sodium type of water (C1-S1) (Fig.4.11(b)).

Table 4.13. Ground water quality based on USSL classification

<table>
<tr><th rowspan="2">Sl.No</th><th rowspan="2">USSL Classification</th><th rowspan="2">Water class</th><th colspan="2">Seasons</th></tr>
<tr><th>Pre monsoon</th><th>Post monsoon</th></tr>
<tr><td rowspan="4">1</td><td>C1-S1</td><td rowspan="4">Good</td><td>Nil</td><td>Nil</td></tr>
<tr><td>C2-S1</td><td>Nil</td><td>W3, W4, W19, W20</td></tr>
<tr><td>C3-S1</td><td>Nil</td><td>W18</td></tr>
<tr><td>C4-S1</td><td>Nil</td><td>Nil</td></tr>
<tr><td rowspan="4">2</td><td>C1-S2</td><td rowspan="4">Moderate</td><td>W8</td><td>W15</td></tr>
<tr><td>C2-S2</td><td>Nil</td><td>W5, W6, W16, W17</td></tr>
<tr><td>C3-S2</td><td>W1</td><td>Nil</td></tr>
<tr><td>C4-S2</td><td>Nil</td><td>Nil</td></tr>
<tr><td>3</td><td>C1-S3</td><td></td><td>Nil</td><td>Nil</td></tr>
</table>

	C2-S3	Bad	W2, W5, W15, W18	W7, W10, W11, W13, W14
	C3-S3		W4, W7, W9, W10, W16, W19, W20	Nil
	C4-S3		Nil	Nil
	C1-S4		Nil	Nil
	C2-S4		W3,	W1, W2, W8, W12
	C3-S4		W6, W11, W12, W13, W14, W17	W9
	C4-S4		Nil	Nil

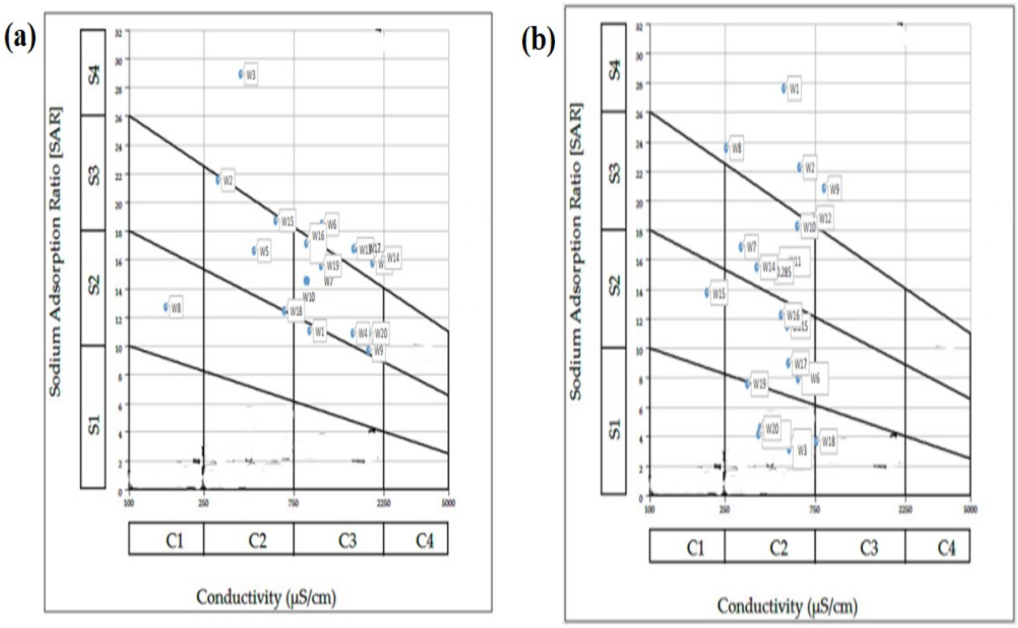


Fig.4.11. Rating of ground water samples in relation to salinity hazard and Sodium hazard during **a)** pre monsoon **b)** post monsoon season

4.3.3.7 Permeability Index

The classification of water for irrigation based on PI explained on account of the Na+, Ca2+, Mg^{2+} and HCO_3^- contents of the soil (Doneen,1964). Based on P.I 15% of the ground water samples fall in the excellent category and 85% good during pre-monsoon period. Whereas during post monsoon season 75% belongs to excellent and 25 % good (table 4.14).

Table 4.14. Ground water quality based on permeability index

Class	Permeability	Usage Quality	Sample	
			Pre monsoon	Post monsoon
Class I	>75%	Excellent for irrigation	W2, W3, W8	W1, W2, W5, W6, W7, W8, W9 W10, W11W13,W14,W15, W16 W19,W20
Class II	75% - 25%	Good for irrigation	W1,W4,W5,W6,W7 W9,W10, W11,W12,W13 W14,W15,W16,W17,W18 W19,W20	W3, W4, W12 W17,W18
Class III	< 25%	Unsuitable for irrigation	-	-

4.3.3.8. Magnesium Hazard

Calcium and magnesium salts in the aquatic system always maintain a state of equilibrium. The soil became more alkaline when the high magnesium hazard value increased (>50 %) and adverse affected the crop yield (Rajesh et al.,2001 and Gupta and Gupta,1987). During pre-monsoon season 85% of the samples fall in the suitable class and only 15% in unsuitable class. It was found that all the samples during the post monsoon season are suitable for irrigation (Table 4.15).

Table 4.15. Ground water quality based on MH

Sl. No	Class	MH	Sample	
			Pre monsoon	Post monsoon
1	Suitable	< 50	W1,W2,W3,W4, W5,W6,W7, W8 W10,W11,W12, W13,W14,W17, W18,W19,W20	All the samples
2	Unsuitable	>50	W9, W15,W16	

4.3.3.9. Kelly's Ratio

Groundwater with a Kelly's ratio value greater than one (KR > 1) is deemed unfit for irrigation. From table 4.16, it was learned that 90 % of the samples in pre monsoon season were suitable for irrigation and only 10% unsuitable for irrigation. But all the samples of post monsoon falls in the suitable category.

Table 4.16. Ground water quality based on Kelly's Ratio

Sl. No	Class	Kelly's ratio	Sample	
			Pre monsoon	Post monsoon
1	Suitable	<1	W1,W4,W5, W6,W7, W8, W9,W10,W11, W12,W13,W14,W15, W16,W17,W18,W19, W20	All the samples
2	Permissible	1-2	W2, W3,	Nil
3	Unsuitable	>2	Nil	Nil

4.3.4 Linear regression analysis by scatter diagram

With the help of scatter diagram and linear regression line, the correlation between the total anions and total cations were determined (Table 4.17). The relationship between anions and cations shows positively strong correlation with total anions during pre-monsoon and moderate correlation during post monsoon (Fig 4.12) attesting the cation-anion balance.

Table 4.17. Linear correlation coefficient R and regression equation for total cation and anion which have significant value of correlation.

Seasonal Representation	R2 Value	R Value	Regression Equation
Pre monsoon	0.786	0.8865	Total Anion = 3.462 (Total Cation) + 24.004
Post monsoon	0.4542	0.6739	Total Anion = 1.2777 (Total Cation) + 24.004

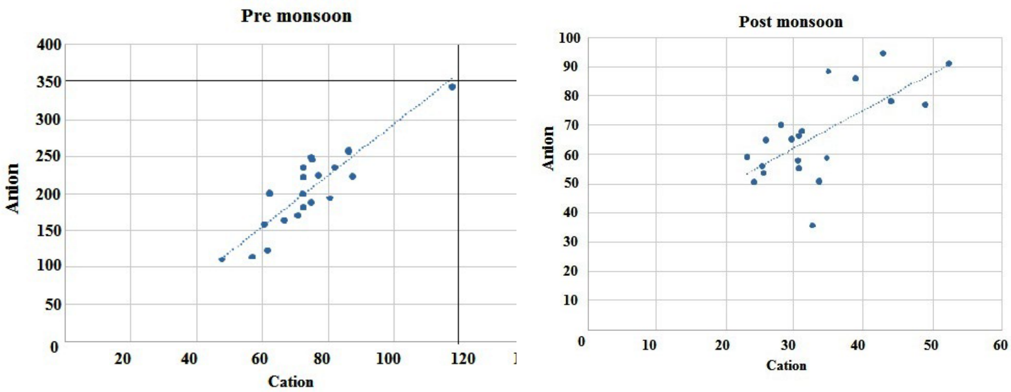
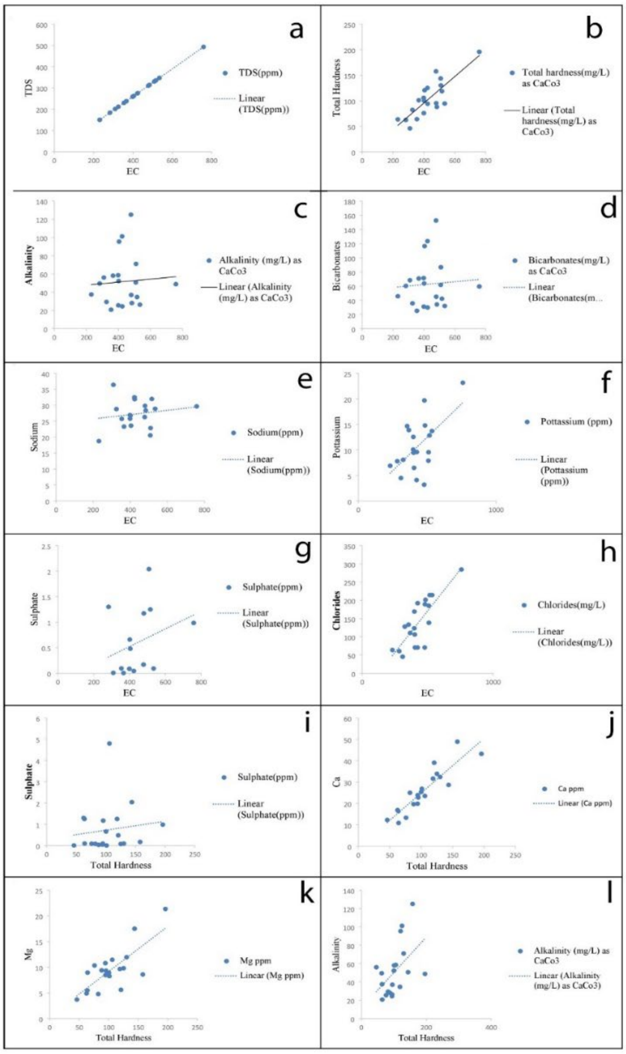


Fig 4.12. The relationship between anions and cations during two seasons- pre-monsoon & post monsoon.

Table 4.18. Linear correlation coefficient R and regression equation for some pairs of parameters which have significant value of correlation (Pre monsoon)

Parameters	Equation	R²	R	Strength of Relationship
EC – TDS	TDS = 0.65(EC) + 8E-13	1	1.000	Perfect
EC – TH	TH = 0.2597(EC) – 8.2272	0.6745	0.821	Strong
EC - Alkalinity	Alkalinity = 0.0164(EC) + 44.486	0.0044	0.066	None/Very Weak
EC - HCO_3^-	HCO_3^- = 0.02(EC) + 54.273	0.0044	0.066	None/Very Weak
EC – Na^+	Na^+ = 0.0067(EC) +24.362	0.0295	0.172	None/Very Weak
EC – K^+	K^+ = 0.0262(EC) – 0.5882	0.3418	0.585	Moderate
EC - SO_4^{2-}	SO_4^{2-} = 0.0017(EC) – 0.1669	0.1	0.316	Weak
EC – Cl^-	Cl^- = 0.4542(EC)- 56.177	0.6227	0.789	Strong
TH - SO_4^{2-}	SO_4^{2-} = 0.0042(TH) – 0.3628	0.0179	0.134	None/Very Weak
TH – Ca^{2+}	Ca^{2+} = 0.2554(TH) – 0.6401	0.8103	0.900	Strong
TH – Mg^{2+}	Mg^{2+} = 0.0879(TH) + 0.3888	0.5781	0.760	Strong
TH - Alkalinity	Alkalinity = 0.3866(TH)+ 11.618	0.2448	0.495	Weak
Ca^{2+}-Mg^{2+}	Mg^{2+} = 0.1635(Ca^{2+}) + 5.2526	0.1612	0.401	Weak
Ca^{2+}-Cl^-	Cl^- = 0.7477(Ca^{2+}) + 119.55	0.0136	0.117	None/Very Weak
Ca^{2+}-SO_4^{2-}	SO_4^{2-} = 0.0035(Ca^{2+}) + 0.6153	0.001	0.032	None/Very Weak
Mg^{2+}-SO_4^{2-}	SO_4^{2-} = 0.0738(Ca^{2+}) + 0.038	0.0739	0.272	None/Very Weak
Mg^{2+}-Cl^-	Cl^- = 11.235(Ca^{2+}) + 32.495	0.5088	0.713	Strong
Turbidity –Fe^{2+}	Fe^{2+} = -0.0291(Turbidity) + 1.161	0.0299	0.173	None/Very Weak
PO_4^{3-} - NO_3^-	NO_3^- = 0.244(PO_4^{2-}) + 2.3388	0.0463	0.215	None/Very Weak
PO_4^{3-} - SO_4^{2-}	SO_4^{2-} = -0.0149(PO_4^{2-}) + 0.7928	0.0011	0.033	None/Very Weak
NO_3^- - SO_4^{2-}	SO_4^{2-} = 0.0743(NO_3^-) + 0.4939	0.0348	0.187	None/Very Weak

The regression analyses carried out for the water quality parameters for the pre monsoon season found to have better and higher level of significance in their correlation coefficient as shown in Table 4.18 and Fig 4.13.EC and TDS showed a perfect correlation and EC and TH showed a strong correlation with a R value of 0.821. EC and alkalinity, EC-HCO_3^-, EC-Na^+, TH- SO_4^{2-}, Ca^{2+}-Cl^-,Ca^{2+}- SO_4^{2-},Mg^{2+}-SO_4^{2-}, PO_4^{3-}-NO_3^-,PO_4^{3-}- SO_4^{2-}, NO_3^-- SO_4^{2-} and turbidity-Fe^{2+} showed a very weak correlation between them. EC and K^+ showed a moderate correlation(R=0.585) and EC-SO_4^{2-} weakly correlated (R=0.316).EC and Cl^- showed a strong correlation with a R value of 0.789. TH strongly correlated with Ca^{2+}(R=0.900) and Mg^{2+} (R=0.760). Mg^{2+} showed a strong correlation with Cl^- with R value of 0.713.



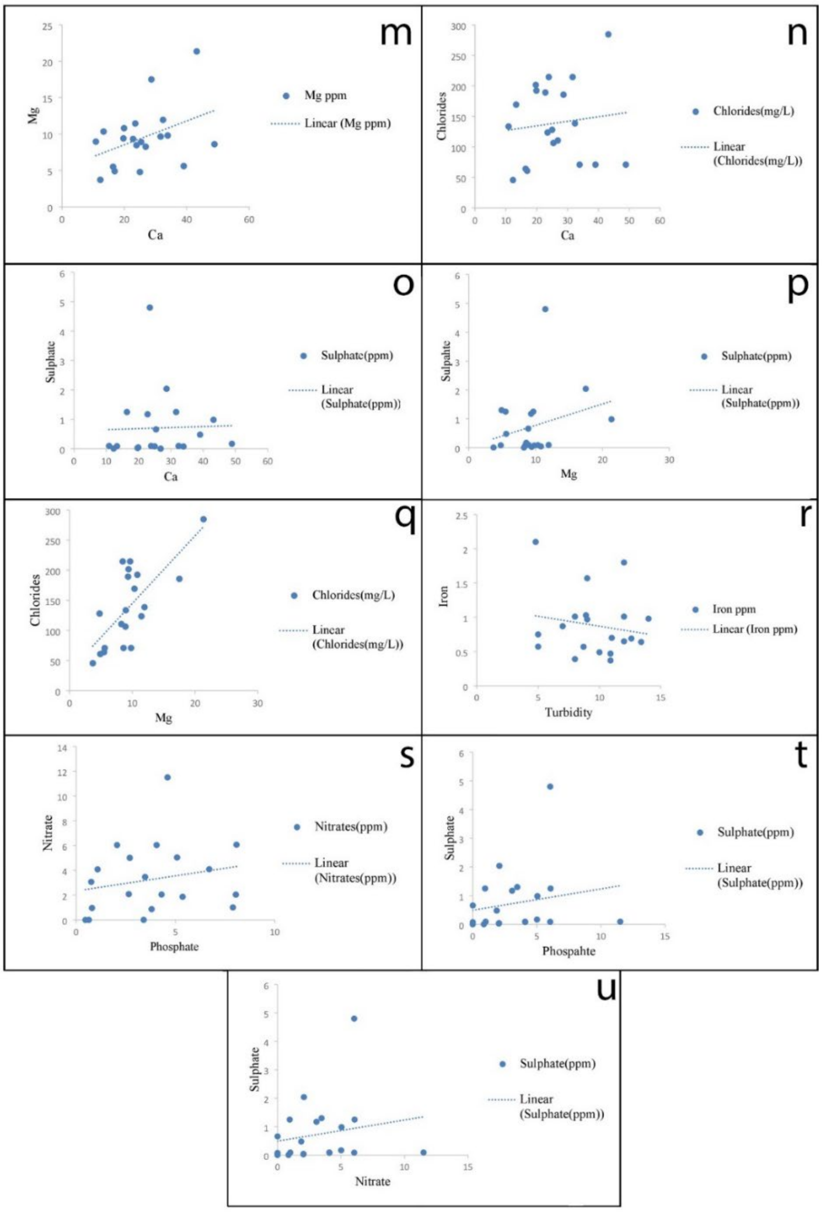


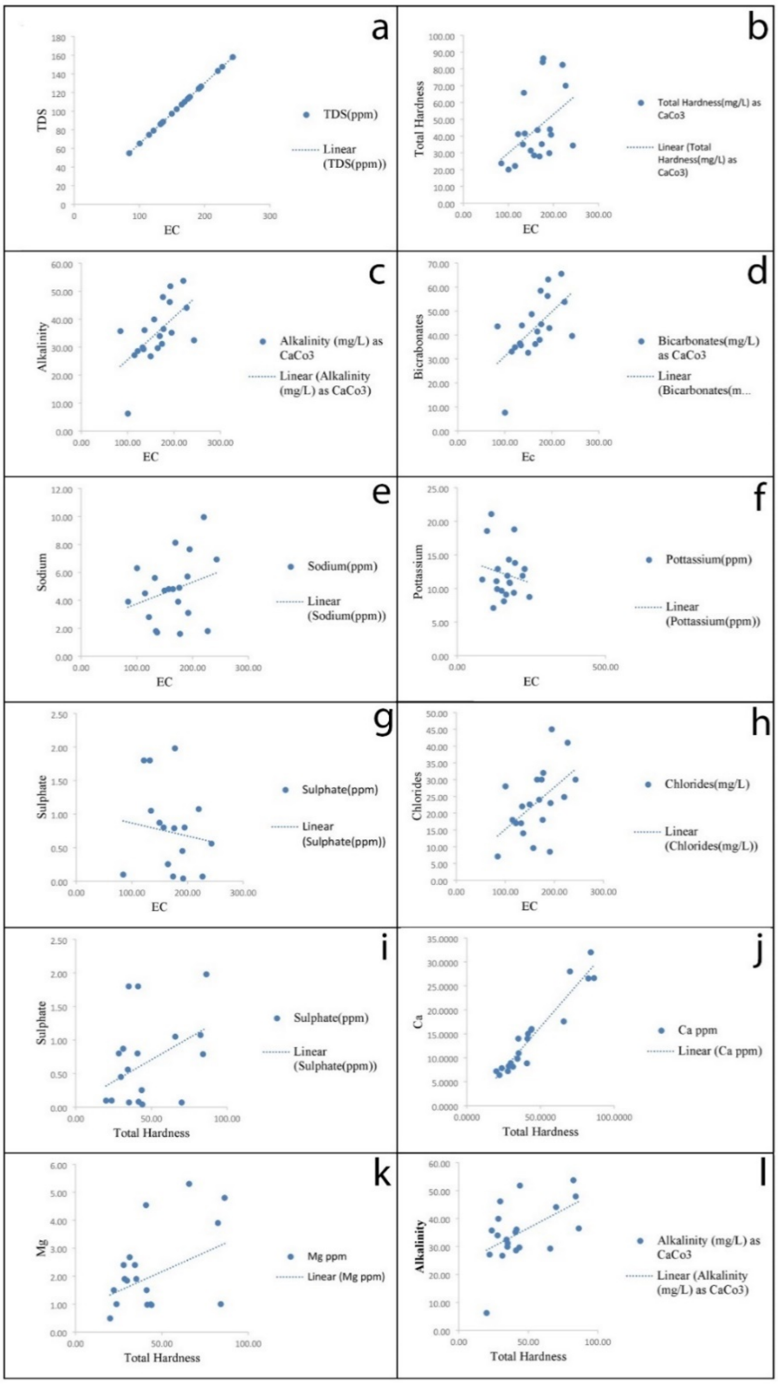
Fig 4.13. The relationship between anions and cations during pre-monsoon; **a)** EC-TDS, **b)** EC-TH ,**c)**EC-Alkalinity, **d)**EC-Bicarbonate ,**e)** EC-Na^{+}, **f)**EC-K^{+} ,**g)**EC-SO_4^{2-},**h)**EC-Cl^{-},**i)**TH- SO_4^{2-},**j)**TH-Ca^{2+}, **k)**TH-Mg^{2+},**l)**TH- Alkalinity ,**m)**Ca^{2+}-Mg^{2+}, **n)**Ca^{2+}-Cl^{-} ,**o)**Ca^{2+}- SO_4^{2-},**p)**Mg^{2+}- SO_4^{2-},**q)**Mg^{2+}-Cl^{-}, **r)**Turbidity-Fe^{2+}, **s)** PO_4^{3-} - NO_3^{-} ,**t)** PO_4^{3-} - SO_4^{2-}, **u)** NO_3^{-} - SO_4^{2-}

Table 4.19 Linear correlation coefficient R and regression equation for some pairs of parameters which have significant value of correlation (Post monsoon).

Parameters	Equation	R^2	R	Strength of Relationship
EC - TDS	TDS = 0.65(EC) + 7E-13	1	1	Perfect
EC - TH	TH = 0.2303(EC) +6.8446	0.2076	0.4556	Weak
EC - Alkalinity	Alkalinity = 0.1524(EC) + 10.258	0.3662	0.6051	Moderate
EC - HCO_3^-	HCO_3^- = 0.186(EC) + 12.514	0.3662	0.6051	Moderate
EC – Na^+	Na^+ = 0.0155(EC) +2.2039	0.0807	0.2841	None/Very Weak
EC – K^+	K^+ = -0.0153(EC) + 14.599	0.0307	0.1752	None/Very Weak
EC - SO_4^{2-}	SO_4^{2-} = -0.0019(EC) + 1.0604	0.016	0.1265	None/Very Weak
EC - Cl^-	Cl^- = 0.1253(EC)+ 2.6536	0.2773	0.5266	Moderate
TH - SO_4^{2-}	SO_4^{2-} = 0.013(TH) + 0.0567	0.1849	0.4300	Weak
TH – Ca^{2+}	Ca^{2+} = 0.3544(TH) – 1.2771	0.9113	0.9546	Strong
TH – Mg^{2+}	Mg^{2+} = 0.0277(TH) + 0.0.7758	0.1452	0.3811	Weak
TH - Alkalinity	Alkalinity = 0.2627(TH)+ 23.45	0.2778	0.5271	Moderate
Ca^{2+}-Mg^2	Mg^{2+} = 0.0173(Ca^{2+}) + 1.7543	0.0078	0.0883	None/Very Weak
Ca^{2+}-Cl^-	Cl^- = 0.37(Ca^{2+}) + 17.332	0.0823	0.2869	None/Very Weak
Ca^{2+}-SO_4^{2-}	SO_4^{2-} = 0.0272(Ca^{2+}) + 0.2411	0.1113	0.3336	Weak
Mg^{2+}-SO_4^{2-}	SO_4^{2-} = 0.1676(Ca^{2+}) + 0.2981	0.162	0.4025	Weak
Mg^{2+}-Cl^-	Cl^- = 11.235(Ca^{2+}) + 32.495	0.0812	0.2850	None/Very Weak
Turbidity – Fe^{2+}	Fe^{2+} = 0.094(Turbidity) + 1.4989	0.0102	0.1010	None/Very Weak
PO_4^{3-} - NO_3^-	NO_3^- = 2.2428(PO_4^{3-}) + 4.805	0.1545	0.3931	Weak
PO_4^{3-} - SO_4^{2-}	SO_4^{2-} = -0.0209(PO_4^{3-}) + 0.6746	0.004	0.0632	None/Very Weak
NO_3^- - SO_4^{2-}	SO_4^{2-} = -0.0042(NO_3^-) + 0.6721	0.0051	0.0714	None/Very Weak

The regression analysis for the post monsoon showed that EC and TDS showed a perfect correlation and EC and TH showed a weak correlation with a R value of 0.455.

EC and alkalinity(R=0.605) and EC-HCO_3^- (R=0.605), EC- Cl^- (R=0.526) and TH – alkalinity (R=0.527) showed a moderate correlation among them.TH-Ca showed a strong correlation with a R value of 0.954. EC-Na^+, EC-K^+, EC- SO_4^{2-}, Ca^{2+}-Mg^{2+}, Ca^{2+}-Cl^-, Mg^{2+}-Cl^-, Turbidity-Fe^{2+}, PO_4^{3-}- SO_4^{2-}, NO_3^- - SO_4^{2-} showed very weak correlation among them. TH- SO_4^{2-} (R=0.430), TH-Mg^{2+}(R=0.381), Ca^{2+}- SO_4^{2-} (0.336), Mg^{2+}- SO_4^{2-} (0.402) and PO_4^{3-}-NO_3^- (R=0.393) found to be a weak correlation among them(Table.4.19 and fig.4.14).



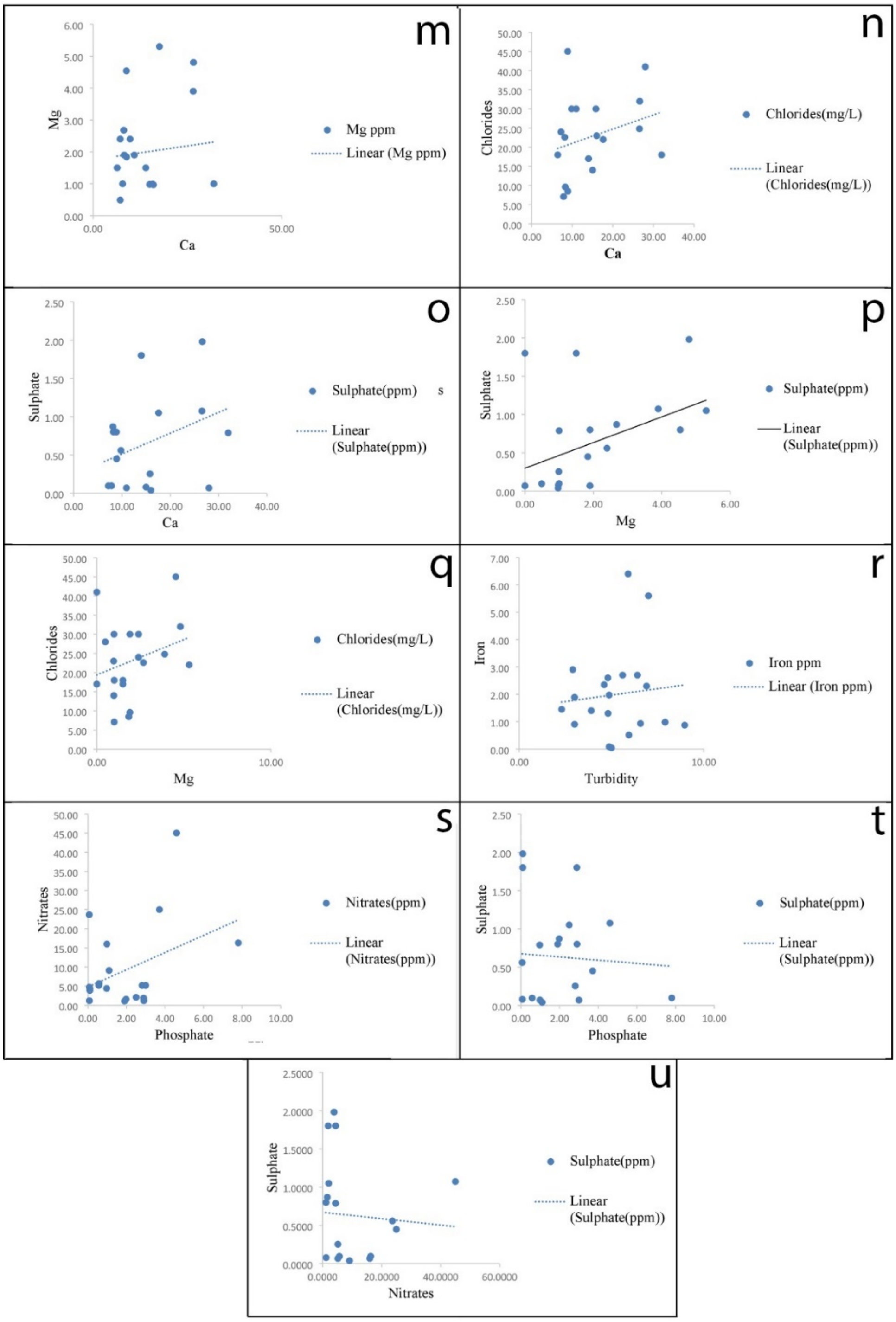


Fig 4.14. The relationship between anions and cations during post monsoon; **a)** EC-TDS, **b)** EC-TH, **c)** EC-Alkalinity, **d)** EC-Bicarbonate, **e)** EC-Na^{+}, **f)** EC-K^{+}, **g)**EC-SO_4^{2-},**h)**EC-Cl^{-} ,**i)**TH- SO_4^{2-} ,**j)**TH-Ca^{2+}, **k)**TH-Mg^{2+}, **l)**TH- Alkalinity, **m)**Ca^{2+}-Mg^{2+}, **n)**Ca^{2+}-Cl^{-}, **o)**Ca- SO_4^{2-},**p)**Mg^{2+}- SO_4^{2-},**q)**Mg^{2+}-Cl^{-}, **r)**Turbidity-Fe $^{2+}$,**s)** PO_4^{2-} - NO_3^{-} ,**t)** PO_4^{3-} - SO_4^{2-}, **u)** NO_3^{-} - SO_4^{2-}

4.3.5. Univariate Statistical Analysis

4.3.5.1 Karl Pearson's Correlation matrix

Correlation is a mutual relationship between two variables. During pre-monsoon season, pH shows a moderate positive correlation with Na^+ (0.444) and with DO (0.386). pH shows moderate negative correlation with TH, Ca^{2+}, alkalinity and bicarbonate .EC and TDS showed perfect correlation between them and are positively correlated with the parameters K^+, Cl^-, TH, Ca^{2+} and Mg^{2+}. TDS has a moderate positive correlation with K^+ (0.585) and Ca^{2+} (0.609) and strong correlation with Cl^- (0.789), TH (0.821) and Mg^{2+} (0.818). The K^+ showed a strong correlation with Cl^- (0.800) and moderate correlation with Mg^{2+}. K^+ shows strong positive correlation with Mg^{2+}(0.800) and moderate negative correlation with alkalinity and bicarbonate. Cl^- shows moderate positive correlation with TH (0.422) and strong correlation with Mg^{2+} (0.713) and moderate negative correlation with alkalinity (-0.530). TH is strongly correlated with Ca^{2+}(0.900) and Mg^{2+}(0.760).TH is moderately correlated with alkalinity, bicarbonate and fluoride. Ca^{2+} showed strong correlation with alkalinity and bicarbonate, moderately correlated with Mg and fluoride and negatively with DO (-0.553).DO is negatively correlated with fluoride (-0.553), fluoride shows moderate positive correlation with Fe^{2+}(0.414) and positive weak correlation with phosphate (0.330). Fe^{2+}showed a positive moderate correlation with sulphate (0.419) (Table.4.20).

During post monsoon season, pH shows a weak correlation with Na^+ (0.331), alkalinity and bicarbonate (0.388), NO_3^- (0.431) and negative moderate correlation with Mg^{2+}(-0.334) and DO (-0.373).EC and TDS perfectly correlated each other. EC showed a weak correlation with TH (0.456), Ca^{2+}(0.416) and NO_3^- (0.438), moderate correlation with turbidity (0.518), Cl^- (0.527), alkalinity and bicarbonate (0.605). TDS showed a moderate correlation with turbidity (0.518), Cl^- (0.527), alkalinity and bicarbonate (0.605). TDS showed a weak correlation with TH (0.456), Ca^{2+} (0.416) and NO_3^- (0.438). Turbidity showed a weak correlation with TH (0.473), Ca^{2+} (0.434) and NO_3^- (0.460). Na^+ shows moderate positive with NO_3^-. K^+ is negatively correlated with Sulphate (-0.524). Chloride weakly correlated with TH (0.320). TH is strongly correlated with Calcium but weakly correlated with Magnesium. TH is weakly correlated with Sulphate and Phosphate is weakly correlated with Sulphate.

Table 4.20. Correlation of the water quality parameters of ground water during Pre monsoon

	pH	EC	TDS	Turbidity	Na^+	K^+	Cl^-	TH	Ca^{2+}	Mg^{2+}	Alkalinity	DO	HCO_3^-	F^-	Fe^{2+}	PO_4^{3-}	NO_3^-	SO_4^{2-}
pH	1																	
EC	-0.248	1																
TDS	-0.248	**1.000**	1															
Turbidity	-0.060	0.232	0.232	1														
Na^+	**0.444**	0.092	0.092	-0.059	1													
K^+	-0.064	**0.585**	**0.585**	0.220	0.040	1												
Cl^-	0.040	**0.789**	**0.789**	0.270	0.080	**0.800**	1											
TH	-0.450	**0.821**	**0.821**	0.039	-0.161	0.212	**0.422**	1										
Ca^{2+}	-0.450	**0.609**	**0.609**	-0.098	-0.116	-0.050	0.117	**0.900**	1									
Mg^{2+}	-0.277	**0.818**	**0.818**	0.228	-0.166	**0.519**	**0.713**	**0.760**	**0.402**	1								
Alkalinity	-0.407	0.066	0.066	-0.172	-0.083	**-0.547**	**-0.530**	**0.495**	0.721	-0.035	1							
DO	**0.386**	-0.124	-0.124	-0.035	0.054	0.179	0.017	-0.402	**-0.449**	-0.176	-0.360	1						
HCO_3^-	-0.407	0.066	0.066	-0.172	-0.083	**-0.547**	**-0.530**	**0.495**	**0.721**	-0.035	**1.000**	-0.360	1					
F^-	-0.285	0.235	0.235	0.165	0.082	0.141	0.158	**0.335**	**0.410**	0.094	0.101	**-0.553**	0.101	1				
Fe^{2+}	-0.080	0.145	0.145	-0.173	0.224	0.011	0.169	0.232	0.287	0.061	0.016	-0.228	0.016	**0.414**	1			
PO_4^{3-}	0.176	-0.027	-0.027	0.161	-0.267	-0.102	0.009	-0.042	-0.009	-0.075	-0.109	**0.330**	-0.109	0.143	0.001	1		
NO_3^-	-0.153	0.118	0.118	-0.075	-0.135	0.212	0.261	-0.053	-0.105	0.044	-0.275	-0.101	-0.275	0.204	-0.017	0.215	1	
SO_4^{2-}	-0.100	0.017	0.017	-0.182	-0.159	0.045	0.047	0.134	0.006	0.272	0.000	0.117	0.000	-0.119	**0.419**	-0.033	0.187	1

Table 4.21. Correlation of the water quality parameters of ground water during post monsoon

	pH	EC	TDS	Turbidity	Na^+	K^+	Cl^-	TH	Ca^{2+}	Mg^{2+}	Alkalinity	DO	HCO_3^-	F^-	Fe^{2+}	PO_4^{3-}	NO_3^-	SO_4^{2-}
pH	1																	
EC	0.291	1																
TDS	0.291	**1.000**	1															
Turbidity	0.020	**0.518**	**0.518**	1														
Na^+	**0.331**	0.284	0.284	-0.042	1													
K^+	0.294	-0.174	-0.174	-0.250	0.019	1												
Cl^-	0.129	**0.527**	**0.527**	0.241	0.112	0.200	1											
TH	0.036	**0.456**	**0.456**	**0.473**	-0.181	-0.206	**0.320**	1										
Ca^{2+}	0.147	**0.416**	**0.416**	**0.434**	-0.239	-0.152	0.253	**0.955**	1									
Mg^{2+}	-0.334	0.233	0.233	0.236	0.137	-0.215	0.285	**0.381**	0.088	1								
Alkalinity	**0.388**	**0.605**	**0.605**	0.288	0.053	-0.163	-0.103	**0.527**	**0.539**	0.090	1							
DO	-0.373	-0.123	-0.123	0.065	0.145	-0.119	0.068	-0.277	**-0.397**	**0.306**	-0.299	1						
HCO_3^-	**0.388**	**0.605**	**0.605**	0.288	0.053	-0.163	-0.103	**0.527**	**0.539**	0.090	**1.000**	-0.299	1					
F^-	-0.145	-0.072	-0.072	0.118	-0.161	0.037	0.216	0.178	0.117	0.230	-0.249	**0.378**	-0.249	1				
Fe^{2+}	0.208	-0.172	-0.172	0.101	-0.105	-0.086	0.038	0.133	0.265	**-0.377**	-0.052	**-0.301**	-0.052	-0.251	1			
PO_4^{3-}	0.027	-0.112	-0.112	-0.061	0.157	-0.243	-0.300	-0.014	0.002	-0.053	0.304	-0.062	**0.304**	-0.234	-0.186	1		
NO_3^-	**0.431**	**0.438**	**0.438**	**0.460**	**0.527**	-0.068	-0.079	0.161	0.126	0.148	**0.430**	-0.107	**0.430**	-0.246	-0.244	**0.393**	1	
SO_4^{2-}	-0.196	-0.005	-0.005	0.199	-0.066	**-0.524**	-0.018	**0.430**	0.334	**0.403**	0.021	-0.129	0.021	0.281	0.234	-0.063	-0.072	1

4.3.5.2 ANOVA

The results of one-way ANOVA (Table 4.22) suggested that there was significant difference in the means of the parameters [$F_{(17,342)}$=181.5, p =<2e^{-16}] valuated in the ground water samples that was collected from 20 locations in the pre monsoon season. The results of one way ANOVA suggested that there was significant difference in the means of the parameters [$F_{(17,342)}$=184.1, p =<2e^{-16}] valuated in the ground water samples that was collected from 20 locations in the post monsoon season.

Table 4.22. The water quality parameters of Thrissur Kole wetlands (n = 20) and 18 parameters during the 2 different seasons.

	df	SS	MS	F	Significance F
Pre monsoon					
Treatment	17	4492706	264277	181.5	<2e-16 ***
Residuals	342	498010	1456		
Post monsoon					
Treatment	17	622900	36641	184.1	<2e-16 ***
Residuals	342	68080	199		
Sign if. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1					

4.3.6 Multivariate Analysis

4.3.6.1Principal Component Analysis

In Principal component analysis, eigenvalues are normally used to determine the number of the principal components (PCs) that can be retained for further study. Scree plot for the eigenvalues obtained in this study shows a pronounced change of slope after the third eigenvalue (Fig. 4.15).

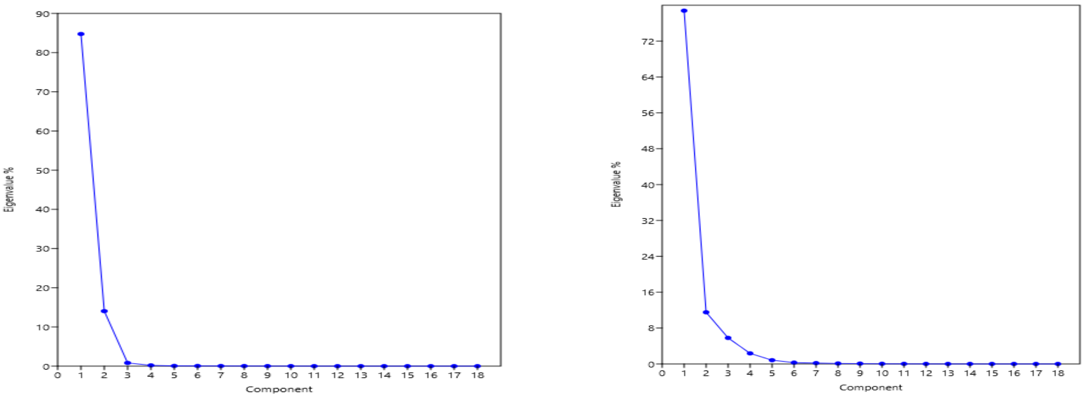


Fig 4.15. Scree plot for the eigenvalues obtained in this study **a)** pre monsoon, **b)** post monsoon

During pre monsoon (Table 4.23), the PC1 explained 84.739 % of total variance parameters and PC1 was positively and strongly contributed by EC (0.7615) and moderately by TDS(0.495) and poorly loaded by TH and Cl .The PC2 showed positive moderate loading by alkalinity(0.4611) and HCO_3^- (0.5626). EC, TDS, TH and Ca^{2+} loaded poorly with PC2.The Cl^- showed a negative moderate loading of -0.5791. In PC3, strongly loaded by TH (0.7866) and moderately by Cl^- (0.4281) In PC4, majority components loaded by negatively. The result indicated the changes in the ground quality of the water with respect to the seasonal fluctuations. The moderate loading by Cl^- (0.5772), alkalinity (0.4080) and HCO_3^- (0.4978).

Table 4.23. Principal Component Analysis for pre-monsoon season

PC	Eigenvalue	% variance	PC 1	PC 2	PC 3	PC 4
PH	22211.1	**84.739**	-0.0018	-0.0085	-0.0130	0.0345
EC	3680.02	14.04	**0.7615**	**0.1413**	-0.2929	-0.1222
TDS	213.822	0.81577	**0.4950**	**0.0918**	-0.1904	-0.0795
Turbidity	51.4527	0.1963	0.0044	-0.0077	-0.0393	-0.0149
Na^+	15.7046	0.059916	0.0024	-0.0066	-0.1610	0.1702

K^+	13.1358	0.050116	0.0214	-0.0453	-0.0211	-0.0587
Cl^-	9.48867	0.036201	**0.3679**	**-0.5791**	**0.4281**	**0.5772**
TH	7.58326	0.028932	**0.1927**	**0.2999**	**0.7866**	-0.4012
Ca^{2+}	4.02462	0.015355	0.0389	0.1216	**0.1933**	0.0746
Mg^{2+}	3.19152	0.012176	0.0232	-0.0010	0.0737	-0.1428
Alkalinity	0.902387	0.003443	-0.0013	**0.4611**	0.0391	**0.4080**
DO	0.555498	0.002119	-0.0006	-0.0040	-0.0242	-0.0247
HCO_3^-	0.070269	0.000268	-0.0016	**0.5626**	0.0477	**0.4978**
F^-	0.034077	0.00013	0.0001	0.0001	0.0007	-0.0003
Fe^{2+}	0.000296	1.13E-06	0.0005	0.0000	0.0107	0.0086
PO_4^{3-}	3.96E-17	1.51E-19	-0.0004	-0.0033	0.0018	-0.0974
NO_3^-	5.94E-19	2.27E-21	0.0026	-0.0130	-0.0088	0.0082
SO_4^{2-}	2.06E-20	7.87E-23	0.0002	0.0000	0.0241	-0.0175

The principal component analysis for post monsoon season (Table 4.24) showed that a total variance of 78.784 % in which the PC1 showed a moderately positive loading of 0.7880 with EC and moderately loaded by TDS (0.5122). PC1 components poorly loaded by TH, alkalinity, HCO_3^- ,TDS. The PC2 showed strong positive loading of TH (0.8540) and a moderate positive loading by Ca^{2+}(0.3162).The component PC3 explained about the moderate loading of alkalinity , HCO_3^- and NO_3^-. It maybe from agricultural or wastewater runoff. Majority of PC3 components loaded negatively and indicated the alteration in the running water with season and locations. In PC4 only NO_3^- showed significant loading relation, strong positive loading with 0.8854, indicating the presence of nitrogenous fertilizer residues. Majority of PC4 components loaded negatively and indicated the alteration in the running water with season and locations.

Table 4.24. Principal Component Analysis for post monsoon season.

PC	Eigenvalue	% variance	PC 1	PC 2	PC 3	PC 4
PH	2822.98	**78.784**	0.0067	-0.0043	0.0249	0.0172
EC	412.761	11.519	**0.7880**	-0.2362	-0.0656	-0.0368
TDS	207.857	5.8009	**0.5122**	-0.1535	-0.0426	-0.0239
Turbidity	84.1969	2.3498	0.0178	0.0150	-0.0061	0.0681
Na^{+}	29.8761	0.83379	0.0108	-0.0445	0.0263	0.1060
K^{+}	10.218	0.28517	-0.0128	-0.0237	-0.0265	0.0074
Cl	6.69385	0.18681	0.0962	-0.0480	-0.5203	0.0430
TH	3.47914	0.097097	0.2199	**0.8540**	-0.2540	0.1612
Ca^{2+}	2.58006	0.072005	0.0757	**0.3162**	-0.0669	0.0076
Mg^{2+}	1.20628	0.033665	0.0075	0.0155	-0.0211	0.0345
Alkalinity	0.756517	0.021113	0.1327	0.1836	**0.4468**	-0.2584
DO	0.380167	0.01061	-0.0029	-0.0137	-0.0102	0.0043
HCO_3^{-}	0.139371	0.00389	0.1618	0.2240	**0.5451**	-0.3152
F^{-}	0.045417	0.001268	-0.0005	0.0031	-0.0110	0.0006
Fe^{2+}	0.003626	0.000101	-0.0045	0.0212	-0.0162	-0.0244
PO_4^{3-}	8.29E-11	2.31E-12	-0.0029	0.0133	0.0706	0.0458
NO_3^{-}	3.28E-12	9.15E-14	0.0946	-0.0328	**0.3865**	**0.8854**
SO_4^{2-}	0.000	0.000	0.0005	0.0140	-0.0076	0.0050

4.4. Water quality analysis using Kriging

Water quality parameters such as pH, iron, sodium and the irrigational parameter (percent sodium) were analysed using Kriging.

4.4.1. pH

The spatial distribution of pH in the wetland system during pre and post monsoon is presented in the Fig4.16. The majority of the area found to have acidic ground water as displayed in Fig4.16(a). However, during post monsoon period, the ground water became alkaline in the southern most part and acidic in the northern most part(Fig.4.16(b)). In few parts of the study area, the ground water remains neutral.

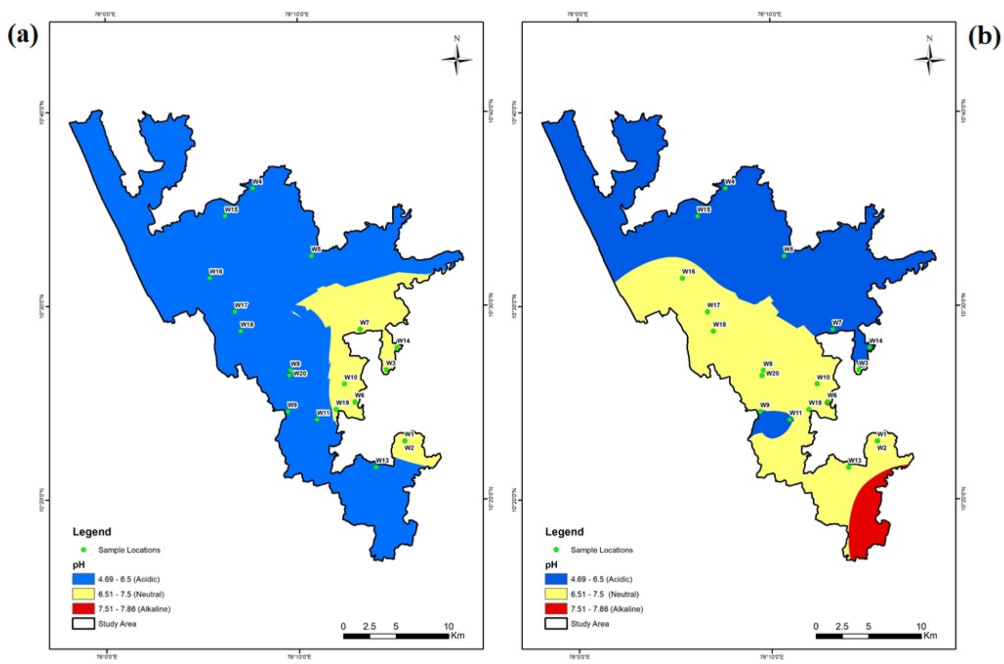


Fig 4.16. Map of pH by Kriging method during **a)** pre monsoon, **b)** post monsoon

4.4.2. Iron

During pre monsoon, the concentration of iron ranged from 2.100 ppm to 0.370 ppm (Fig.4.17(a)). In post monsoon, the iron content ranged from 0.040 ppm to 2.900ppm .in limited areas of NE part of the wetland. The concentration of iron reached a maximum value of 5.60ppm during post monsoon season in southern part of the wetland. The Iron content in ground water in pre- monsoon showed a maximum value at location (W11) and a minimum value at location (W18). During the post monsoon season, the values ranged between 0.04 ppm (W4) and 2.9 ppm (W14).

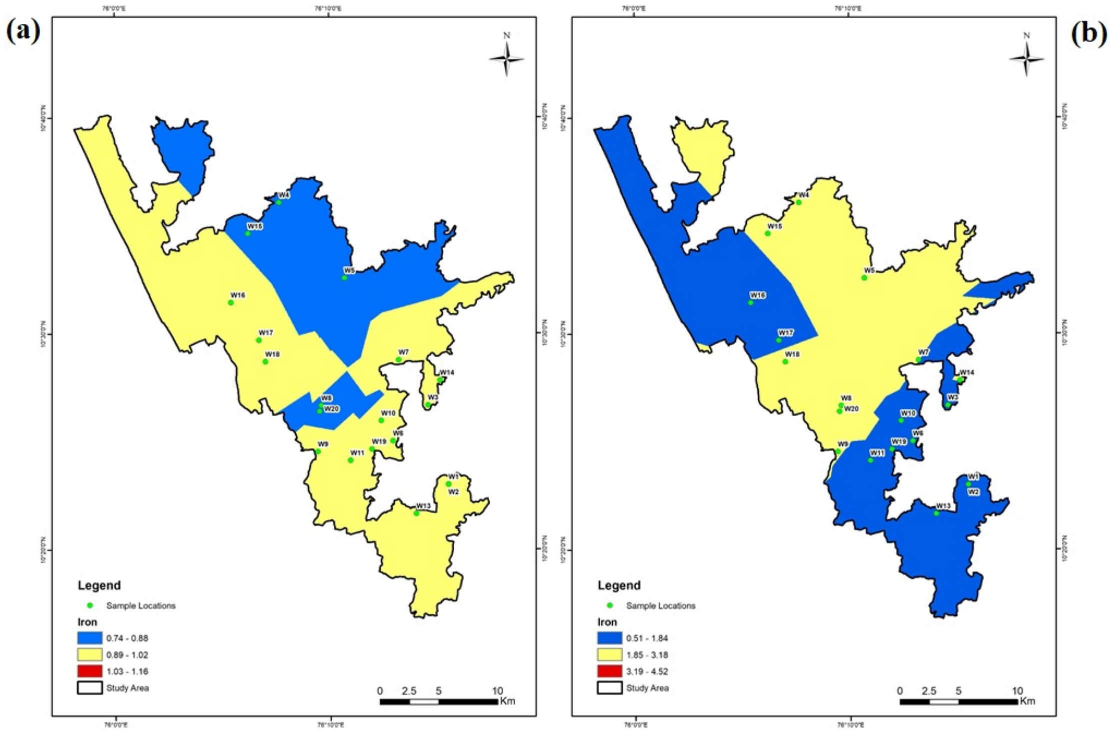


Fig 4.17. Map of iron by Kriging method during **a)** pre monsoon **b)** post monsoon

4.4.3. Sodium

The concentration of sodium in ground water exceeds the permissible limit of BIS in the entire study area during pre monsoon period Fig4.18. During post monsoon period, the concentration of sodium ranges from 2.10 ppm and falls well within the permissible limit of the drinking water standards.

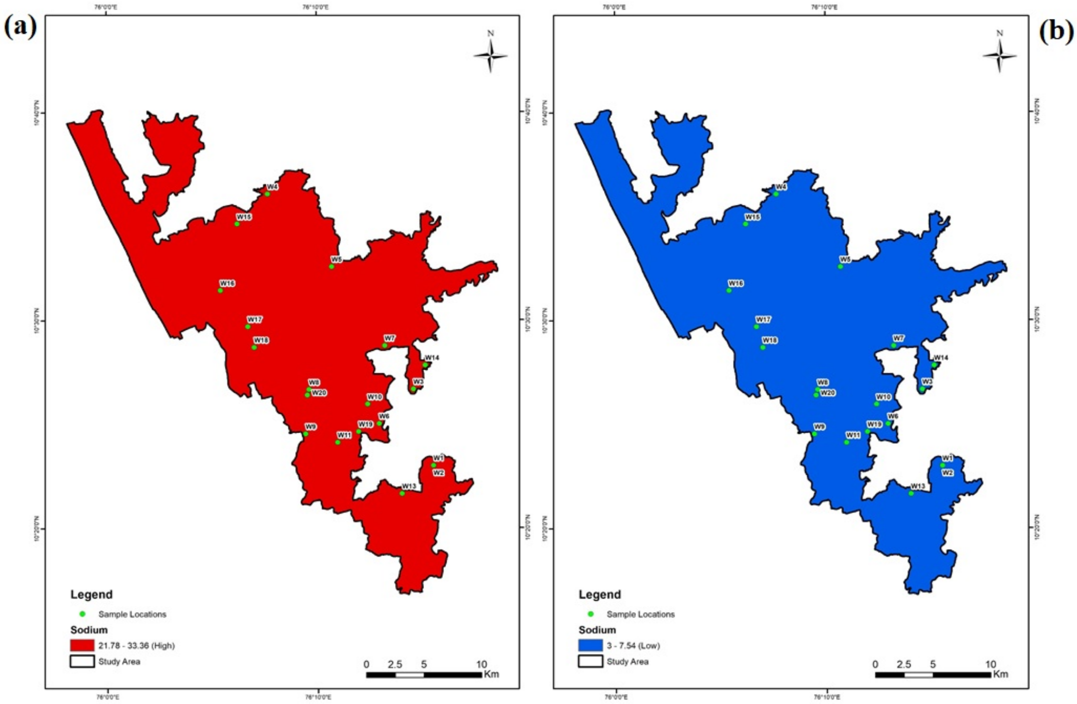


Fig .4.18. Map of sodium by Kriging method during **a)** pre monsoon **b)** post monsoon

4.4.4. Percentage sodium

The distribution of % Na displayed in fig. 4.19 indicates that the ground water remains under the permissible category in 477.43 sq.km and 377.22 sq.km area during pre monsoon and post monsoon period respectively. The figure illustrates that the central segment of the wetland (53.02 sq.km) falls under good category during pre monsoon and 153.24 sq.km during post monsoon period. (Table 4.25).

Table 4.25. Area(sq.km) wise variation in ground water quality(%Na)

% Na	Area (during pre monsoon)	Area(during post monsoon)
Good	53.02	153.24
Permissible	477.43	377.22

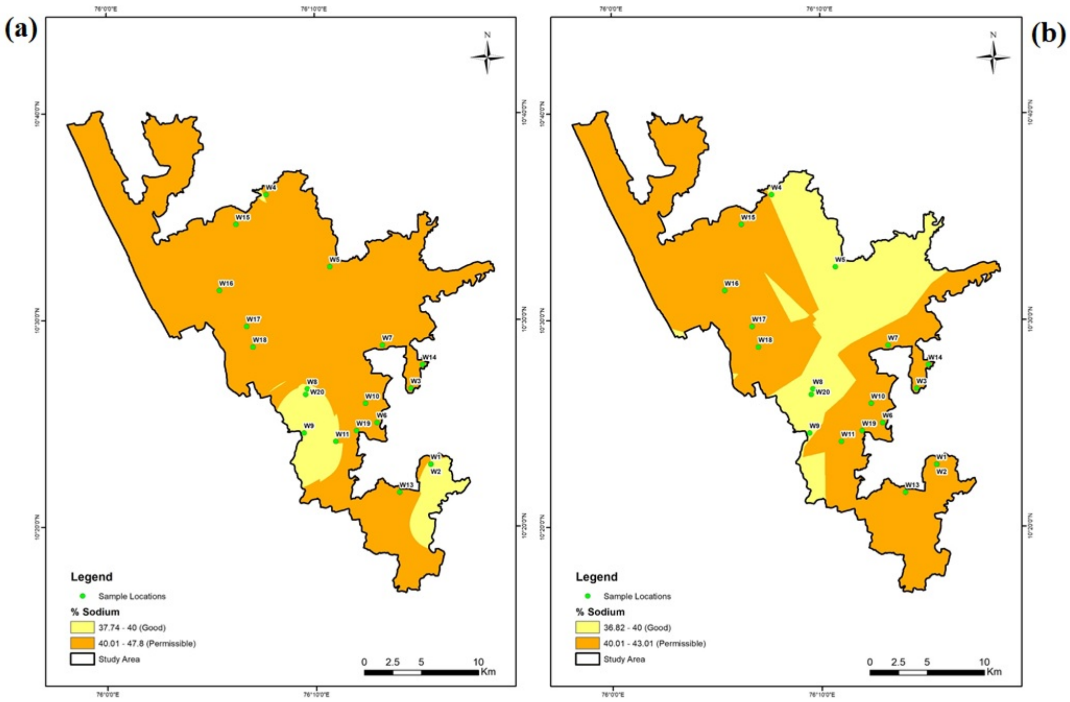


Fig.4.19. Map of percentage sodium by Kriging method during **a)** pre monsoon **b)** post monsoon

4.5. Conclusion

Fifty percent of the of the ground water samples were acidic while the lone sample W3 remained alkaline during pre-monsoon whereas 20% of the samples were acidic and 15% were alkaline during post-monsoon. The electrical conductivity of 25% ground water samples was above the permissible limit during pre-monsoon and 50% of the samples were above the permissible limit during post monsoon. Based on the turbidity, only three water samples (W1, W11 and W8) have values within permissible limit during pre-monsoon and 50% during post-monsoon period. During pre-monsoon, except W8 all the others have sodium value above the acceptance limit whereas the concentration of chloride is above the acceptance limit only in W12. The iron content of the water samples except W1, W4, W15, W18 were above the acceptance limit during pre-monsoon and the samples except W4, W5, W11, W12 have the values above the acceptance limit during post monsoon season. In the ground water chemistry, the order of cation abundance is Ca > Na/K>Mg in both seasons. The anionic abundance is Cl>HCO_3 >SO_4 in pre-monsoon and HCO_3 > Cl>SO_4 in post-monsoon. Based on the USSL diagram, 95 % and 50% of the ground water samples were categorized as bad quality for irrigation purposes during pre-monsoon and post-monsoon respectively. This indicated that wetland system was under the threat of salinity hazard.

pH shows moderate negative correlation with TH, Ca^{2+}, alkalinity and bicarbonate. EC and TDS showed perfect correlation between them and positively correlated with the parameters K^+, Cl^-, TH, Ca^{2+} and Mg^{2+}. During post monsoon season, pH showed a weak correlation with Na^+, alkalinity ,bicarbonate and nitrate and negative moderate correlation with Mg^{2+} and DO.EC and TDS perfectly correlated with each other. The regression analysis showed that EC-Na^+, EC-K^+, EC- SO_4^{2-}, Ca^{2+}-Mg^{2+}, Ca^{2+}-Cl^-, Mg^{2+}- Cl^-, Turbidity-Fe^{2+}, PO_4^{3-}- SO_4^{2-}, NO_3^- - SO_4^{2-} showed very weak correlation among them.

The result of PCA indicated the changes in the ground quality of the water with respect to the seasonal fluctuations during pre-monsoon period. Majority of PC3 components loaded negatively and indicated the changes in the flow pattern of in the surface water with season's rotation in the post-monsoon period.

The illustration based on the kriging method revealed that the sodium content in the ground water in the whole wetland area was above acceptance limit of drinking water standards during pre-monsoon period. However, during post monsoon period because of the groundwater recharging the quality of the water improves. Based on the percentage sodium, the water is suitable for irrigation during all times. The iron content in ground water is above the permissible limit during both seasons. It is found that the concentration of iron is greater during post monsoon season. All the wells are situated in lateritic rocks which act as the main source of iron. In the majority of the areas ground water was acidic in pre monsoon season and after monsoon the water in the northern segment remained acidic and the southern tip of the wetland area turned alkaline due to intrusion of saline water and its leachate.

CHAPTER 5

PESTICIDE RESIDUE ANALYSIS

PESTICIDE RESIDUE ANALYSIS

5.1 Introduction

The term "pesticide" is a composite term that includes all chemicals that are used to kill or control pests. In agriculture, this includes herbicides (weeds), insecticides (insects), fungicides (fungi), nematocides (nematodes), and rodenticides (rodents). The beneficial effects of pesticides include crop protection, preservation of food and materials and prevention of vector-borne diseases. Pest control is one of the goals of the modern human era. Pesticides have an important role in controlling pests of crops and it is an important tool used against vector borne diseases which could even wipe out humans. Their mode of action is by targeting systems or enzymes in the pests which may be identical or very similar to systems or enzymes in human beings and therefore, they pose risks to human health and the environment. Most of the pesticides are synthetic and ubiquitous in nature.

5.2 Types of pesticides

Pesticides are classified into two types based on their origin as chemical pesticides and bio pesticides. Chemical pesticides are further divided into four types as organophosphate, carbamates, organochlorine and pyrethroid based on their origin. Organophosphate pesticides are the chemical substances which are produced due to reaction between phosphoric acid and alcohols. This causes irreversible blockage leading to accumulation of the enzyme which results in overstimulation of muscles. It affects the nervous system by inhibiting the action of enzyme acetyl cholinesterase (AChE). These mainly include insecticides, nerve gases, herbicides etc. Examples are Chlorofenvinphos, Methyl parathion, Methidathion, Phosalone, Fenitrothion and

Diazinon. Carbamates are esters of carbamic acids. Organochlorine pesticides are derived from chlorinated hydrocarbons.

Biopesticides are naturally occurring materials or derived naturally from living organisms or their metabolites, like bacteria, fungi, plants etc. Microbial pesticides consist of a microorganism and can be derived from viruses. Microbial pesticides have microorganisms acting as pest controllers like bacteria, fungi or viruses. Widely used are strains of *Bacillus thuringensis* and its subspecies. Biochemical pesticides are naturally occurring, nontoxic pest controllers. These include pheromones, natural plant and insect regulators, enzymes, bio repellents or attractants.

5.3 Adverse effect of pesticides

Pesticides are chemicals that are highly specific to target an organism, but they can also pose hazard to other living beings including humans. Pesticides can contaminate soil, water, turf, and other vegetation. In addition to killing insects or weeds, pesticides can be toxic to a host of other organisms including birds, fish, beneficial insects, and non-target plants. Insecticides are generally the most acutely toxic class of pesticides, but herbicides can also pose risks to non-target organisms. Pesticides can be acutely toxic. This means that they can cause harmful or lethal effects after one single episode of ingestion, inhalation or skin contact. The symptoms are evident shortly after exposure or can arise within 48 hours. (PAN UK.2017).

The bioaccumulation and biomagnifications are the processes of accumulating higher and higher doses through food chain. Trace number of pesticides accumulated in the body produce toxic effects sooner or later. The most distressing fact is that there are no warning symptoms for early detection. (Erach Bharucha, 2005).

The greatest exposure to highly hazardous pesticides is for agricultural and public health workers during handling, dilution, mixing and application. Exposure is mainly through the dermal route during preparation of sprays. It also happens through contaminated clothing and inhalation during application. Ingestion through consumption of contaminated food during or following work or through oral contact with contaminated hands can also occur. Bystanders might be exposed to the sprayed pesticides and can be affected dermally and *via* inhalation (WHO 2010).

Many researchers point out that many pesticides including Atrazine, Alachlor, DDT, Endosulfan, Diazinon and Methoxychlor interfere with reproductive hormones. This may lead to breast cancer in human beings. It is also documented that farm workers and herbicide sprayers have defective and a low count of sperm. The pesticides may enter the worker's body through drinking water. Abnormal sexual development in animals is also reported because these chemicals can mimic or disrupt the effects of estrogenic hormones at low levels.

Dieldrin binds strongly to soil particles and hence is very resistant to leaching into groundwater. Dieldrin is extremely persistent, hydrophobic, a tendency to bioconcentrate and bio magnify as it passes along the food chain. As Aldrin is readily and rapidly converted to Dieldrin in the environment and in organisms, the levels of Dieldrin detected are likely to reflect the total concentrations of both compounds. Dieldrin residues have been detected in air, water, soil, fish, birds and mammals, including humans and human breast milk the application of this pesticide is now banned in most countries of the world. Many studies linked to this organochloride pesticides show health problems such as Parkinson's, breast cancer, and damage to the immune, reproductive, and nervous system. Dieldrin compounds decrease the effectiveness of our immune system and damage the kidneys. It can also adversely affect the reproductive success – increase infant mortality, testicular descent in the foetus if a pregnant woman is exposed to it.

Chlorofenvinphos is an organophosphorous compound that was widely used as an insecticide and an acaricide. Its use in the United States was cancelled in 1991(RFS, 1995). Diazinon is considered to be of relatively high toxicity for vertebrates. Studies have suggested that exposure to some organophosphate pesticides can result in long-term neurological problems including organophosphate-induced delayed neuropathy (weakness or paralysis as well as paraesthesia in the extremities).

Methyl parathion is an organophosphorus compound highly toxic by inhalation, ingestion and moderately toxic in dermal adsorption. It may cause contact burns to skin or eyes and accidental cases can be fatal (Emergency Response Guidebook, 1984). There is no carcinogenicity (WHO, 1993 and IARC, 1987). Methidathion is another highly toxic compound. The compound is poisonous to humans and acute exposure may cause intense breathing problems including paralysis of the respiratory muscles.

Phosalone is an Organophosphorous compound which has moderate toxicity and cause irritation to skin and eyes. (NIHS, 2010). Phosalone rapidly dissipates in untreated waters. Fenitrothion is another Organophosphorous pesticide used against wide range of pests. The compound is intermediately mobile in a variety of soils ranging from sandy loam to clay (Meister, 1994). Fenvalerate is an Organophosphorous compound of moderate mammalian toxicity and not classifiable as to its carcinogenicity to humans. Fenpropathrin is a pesticide that is not likely to be carcinogenic to humans (USEPA 2006). Permethrin is the Pyrethroids insecticide and among the most widely used insecticides in homes and crops and is used against a wide spectrum of pests. Cis-permethrin, Trans- permethrin and Alfa Cypermethrin are synthetic in nature.

Piperonyl butoxide (PBO) is a Pyrethroid and is practically non-toxic to birds, mammals, and bees. However, it is moderately toxic to fish. Very small amounts of PBO may be present as residue in food. However, the Internal Agency for Research on Cancer (IARC) evaluated PBO as 'not classifiable as to its carcinogenicity to humans'. PBO does not dissolve easily in water and may be more or less mobile depending on soil type. PBO can cling to soil types with more organic material. PBO did not leach through loam soils but did leach easily in sandy soils (Hallman et al., 2017).

The Government of India has banned a number of pesticides due to their adverse effects on living organisms. The Pesticides banned for manufacture, import and use are BHC group, Chlorofenvinphos and Dieldrin. The pesticides restricted for use in India are Methyl Parathion, Diazinon and Fenitrothion (http: //cibrc.nic.in/list_pest_bann.htm.).

Ashok Kumar and Aman Kumar (2013) reported the concentration levels and distribution patterns of the 21 Organochlorine pesticide residues in the surface water of Sharda river region in Lakhimpurkheeri, Uttar Pradesh-India. The occurrence of these compounds in Sharda river region surface waters can be attributed to intense agricultural activity as well as to trans boundary pollution. The most commonly encountered Organochlorine pesticides in surface water were Dieldrin, Heptachlor epoxide, isomers of Hexachlorocyclohexane and DDT. Farshid Kafilzadeh et al., (2012) determined organochlorine pesticide residues in water, sediments and fish from Lake Parishan, Iran. Six OC pesticides namely DDT, DDE, Lindane, Endosulfan, Heptachlor and Chlordane were analyzed in four sites during four seasons. The lowest levels of OC pesticides were related to Heptachlor and Chlordane while none of them were found in water samples.

Agrawal et al., (2010) studied water pollution with special reference to Pesticide contamination in India. In India, Organochlorine insecticides such as DDT and HCH constitute more than 70% of the pesticides used at present. Reports from Delhi, Bhopal and other cities and some rural areas have indicated presence of significant levels of pesticides in fresh water systems as well as bottled drinking mineral water samples.

5.4 Methodology

The samples were collected from different locations of Thrissur Kole wetlands. Water, plant and rice (paddy) samples were collected for the pesticide residue analysis. Ten water samples, five plant and five rice samples were selected randomly from various sites in the wetland system for the analysis (Table 5.1, Fig.5.1 & plates 5.1 to 5.3). Samples were separately stored in labeled polyethylene bags and transported to the laboratory. The objective of residue analysis was to estimate the residue present at the time of sampling and every precaution was taken to ensure that the sample arriving at the laboratory had not been allowed to deteriorate in such a way that the results were meaningless. The water samples were collected in clean high purity amber glass bottles and refrigerated in ice box until it reached the laboratory. The plant which was selected for the study was *Grangea maderaspatana*, a tropical plant commonly seen in harvested fields, dry river and pond beds and is distributed throughout India. The rice samples, seeds of *Oryza sativa*, were collected from paddy fields. Both the samples were stored in refrigerator at 4˚C. The sampling was done before the harvesting time of January, a winter month.

Table 5.1 Sampling sites

Sample Number	Sampling Site	Latitude	Longitude
S1	Muriyad	N10º21'06.4"	E 076º15'47.1"
S2	Madavakara	N10º26'17.9"	E 076º15'24.1"
S3	Kanimangalam	N10º 28'42.6"	E 076º13'05.1"
S4	Parapur	N10º33'46.9"	E 076º08'09.4"
S5	Parakad	N10º34'41.9"	E 076º05'16.8"
S6	Perumpuzha	N10º29'21.8"	E 076º08'05.9"
S7	Veluthur	N10º 28'08.5"	E 076º08'59.7"
S8	Anthikad	N10º 27'38.7"	E 076º07'49.3"
S9	Karalam	N10º 24'4.2"	E 076º10'58.4"
S10	Thommana	N10º 20' 04.9"	E 076º15'16.5"

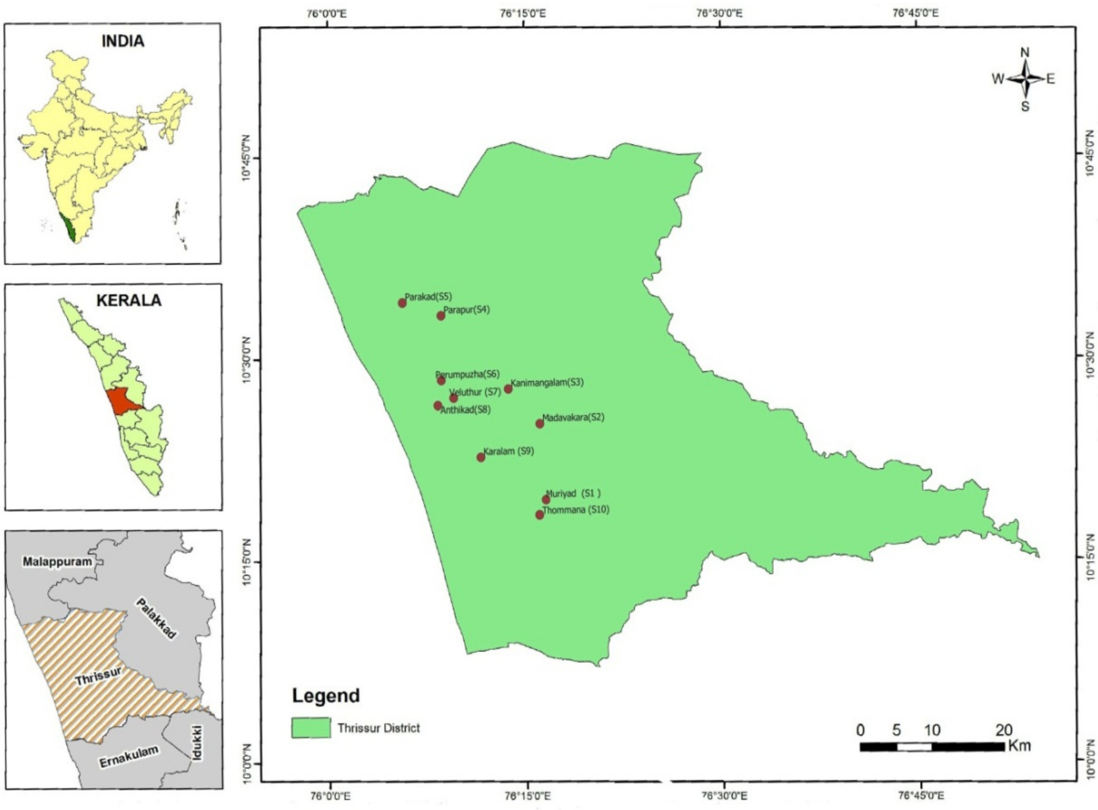


Fig.5.1 Location of sampling sites

5.5 Determination of Pesticides

Polychlorinated Organochlorine and Organophosphorous pesticides in water sample was quantitatively determined. Measured volume of the water sample was extracted with dichloromethane (or 15% diethyl ether in hexane). The extract was concentrated using rotary evaporator/turbovap. The residue was reconstituted in 10% diethyl ether in hexane/DCM and analyzed by gas chromatography/ mass spectrometry.

5.6 Determination of Pesticide Residue

This method describes procedure for the quantitative determination of pesticides in Plant extract and raw plant material using QuEChERS method (Quick, Easy, Cheap, Effective, Rugged and Safe). This method uses a single step buffered acetonitrile extraction and salting out liquid-liquid partitioning from water in the sample with $MgSO_4$. Dispersive solid phase extraction (Dispersive SPE) cleanup was done to remove organic acids, excess water and other components with a combination of primary secondary amine sorbent, $MgSO_4$, C-18, and GCB. Then the extracts were analyzed by GC ECD technique after chromatographic analytical separation(AOAC,2012).

5.7 Result and discussions

The chromatograms of different samples are represented in figures 5.2 to 5.22. The chromatograms show the presence of pesticides present in all type of samples.

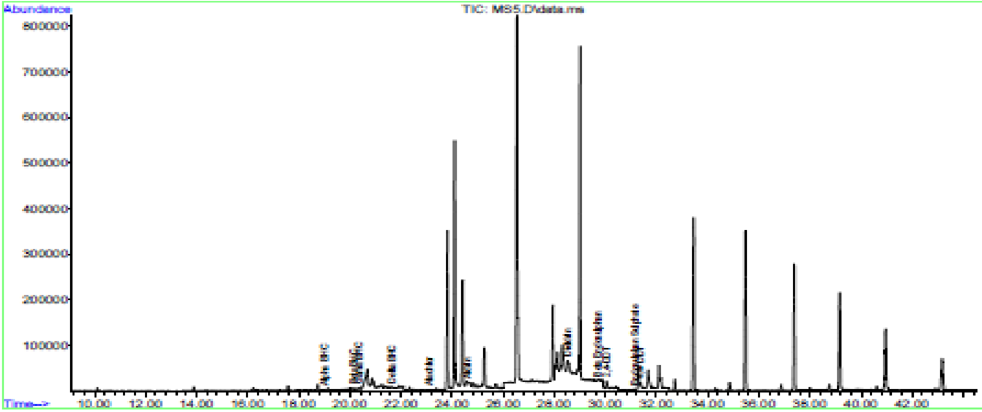


Fig.5.2 Chromatogram showing pesticide residues in water sample S1

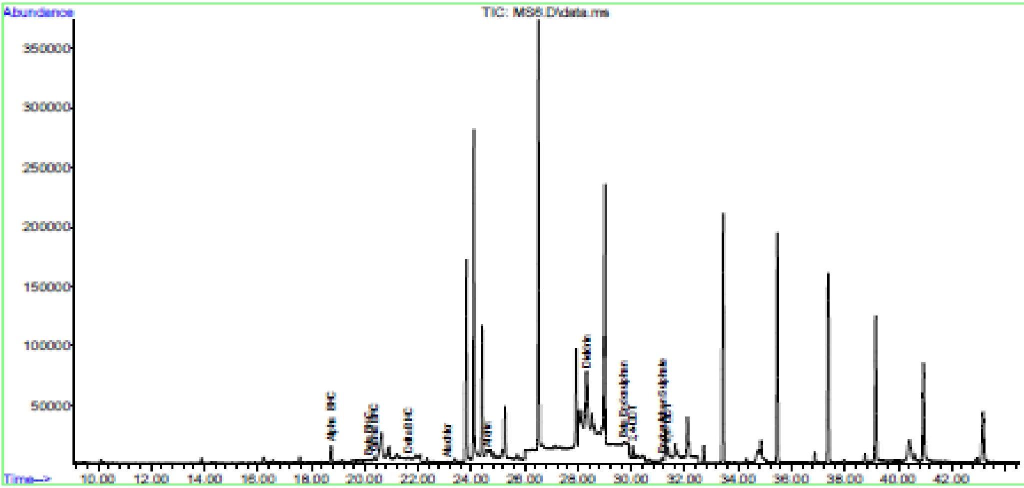


Fig. 5.3 Chromatogram showing pesticide residues in water sample S2

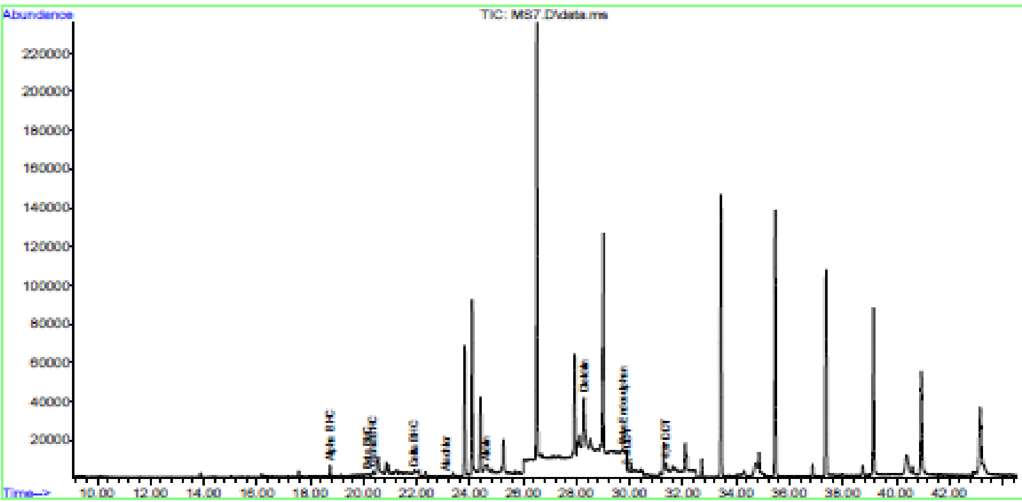


Fig.5.4 Chromatogram showing pesticide residues in water sample S3

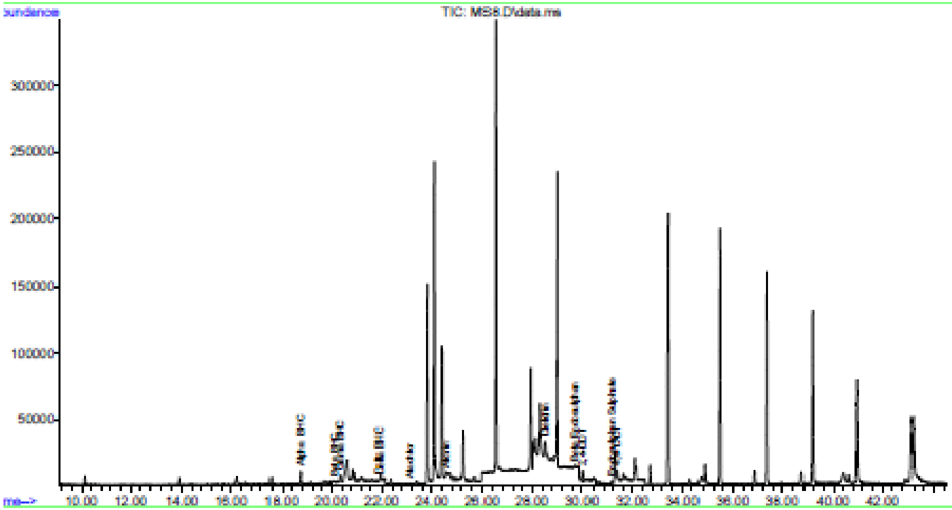


Fig.5.5 Chromatogram showing pesticide residues in water sample S4

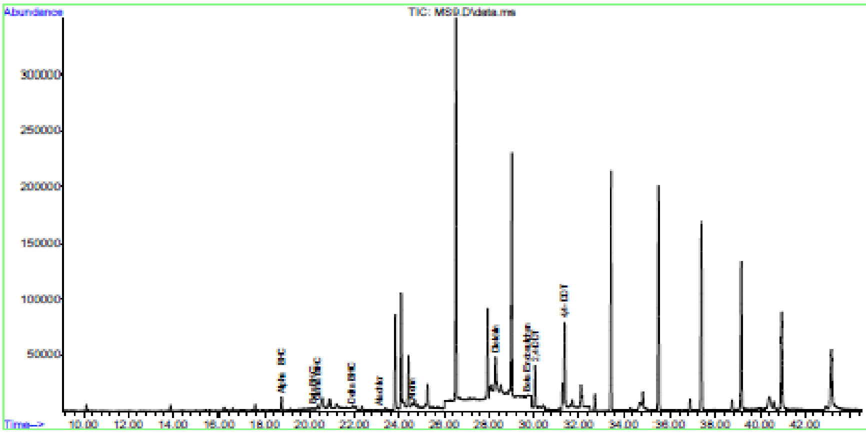


Fig.5.6 Chromatogram showing pesticide residues in water sample S5

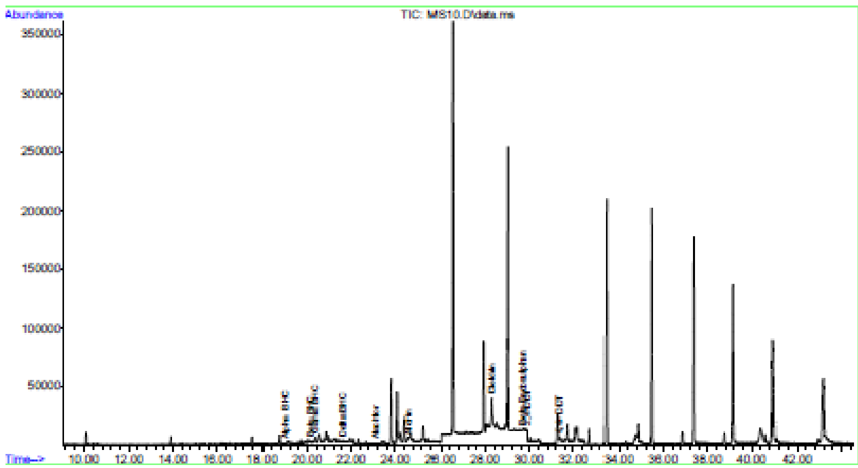


Fig.5.7 Chromatogram showing pesticide residues in water sample S6

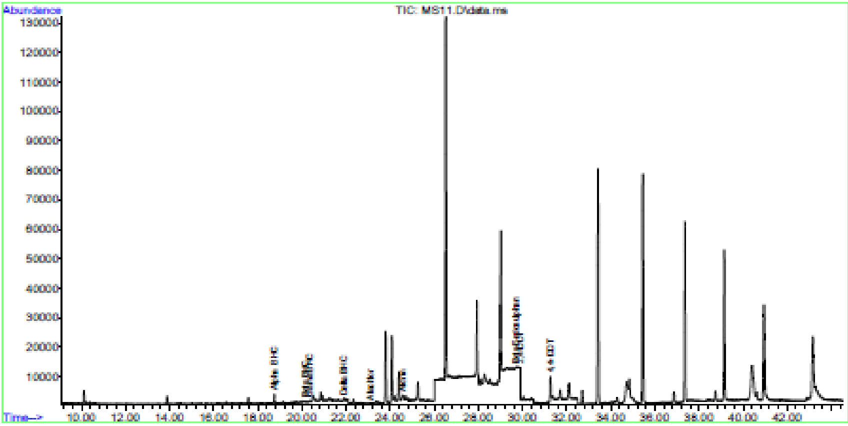


Fig.5.8 Chromatogram showing pesticide residues in water sample S7

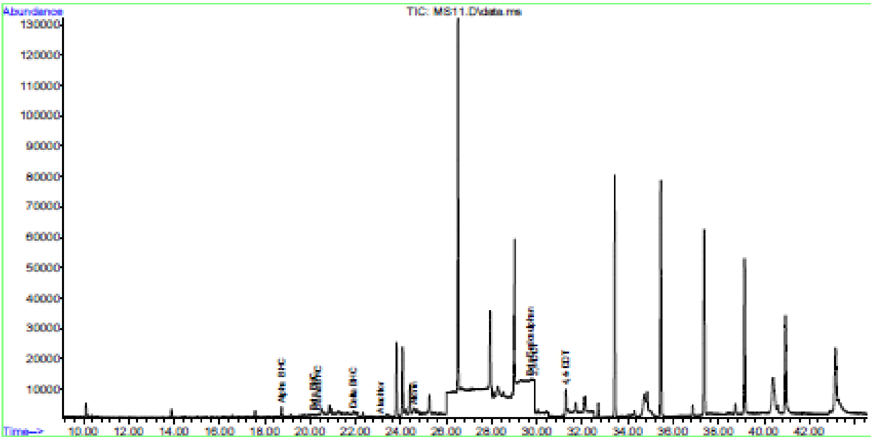


Fig.5.9 Chromatogram showing pesticide residues in water sample S8

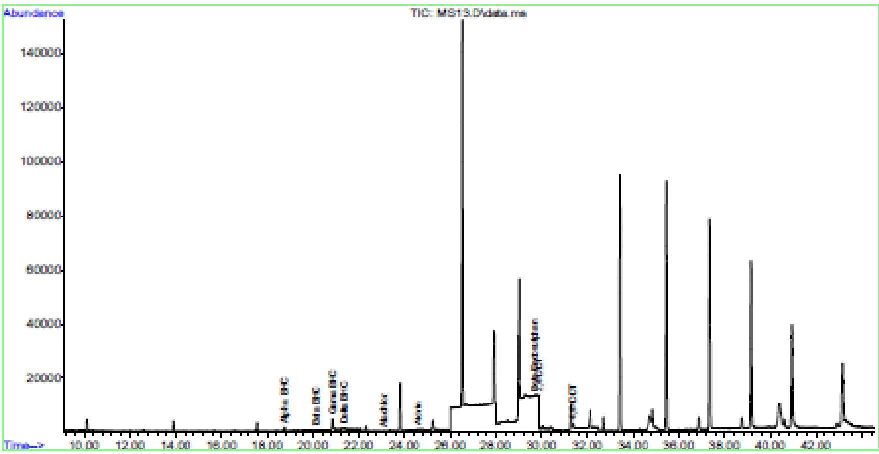


Fig.5.10 Chromatogram showing pesticide residues in water sample S9

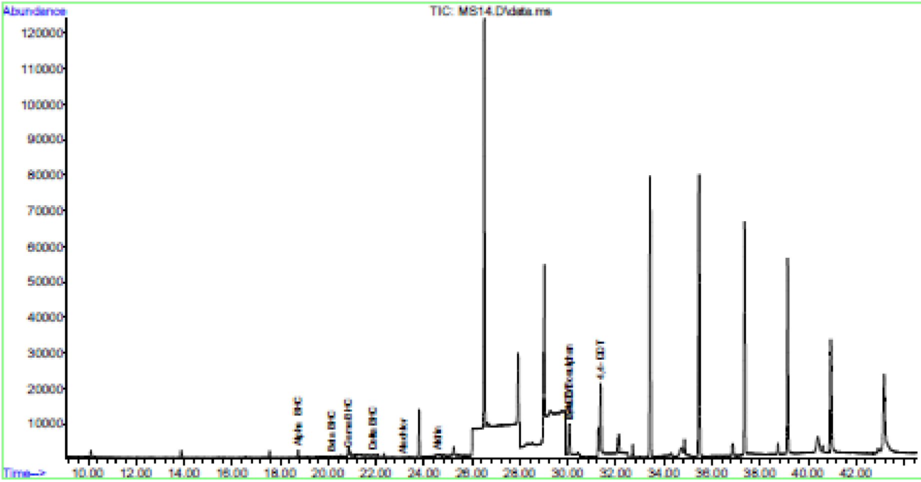


Fig.5.11 Chromatogram showing pesticide residues in water sample S10

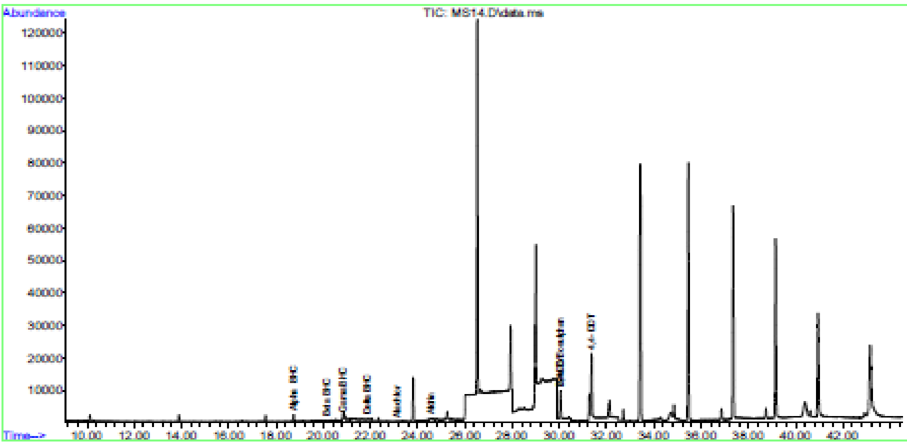


Fig.5.12 Chromatogram showing pesticide residues in plant sample S1

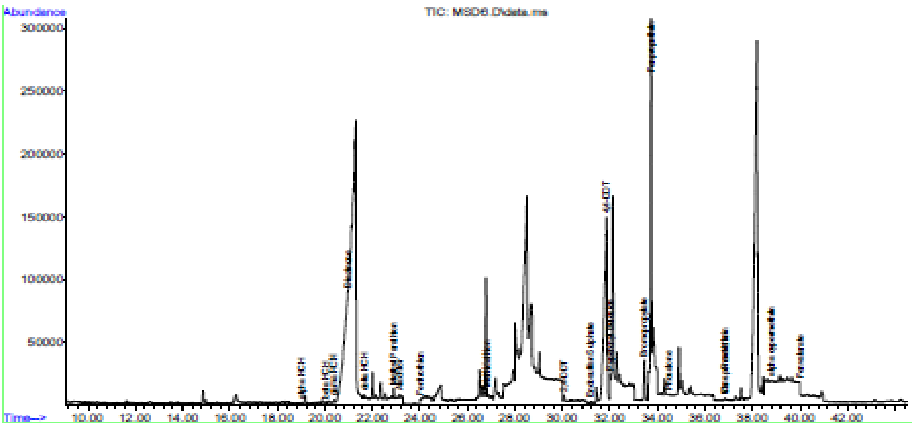


Fig.5.13 Chromatogram showing pesticide residues in plant sample S2

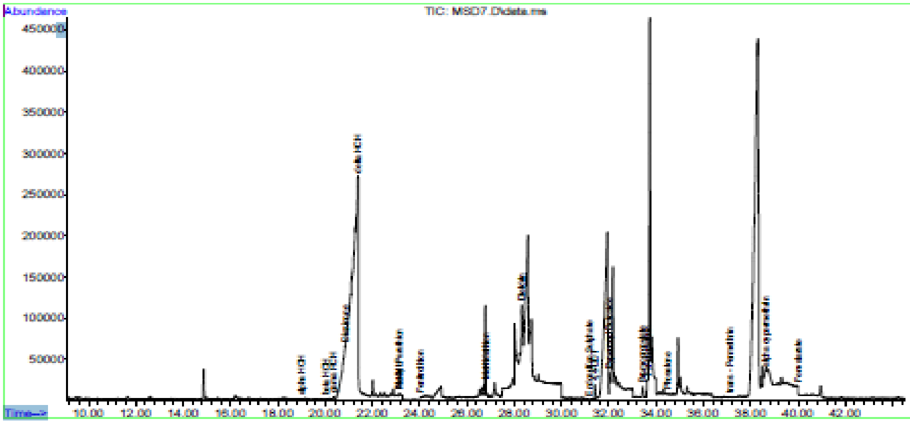


Fig.5.14 Chromatogram showing pesticide residues in plant sample S4

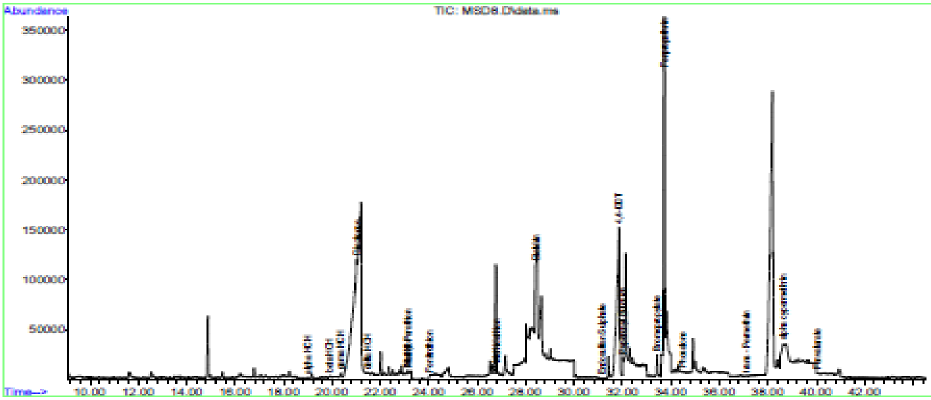


Fig.5.15 Chromatogram showing pesticide residues in plant sample S6

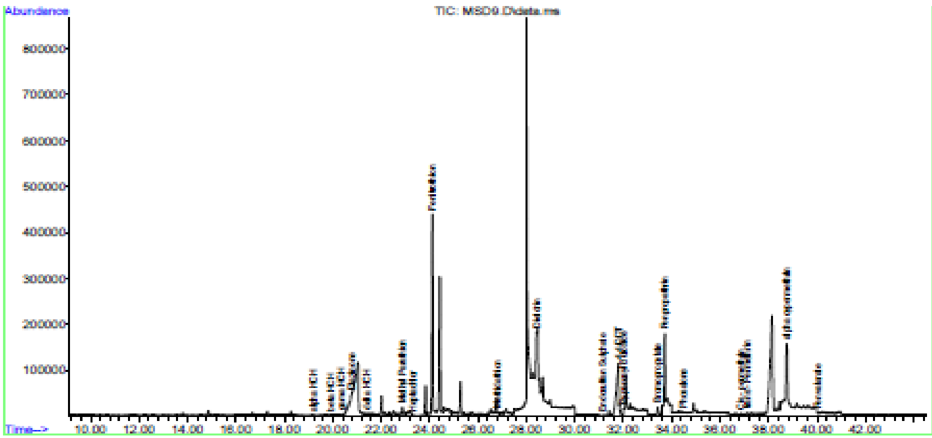


Fig.5.16 Chromatogram showing pesticide residues in plant sample S8

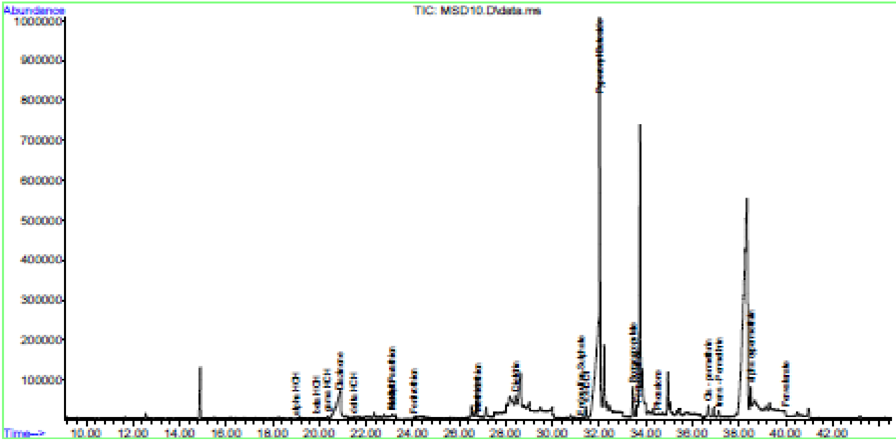


Fig.5.17 Chromatogram showing pesticide residues in rice sample S1

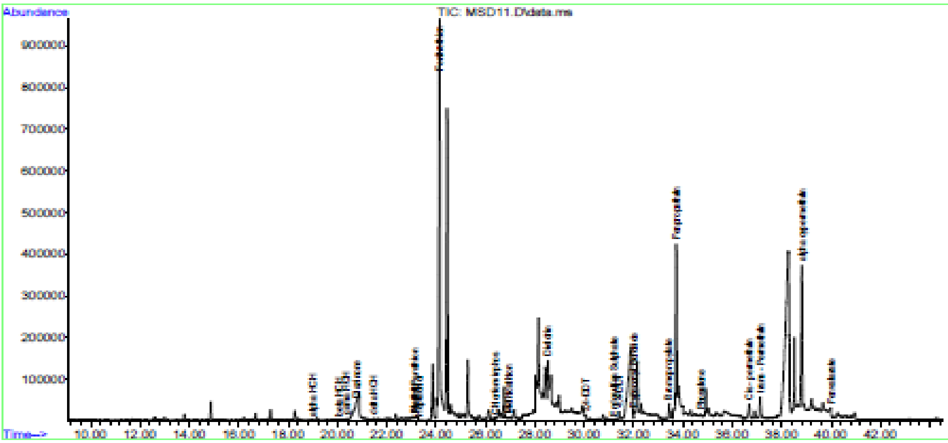


Fig.5.18 Chromatogram showing pesticide residues in rice sample S2

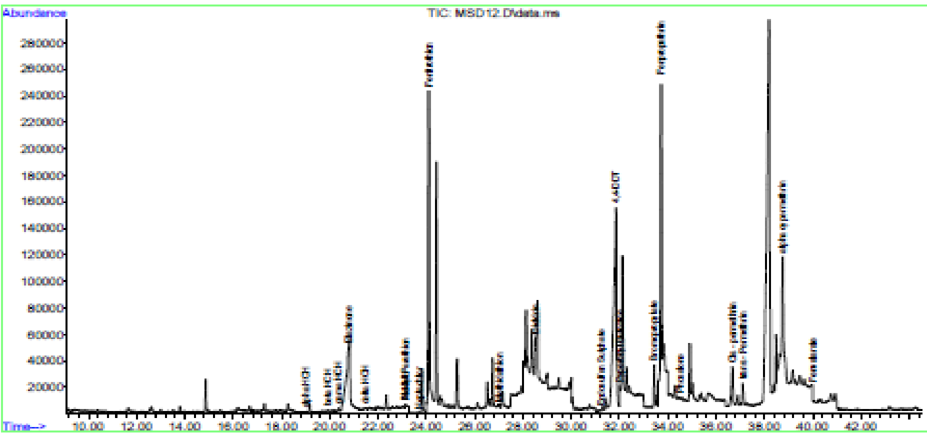


Fig. 5.19 Chromatogram showing pesticide residues in rice sample S4

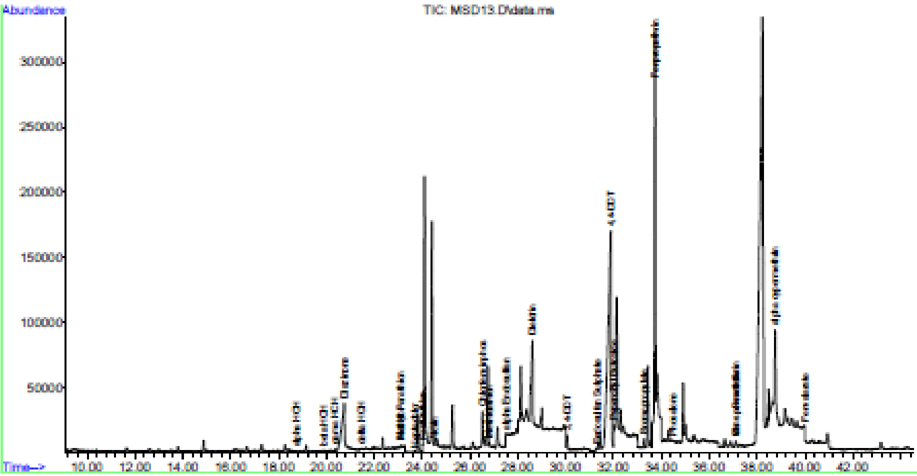


Fig. 5.20 Chromatogram showing pesticide residues in rice sample S6

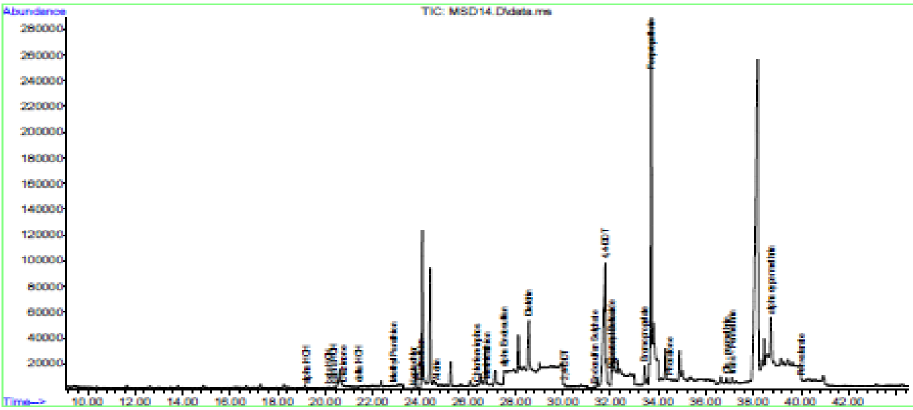


Fig. 5.21 Chromatogram showing pesticide residues in rice sample S8

Dieldrin was the Organochlorine pesticide present in rice samples with values ranging from 0.120 to 0.610 (Table 5.2 and Fig. 5.22). The residue limit for Dieldrin is 0.03 µg/l (ISI, 2012). All the five samples show higher value than the permissible limit. Dieldrin residues were Persistent Organic Pollutants (POP). Their bio accumulative properties affect non targeted organisms in the environment through the food chain.

Organophosphorous residues like Methyl Parathion, Methidathion and Phosalone were absent in all the samples. Chlorofenvinphos, Fenitrothion and Diazinon were detected in the rice samples and the maximum was 1.910, 0.210, 0.220 ppm respectively. Among the Pyrethroids, piperonyl butoxide and fenevalerate were not detected; however Fenpropathrin, Cis-permithrin, Trans- permethrin and α cypermythrin residue were found in the rice samples. The samples from locations S2, S4, S6 and S8 showed high values of Fenpropathrin residue, 4.080, 2.380, 3.690 and 3.550 ppm respectively.

Table 5.2 The quantity of pesticide residue present in rice sample (ppm)

S No.		S1	S2	S4	S6	S8
Organochlorine pesticides						
1	Dieldrin	0.160	0.530	0.120	0.610	0.30
Organophosphorous pesticides						
2	Chlorofenvinphos	ND	ND	ND	1.910	ND
3	Methyl parathion	ND	ND	ND	ND	ND
4	Methidathion	ND	ND	ND	ND	ND
5	Phosalone	ND	ND	ND	ND	ND
6	Fenitrothion	ND	0.210	0.060	0.098	0.080
7	Diazinon	0.220	ND	0.090	0.089	ND
Pyrethroids						
8	Piperonylbutoxide	ND	ND	ND	ND	ND
9	Fenvalerate	ND	ND	ND	ND	ND
10	Fenpropathrin	0.260	4.080	2.380	3.690	3.550
11	Cis-permithrin	ND	0.710	0.780	ND	ND
12	Trans- permethrin	ND	0.770	0.260	ND	ND
13	αCypermethrin	0.450	0.110	0.680	0.550	0.200

*ND= Not Detected

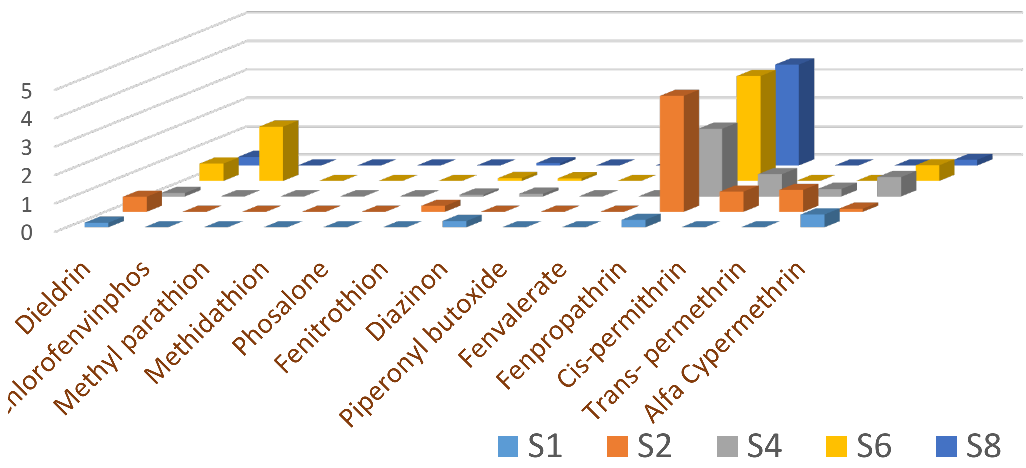


Fig.5.22 Pesticide residue present in the rice sample (ppm)

The quantities of pesticide residues present in plant sample were determined (Table 5.3 and Fig. 5.23). All the samples except S2 showed higher values of Dieldrin than the permissible limit. The residue values ranged from 0.420 to 2.030 ppm. From the group of Organophosphorus residues Diazinon, Fenitrothion and Methyl parathion were detected in the plant sample. The minimum value of the residue is 0.090 and maximum is 0.887 ppm. Cholorofenvinphos, Methidathion and Phosalone were absent in all samples. Methyl parathion was detected only in S2 (0.420 ppm) and Fenitrothion in S8 (0.130 ppm). Diazinon was present in all the samples with a concentration of 0.090 and 0.887 ppm. Residues of Pyrethroids present in the samples were Fenpropathrin and α Cypermethrin. Fenpropathrin residue was detected in all samples except S1. Fenpropathrin residue value ranged from 0.180 to 3.760 ppm. The sample S6 and S8 showed the presence of α Cypermethrin and the estimated value was 0.140 and 0.660 ppm respectively. Piperonyl buttoxide, Fenvalerate, Cispermithrin and Transpermithrin were not detected in any of the samples. Many of these pesticides and their metabolites have been implicated in a wide range of adverse human and environmental effects including reproduction and birth effects.

Table 5.3 Pesticide residue in plant sample (ppm)

Sl.No	Parameters	S1	S2	S4	S6	S8
			Organochlorine pesticides			
1	Dieldrin	0.573	ND	0.420	0.580	2.030
			Organophosphorus pesticides			
2	Chlorofenvinphos	ND	ND	ND	ND	ND
3	Methyl parathion	ND	0.42	ND	ND	ND
4	Methidathion	ND	ND	ND	ND	ND
5	Phosalone	ND	ND	ND	ND	ND
6	Fenitrothion	ND	ND	ND	ND	0.130
7	Diazinon	0.887	0.478	0.230	0.850	0.090
			Pyrethroids			
8	Piperonyl butoxide	ND	ND	ND	ND	ND
9	Fenvalerate	ND	ND	ND	ND	ND
10	Fenpropathrin	ND	2.680	0.180	3.760	1.670
11	Cis-permithrin	ND	ND	ND	ND	ND
12	Trans- permethrin	ND	ND	ND	ND	ND
13	α –Cypermethrin	ND	ND	ND	0.140	0.660

*ND= Not Detected

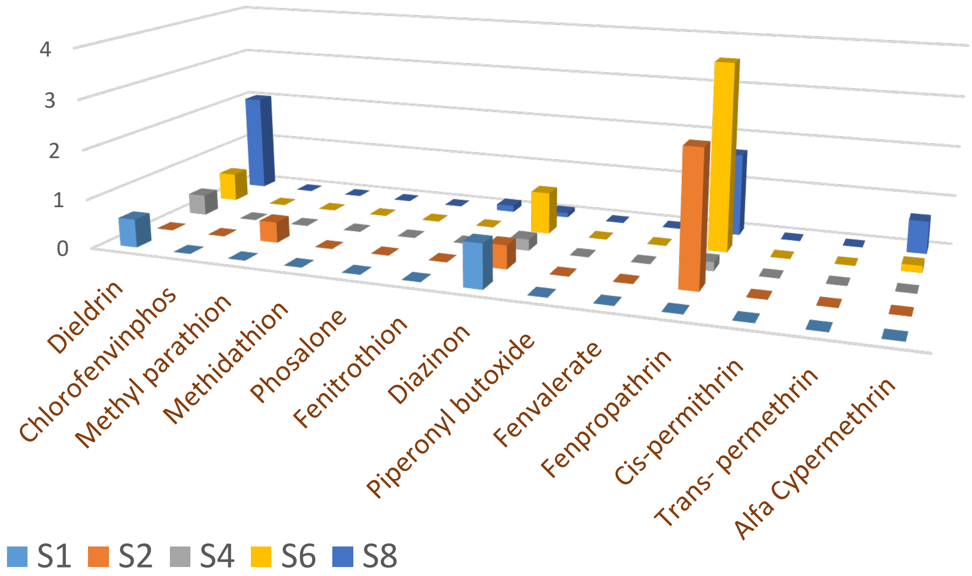


Fig. 5.23: Pesticide residue present in the plant sample(ppm)

The quantity of the pesticide residue present in water sample is presented in Table 5.4 and Fig. 5.24. Organochlorine residues identified were α BHC and Dieldrin. The samples S2, S3, S4, S5 and S8 contain α BHC residue with a minimum value of 0.220 to a maximum of 0.490 ppb. According to ISI (2012), for α BHC 0.01 µg/L is the permissible limit. All the values of α BHC show higher values than ISI (2012). USEPA (2017) recommends that there should not be more than 0.2 mg/L of BHC in drinking water. Dieldrin values ranged from 0.360 to 1.080 ppb. The USEPA norms of Dieldrin in drinking water is 1 to 2 ppb. According to USEPA limit, Dieldrin values in all the samples were under permissible limit. Ground water of Thiruvallur District is contaminated with high level of Organochlorine pesticides such as DDT, HCH, Endosulfan and their derivatives (Jayasree and Vasudevan, 2007). The maximum BHC derivatives found in open wells is 9.8 µg/L. Once ground water is polluted with toxic chemicals, it may take several years for the contamination to dissipate or be cleaned up. Cleanup may also be very costly and complex, if not impossible (Waskom 1994; O'Neil et al., 1998; US EPA, 2001).

Table 5.4 Pesticide residue in water sample (ppb)

Sl No	Parameter	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Organochlorine pesticides											
1	Alachlore	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2	α BHC	ND	0.490	0.220	0.350	0.430	ND	ND	0.290	ND	ND
3	Beta BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4	Gamma BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5	Delta BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6	α Endosulfan	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	Beta Endosulfan	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8	Endosulfan sulphate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	2,4-DDT	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10	4,4'-DDT	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11	Aldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12	Dieldrin	0.360	0.410	0.590	0.600	0.730	0.540	ND	1.080	ND	ND

*ND= Not Detected

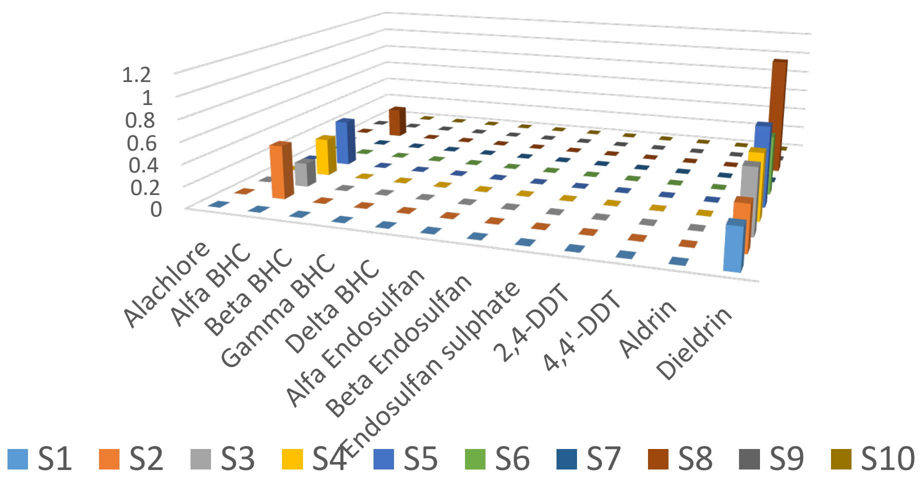


Fig.5.24 Pesticide residue present in the water sample (ppb)

Skin problems were reported as the most common symptom of toxicity. Eye-irritation and vision problems were also very common (plate 5.4). Home remedies or traditional Ayurvedic treatment or Allopathic treatment was resorted to in these cases. Though the frequency of symptoms like nausea, giddiness, breathing problems, dehydration, vomiting, cramps, convulsions, diarrhoea, etc., was comparatively less, life-threatening severe symptoms of breathing problems, dehydration, vomiting, cramps and diarrhoea soon after spraying resulting in hospitalization were frequent. In majority of cases the person was taken directly from the farm to the hospital. Ironically, the public health care system reports no cases of occupational health damage due to pesticide exposure (Indiradevi, 2007) (Plate 5.5).

A study undertaken by Medical College, Thiruvananthapuram has reported very frequent cases of cancer of the lip, stomach, skin and brain, lymphoma, leukemia and multiple myloma from Kuttanad rice area of Kerala, linking the same to high pesticide use in the area (Dinham, 1993). A recent survey conducted by a volunteer group makes a similar observation regarding the rising trend in cancer patients in Kuttanad, identifying pollution as one of the reasons. Reports on the depletion in the fish population and massive deaths due to ulceration in fish in Kuttanad are also common (Indiradevi, 2007).

5.8 Conclusion

Samples of rice, plant and water were found contaminated with pesticide residues. In India, Dieldrin was banned only in July 2001. Dieldrin was present in all samples and the values were higher than the permissible limit. Organophophorous residues like Fenitrothion and Diazinon were present only in plant samples. Methyl parathion and Chlorofenvinphose were only present in one plant sample (S2) and

Chlorofenvinphos was present in sample S4. Fenpropathrin and Alfa Cypermethrin were found both in plant and rice samples. However, Cis-permithrin and Trans-permethrin were found only in rice samples. But in this study, all the samples had higher Dieldrin concentration than the permissible limit. α- BHC was present in water samples which is carcinogenic. According to Canadian drinking water standards, the permissible limit of Diazinon was 0.002 mg/l. All the samples studied had higher values than this permissible limit. The concentration of pesticide residues indicates that in spite of the restriction, excessive and indiscriminate use of pesticides is still being practiced by farmers. The study recommends that farmers should be trained in the judicious and safe use of pesticides and also must be encourage to use alternative environmentally sustainable pest control strategies.

CHAPTER 6

SOIL QUALITY ANALYSIS

SOIL QUALITY ANALYSIS

6.1 Introduction

Wetland soils are unique among soils. Soils of wetland environments possess physical, chemical, and morphological properties that readily distinguish them from upland soils (Jackson et al., 2014). Wetlands are unique in its nature as they hold water improves the water quality, provides fish and wildlife habitats, stores floodwaters and maintains surface water flow during dry periods. The sustainable agriculture is explained in terms of soil quality. Soil quality defined as the capacity of a soil to function within the ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran and Parkin,1994). The quality of soils varies according to the changes in the use and management.

Commonly wetland soils have increased organic matter content. The prolonged saturated and anaerobic conditions in wetland soils slows down decomposition of organic matter leading to organic matter accumulation. Organic matter, specifically humus, in a mineral soil promotes aggregation, structural stability, lowers bulk density, increases porosity, and leads to higher infiltration and percolation rates. Organic matter also contains significant amounts of plant nutrients (in unavailable forms), which can be converted to available forms during decomposition of organic matter. The complex humus molecules also add to the cation exchange capacity of the soil (Jackson et al., 2014).

The chemical changes in the submerged soils influence the chemical nature of sediment or soil that forms, types of crops and other plant species around the wetlands, the quality and quantity of the aquatic life and the capacity of the wetland to serve as sinks for terrestrial wastes. Paddy is extensively grown in this fields. For the cultivation of rice varieties, the paddy soils are managed in a particular traditional method. Several steps involved in making paddy fields suitable for cultivation includes the leveling of the land and construction of levees to impound water, plowing and harrowing the water saturated soil, maintenance of 5-10 cm of standing water during the 4-5 months of crop growth, draining and drying the fields at harvest and reflooding after an interval which varies from a few weeks to 8 months. These agricultural practices and oxygen secretion by rice roots give unique peculiar features to paddy fields (Ponnamperuma, 1972).

During submergence, the soils undergo reduction and turns dark gray. Iron, manganese, silica and phosphate become more soluble and move by diffusion to the surface flow, roots and to the sub soil. When reduced iron and manganese reach the oxygenated surface of rice roots or the oxidized plow sole, they are oxidized and precipitated along with silica and phosphates (Koenings, 1950, Kyuma and Kawaguchi, 1966).

The cyclical nutrient recharging of the wetland during the flood season rendered the areas one of the most fertile soils of Kerala (Sobharani and Latha, 2015). Large scale use of fertilizers containing only major nutrients can result in the deficiencies of secondary and micro nutrients (Ponnusamy, 2006).

Extreme acidity, soil salinity, aluminium, iron and hydrogen sulphide toxicity and associated deficiencies of phosphate, organic matter, copper and zinc are the most important constraints of the wetland soils for the rice cultivation and fish production. So, the wetland soils especially paddy soils require special management practices to counteract these problems and sustain production (Iyer et al., 1989).

Land use activities adjacent to wetlands can affect wetland habitat by altering inputs of sunlight, sediment, organic debris, nutrients, dissolved carbon, and sometimes contaminants such as pesticides, heavy metals, and organic chemicals. Vegetation and soil alteration in a wetland's watershed predominantly affect the wetland through altered hydrology and sediment contributions. Some activities may directly alter outlet hydraulics and thus change a wetland's hydrology. Abiotic effects of human actions may make a wetland wetter, drier, flashier, sunnier, or more nutrient-rich, and consequently alter the biology of the system. Basic hydrologic concepts can be applied to predict likely effects of landscape alteration around and above a wetland (Jackson et al., 2014).

The mobility and plant availability of many trace and toxic metals in wetland soils is often substantially different from upland soils. Oxidation-reduction (redox) and associated pH changes that occur in soils are the results of flooding or drainage. This can affect the retention and release of metals by clay minerals, organic matter, iron oxides and for coastal wetlands sulfides. Except where a flooded soil or sediment becomes strongly acidic upon drainage and oxidation, as sometimes occurs, the processes immobilizing metals tend to be complimentary such that large-scale metal releases from contaminated soils and sediments do not occur with changing redox conditions. Metals tend to be retained more strongly in wetland soils compared with upland soils.

Floods occur worldwide, often after heavy rains in an area. Frequent extreme precipitation events cause flooding which have become common in India. Soil degradation due to flooding was also a serious concern. In 2018, Kerala state witnessed a disastrous flood resulted out of continuous heavy rains adding to the list of great natural disasters of the world (KSDMA,2018).

6.2. Soil sampling and analysis

6.2.1 Study area

The study area covered the Kole wetlands of Thrissur district. A total of 22 locations from the Kole wetland systems were selected randomly and samples were collected from each site (Table 6.1, Fig.6.1 and plate 6.1 & 6.2) after the harvest during dry period of the wetland. The impact of the flooding in soils of this wetland ecosystem due to unprecedented rainfall during 2018 monsoon was also subjected to study. Out of 22 locations from the Kole wetlands, only twelve were selected randomly for post flood study. The study locations include S1 to S12 where the maximum impact of disaster has occurred.

Table 6.1. Details of the sampling locations

Sample site	Area	Latitude	Longitude
S1	Kanimangalam	N10º 28' 42.6"	E 076º 13' 05.1"
S2	Pullazhi	N10º 31' 18.8"	E 076º 09' 45.2"
S3	Anthikkad	N10º 27' 14.8"	E 076º 08' 00.2"
S4	Perumpuzha	N10º 28' 54.7"	E 076º 07' 39.4"
S5	Alappatt	N10º 27' 58"	E 076º 09' 17.4"
S6	Aranattukara	N10º 30' 10.4"	E 076º 11' 19.1"
S7	Mullur	N10º 30' 10.4"	E 076º 11' 19.1"
S8	Annakara	N10º33' 00.7"	E 076º06' 37.5"
S9	Vaka	N10º35' 11.7"	E 076º06' 38.6"
S10	Padoor	N10º31' 41.6"	E 076º04' 48.6"
S11	Ammadam	N10º27' 02.9"	E 076º10' 28.5"
S12	Pullu	N10º 27' 3.1"	E 076º 10'23.1"
S13	Vellani	N10º 23' 50.4"	E 076º 10'1.6"
S14	Karuvannur	N10º 24' 3.58"	E 076º 12'48.61"
S15	Kecheri	N10º 36' 24.5"	E 076º 10'1.6"
S16	Adattu	N10º32' 26.1"	E 076º 10' 41.4"
S17	Amballur	N10º26' 20.0"	E 076º 15' 11.3"
S18	Muriyad	N10º21' 32.2"	E 076º 14' 56.1"
S19	Thazhekkad	N10º20' 00.3"	E 076º 16' 34.8"
S20	Manalur	N10º 29' 42.04"	E 076º 06'51.20"
S21	Mullassery	N10º32' 15.5"	E 076º06'06.8"
S22	Cherpu	N10º 25' 55"	E 076º 12'26.1"

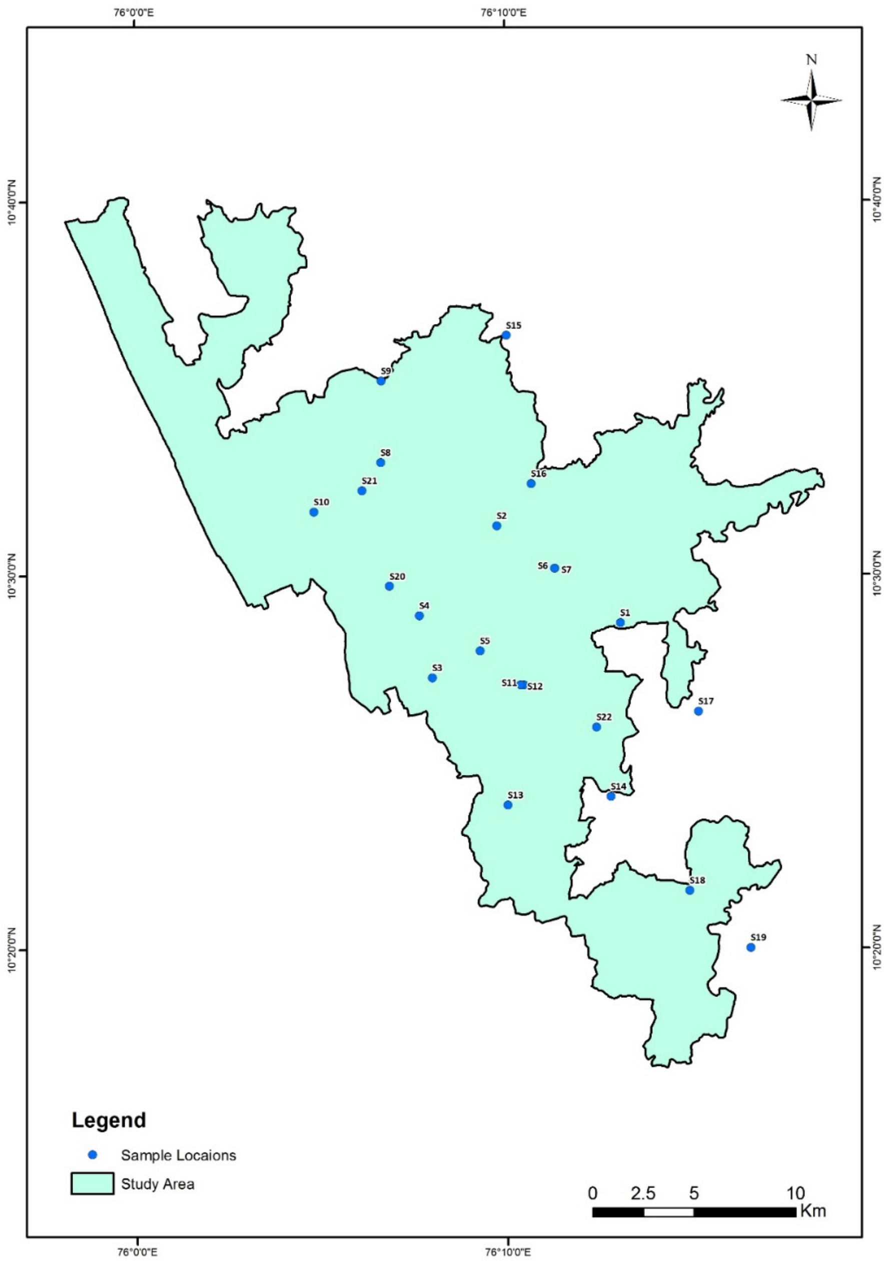


Fig.6.1. The study area

6.3 Methodology

6.3.1. Soil Analysis

Soil samples were collected randomly from the Kole wetland system during dry period (April-May) and also in post flood condition. The soils samples were collected by core sampling in PVC pipe at different depths: 0-10 cm (top layer, A), 10-20 cm (middle layer ,B) and 20-30cm (bottom layer,C). The chemical parameters of the Kole land soil were done by using standard soil procedures. p^H, electrical conductivity, organic carbon, total sulphur, the plant available forms of potassium, sodium, phosphorous, nitrogen, calcium, magnesium, sulphur, aluminium and boron were assessed. The total sulphur in the soil samples were analysed using CHNS analyzer (Eurovector, Italy. Model: EA 3000) Micronutrients like Iron, Manganese, Copper, Zinc and heavy metals such as Cadmium, Nickel, Chromium was also estimated.

pH was measured by potentiometric method (Jackson ,1957). 20g of soil was taken in 10ml beaker to which 50ml of distilled water was added. The suspension was stirred at regular intervals for 30 minutes and pH was recorded using a pH meter. Electrical conductivity was measured by using Eutech instruments con 510 conductivity/TDS/^{0}C/^{0}F Meter. The available phosphorus was determined using Bray's method. The available potassium and sodium were determined using Morgans extraction method. The estimation of sodium and Potassium done by CL 378 ELICO Flame photometer. Walkley and Black method (1934)was used to estimate Soil organic carbon (SOC) for the extraction of micronutrients, 5g soil was treated with **0.**1N HCl and analysed in atomic absorption spectrophotometry (AAS (Varian AA 240)). Boron was extracted with hot water and activated charcoal, boil in Teflon wares and the filtered contents was assessed in UV-VIS Spectrophotometer at 420 nm. Heavy metals were analyzed in 0.1 N HCl extract using AAS.

6.3.2. Interpretation of soil parameters by Interpolation technique – Kriging

Using GIS interpolation tool- Kriging the spatial distribution of soil quality parameters were delineated. The methodology is described in section 3.4.

6.4. RESULT AND DISCUSSION

6.4.1 Soil pH

In the natural environment, soil pH has an enormous influence on soil biogeochemical processes. Soil pH is, therefore, described as the "master soil variable" that influences myriads of soil biological, chemical, and physical properties and processes that affect plant growth and biomass yield (Dora, 2019). It is a rough indicator of plant availability of nutrient in the soil. Soil p^H directly affects the solubility of many of the nutrients in the soil needed for the proper plant growth and development. As soil p^H decreases, the availability of nutrients such as phosphorous for plant decreases. This can be attributed to the precipitation reactions with iron and aluminium. Plants that can influence their microenvironment are often found to grow well over a range of soil pH. The solubility and it's availability of nutrients fluctuates in response to p^H of soil. When the acidic nature of soil increases, the loss of the nutrients by chemical precipitation rises and availability to crops decreases. Application of agrochemicals and agricultural practices may affect the salt content in soil.

The soil samples were found to be generally acidic. The pH of 16 samples ranged from 3.59 to 6.5. Acidity reflected in all the three layers up to 30 cm depth. Neutral soil samples were found in the locations S12, S13, S14, S15, S16 and S19 (Table 6.2 and Fig 6.2(a). The p^H of the Kole wetland varied from 2.6 to 6.3 (Sheela, 1988). John Thomas et al. (2003) reported that the soils of Muriyad area was acidic in nature ranging from 4.9 to 6.1. It is already established that excessive decomposition makes the soil anaerobic and acidic (Hannu et al., 2000). Oxidation of organic sulfur compounds results in the production of sulfuric acid, which produce acidic nature to the sediment. Sulphate reduction, decomposition of organic matter and other anaerobic environment might have also resulted in the decrease in pH towards the surface layer (Robert, 2001).

The acid sulphate soils of Kuttanadu region recorded very low pH of 3 to 5.2. Soil acidity mainly influences the solubility of various elements in the soil, particularly some plant nutrients that influence productivity of wetland environments. It is revealed that during submergence the soil samples were highly acidic and after the paddy cultivation the soil became slightly acidic. This is in concordance with the report of Nair and Money (1972). They reported that soil pH of the saline soils of Kerala varied from 3.0 to 6.8. The slightly acidic pH noticed in Kaipad soils might be attributed to the presence of lime shell depositions (Iyer, 1989) as a result of frequent saline water intrusions during the monsoon period.

6.4.2 Electrical conductivity

It is the ability of a solution to conduct electricity. Salinization, or the accumulation of salts in the topsoil, can also have a deleterious effect on soil productivity and crop yields. In extreme cases, damage from salinization is so great that it is technically unfeasible or totally uneconomic to reverse the process.

In general, salinization is caused by water and dissolved salts moving up in the soil through capillary action. While salinization is occasionally the result of natural soil-forming processes, it occurs most frequently in irrigated soils, where it is worsened by the high salt content of irrigation water. Inherent factors affecting EC include soil minerals, climate, and soil texture. Other factors include bulk density, soil structure, water potential, timing of measurement, soil aggregation and electrolytes in soil water. Salts originate from the disintegration (weathering) of minerals and rocks. In areas that receive a high amount of rainfall, soluble salts are flushed below the root zone and eventually into deep groundwater systems or into streams that transport the salts to the ocean. Non saline soils that have a higher EC value have more available nutrients than those that have a lower EC value. Soil EC is affected by cropping, irrigating, land use, and application of fertilizer, manure, and compost. The electrical conductivity of the soils in the study area ranged from 17.42 to 437 µs/m in the top layer, 24.52 to 200 µs/m in the middle layer and 27.22 to 1530 µs/m in the bottom layer. (Table 6.2, Fig 6.2 b). In Kole wetlands EC mainly due to intrusion of saline water.

The study carried out by Manorama and Jose (2000) in Kuttanadu area showed that EC values were low for surface layers and higher for sub surface layers due to the accumulation of salts in lower layers. A definite trend is not noticed in soil layers. The high salinity recorded during the summer months due to the extremely high accumulation of salts during the dry season period of Kaipad soil (Santhi et al.,2017). These salts get washed away during the onset of monsoon and thus cause a reduction in electrical conductivity of soils, which favors rice cultivation.

6.4.3 Organic carbon

Natural organic matter plays an important role in the biogeochemical cycles of many trace elements and the quality of aquatic environment (Robert, 2001). The decomposition of organic matter in submerged soil differs from that of a well-drained soil in two aspects- it is slower and end products are different. In the well-drained soil, decomposition of plant residues by the aerobic microorganisms produces CO_2, nitrate, sulphate and resistant residues like lignin. In submerged soils, the rate of decomposition is much slower which is carried out by the facultative and obligate anaerobes.

The OC % was found to be increased with depth in locations S1, S2, S7, S8, S20.There was gradual decrease in organic carbon with depth at locations S3, S9, S10, S11, S12, S13, S14, S19, S22.In locations S21, OC % was found below the detectable limit. Based on the OC% range limit all the layers in locations S10, S11, S12, S14, S15, S16, S17, S18, S19 and S20 were found to be low OC category. However, in location S13 only the upper layer remained medium OC category. The rest of the locations fall under high OC category (Table 6.3 and Fig.6.2(c).

The presence of sand layers, differential accumulation of organic matter and sedimentary nature of the parent material are attributed to the reason for the heterogeneity in organic carbon distribution (Manorama and Jose, 2000). The study revealed that continuous monoculture of high yielding rice varieties without proper organic matter replenishment and the prevention of tidal deposition are the major reasons for organic matter depletion in Kuttanadu wetland.

6.4.4. Available Sodium

The available sodium was found to range from 1360 – 33900 kg/Ha in the top layer of the soil ,11960-35800 Kg/Ha in the middle layer and 26200- 35420 kg/Ha in the bottom layer (Table 6.3, Fig.6.2(d)).

Hasegawa et al., (2000) reported that saline and sodic soils are wide spread in inland areas and are progressively expanding due to improper water management. Salt stress limits the rice production in worldwide and increasing because of man-made secondary salinization and global warming. According to FAO (1996), more than 6% of the world's land affected by the salinity or sodicity whereas 6.74 million hectares of land in India suffering from economic losses. The common cations associated with salinity are Na^{+}, Ca^{2+},Mg^{2+},,while the common anions are Cl^{-}, SO_4^{2-} and HCO_3^{-}.since

Na+ in particular causes deterioration of the physical structure of soil and Na^+ and Cl^- both are toxic to plants, these are considered the most important associated ions (Hasegawa et al., 2000). The study carried out on Kaipad soils by Samikutty (1977) that the sodium and potassium contents in these soils were higher than that of the other paddy soils of Kerala due to the continuous submergence with salt water for over six to eight months in a year.

Table 6.2. Soil parameters pH and EC from different locations - top layer (A), middle layer (B) and bottom layer (C)

Locations	pH			EC		
	A	B	C	A	B	C
S1	6.22	6.22	6.23	41.8	46.4	46.8
S2	6.3	6.32	6.46	122.4	60	34.3
S3	6.38	6.4	6.4	32.2	28.7	36
S4	6.2	6.39	6.27	114.2	54.1	70.8
S5	6.16	6.26	6.4	62.9	33.8	37.2
S6	6.2	5.6	3.59	52.1	200	1530
S7	5.6	5.78	5.98	142.5	57.4	24.3
S8	5.92	6.04	6.15	121.4	50.7	30.3
S9	6.21	6.36	6.28	17.4	24.5	27.2
S10	6.51	6.75	6.7	437	111	29.6
S11	6.15	6.66	6.84	272	49	75
S12	6.97	6.92	6.74	241	61.1	56.9
S13	6.7	6.86	7.14	240	108	59
S14	6.81	6.78	6.87	67.5	43.4	48
S15	6.36	6.69	6.66	220	68.2	89
S16	6.65	6.58	6.6	82.1	53.8	60.2
S17	6.04	5.9	6.1	56.8	59.7	48.8
S18	5.82	6.06	6.28	80.2	62.9	36.6
S19	6.25	6.4	7.7	67.5	54.4	83.5
S20	5.7	6.23	6.45	123.7	84.2	41.8
S21	6.07	6.53	6.55	258	96.3	97
S22	6.24	6.07	6.4	62.5	73.8	28.3

Table 6.3. Soil parameters OC % and available sodium from different locations - top layer (A), middle layer (B) and bottom layer (C)

Locations	OC %			Available Sodium		
	A	B	C	A	B	C
S1	15.930	25.343	27.032	30700	30960	34200
S2	22.688	27.032	28.480	32540	32520	31860
S3	29.205	28.722	25.826	31780	29780	32800
S4	25.826	26.308	25.584	30420	21480	29380
S5	25.343	22.446	28.480	32000	32720	35420
S6	23.412	24.619	23.653	30420	30660	30140
S7	25.343	23.171	26.067	30360	11960	29440
S8	21.722	21.481	25.584	30440	29860	31040
S9	26.067	24.136	24.619	33600	35760	31060
S10	0.724	0.241	0.483	29880	34200	32800
S11	0.724	0.483	0.483	30840	30540	31460
S12	0.483	0.483	0.241	29380	30000	30300
S13	0.965	0.483	0.241	31140	35800	28640
S14	0.483	0.241	0.241	29140	32160	29680
S15	0.483	0.000	0.241	27820	29980	31360
S16	0.483	0.724	0.483	12720	31820	33920
S17	0.241	0.483	0.241	13560	33480	32240
S18	0.965	0.483	0.483	32560	37340	26200
S19	0.483	0.483	0.241	24560	17020	32660
S20	0.241	0.483	0.483	30160	32040	27440
S21	0.000	0.000	0.000	1360	31740	31120
S22	20.998	20.516	5.551	33900	35000	29160

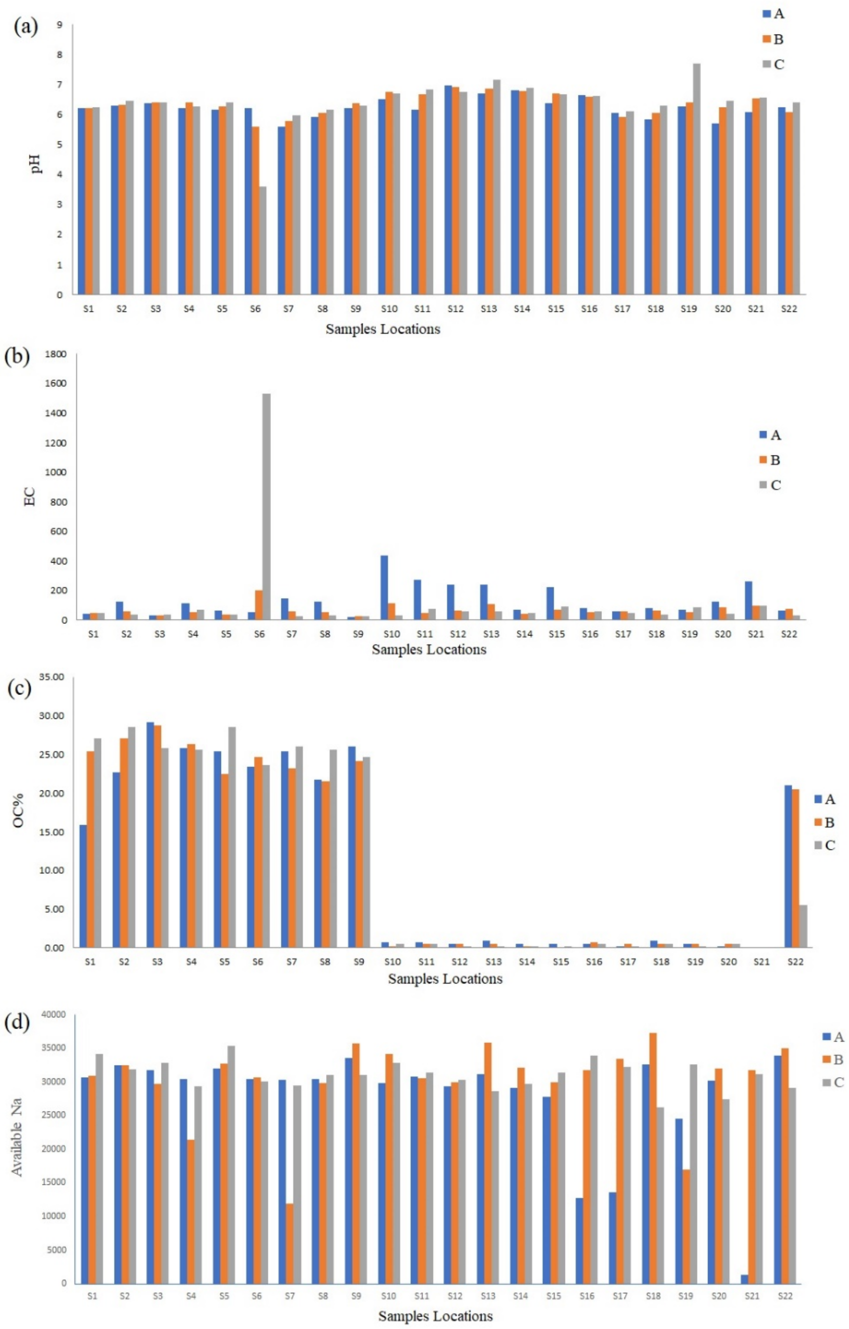


Fig.6.2. Diagrammatic representation of different parameters with depth **a)**pH, **b)**electrical conductivity, **c)**organic carbon **d)** available sodium.

6.4.5. Available nitrogen

Nitrogen occurs in the soil and sediments chiefly as complex organic substances, ammonia, molecular nitrogen, nitrate and nitrite. The transformations that they undergo are largely microbiological inter conversions regulated by the physical and chemical environment. In submerged soils, main transformations include the accumulation of ammonia, denitrification and nitrogen fixation. Although these provide nutrition to rice and aquatic plants, the pollute lakes and estuaries and affect nitrogen balance in nature. An increase in available nitrogen with depth was noticed in the locations S1, S2, S5, S20 and S22 and a decrease in the nitrogen with depth in S3, S9, S10, S1, S12, S13, S14, S15, S18 and S19. The available nitrogen is lacking in location S21 where soil extraction is reported (Table 6.4, Fig 6.3.e). Leiros *et al* (1999) reported that the medium to high value of available nitrogen content may be due to the presence of high amount of organic matter in these soils and the faster mineralization of nitrogen due to the activity of micro-organisms.

6.4.6. Available Phosphorous

The biogeochemical cycle of phosphorous plays a significant role in eutrophication process (Hong Wang et al. 2003). Due to the many different extraction schemes and their modifications, it is quite difficult to compare literature data in the field of phosphorous fractionation. The presence of phosphorous was found to be below the adequate limit. Phosphorous deficiency is common in soils with high aluminum contents due to the formation of insoluble Al-phosphates there by making P unavailable to plants. The study carried out by Beena et al., (2003) revealed that the soils of Kuttanadu region were deficient in available P due to high P fixation. Samikutty (1977) reported that the Kaipad tracts in north Malabar districts of Kozhikode, Kannur and Kasaragod are generally poor in phosphates.

6.4.7. Available Potassium

Potassium is one of the highly soluble alkali metals which acts as a limiting plant nutrient in the soils of humid tropical areas. The requirement of the potassium for the of growth of rice is less compared to that of N and P, however, potassium content in rice fields is equal to or greater than the plant P-N content and greater than all other essential nutrients (Singh and Singh, 2017). Reports from various rice research stations in Kerala have revealed that there exists a high variability in the response of rice to potash fertilizers with respect to yield. The excessive application of fertilizers usually affects the functional ability of the soil to retain and transform the nutrients and synchronize the availability of nutrients with crop needs. All samples in the Kole land were found to be above the limit of Potassium adequacy and can be attributed the application of the K fertilizer. The value of available potassium in the top layer of the soil ranged from 1575 to 10255 kg/ha, 4800 to 10192.5 kg/ha in middle layer and 3912.5 to 100600 kg/ha in the bottom layer (Table 6.4 and Fig 6.3f).

High content of potassium content was in reported in Kuttanadu region by Beena et al. (2003). Naveen and Moossa (2019) reported that water soluble K fraction was found to be higher in Onattukara soils and the plant availability of added potassic fertilizers would be more in these soils. The decrease in the concentration of available K with submergence observed in sandy clay rice soils due to fixation of potassium in the soil which was not noticed in the sandy loam soils.

6.4.8. Calcium

Calcium is the most important secondary nutrients for the growth of the plant. The top layer of the soil was found to contain a minimum of 98.07 ppm and maximum of 696.21 ppm. The range of Ca in the middle layer ranged from 121.63 ppm to maximum of 534.7 ppm and the bottom layer ranged from 103 to 689.4 ppm (Table 6.5 and Fig 6.3(g). Santhi et al., 2017 and Iyer (1989) studied the Ca concentration in the Kaipad soils and found that its high content was due to the presence of lime shell deposits. Similar trends shown in the soils of upper Kuttanadu (Ray et al., 2014).

6.4.9. Magnesium

Magnesium is a common constituent in many minerals, comprising 2% of the Earth's crust. It is also a common component in seawater (1,300 ppm). Magnesium is located both in clay minerals and associated with cation exchange sites on clay surfaces. In alkaline to slightly acidic soils, Mg is usually second in abundance to Ca on cation exchange sites. The Mg in the top layer of the soil ranged from 54.9 to 425.09 ppm, their values found to be ranged from 0.687 to 480.9 ppm in middle layer and 27.745 to 420.06 ppm in bottom layer (Table 6.5 and Fig 6.3h).

Table 6.4. Soil parameters available nitrogen and available potassium from different locations - top layer (A), middle layer (B) and bottom layer (C)

	Available Nitrogen			Available Potassium		
Samples	A	B	C	A	B	C
S1	184800	294000	313600	5563.75	5282.5	5407.5
S2	263200	313600	330400	5285	10192.5	5128.75
S3	338800	333200	299600	5316.25	5050	10060
S4	299600	305200	296800	10255	5141.25	5172.5
S5	294000	260400	330400	5233.75	5188.75	5392.5
S6	271600	285600	274400	5452.5	5606.25	5027.5
S7	294000	268800	302400	5225	5186.25	5046.25
S8	252000	249200	296800	5136.25	5122.5	5133.75
S9	302400	280000	285600	5128.75	5026.25	5022.5
S10	8400	2800	5600	4312.5	6250	4150
S11	8400	5600	5600	6562.5	6562.5	5587.5
S12	5600	5600	2800	5962.5	6500	4125
S13	11200	5600	2800	1575	5237.5	3912.5
S14	5600	2800	2800	5712.5	5825	5987.5
S15	5600	0	2800	6800	7025	6875
S16	5600	8400	5600	2462.5	4937.5	5937.5

S17	2800	5600	2800		4900	7425	4887.5
S18	11200	5600	5600		5062.5	5875	7087.5
S19	5600	5600	2800		5550	5462.5	7275
S20	2800	5600	5600		6325	4800	6912.5
S21	0	0	0		2587.5	7087.5	6000
S22	243600	238000	64400		5715	5147.5	6087.5

Table 6.5. Soil parameters calcium and magnesium from different locations - top layer (A), middle layer (B) and bottom layer (C)

		Calcium				Magnesium		
Samples		A	B	C		A	B	C
S1		452.7	468.1	556		230.075	392.4	240.1325
S2		696.21	457.56	427.03		425.01	280.9	324.09
S3		319	298.04	594.02		147.4475	62.5425	225.3175
S4		487.59	413.02	326.5		293.56	324.8	290.07
S5		217.8	368.04	364.8		313.68	287.53	216.95
S6		255.4	356.9	219.12		293.1	246	189.07
S7		428.9	499.09	213.6		367.04	354.5	117.44
S8		118.6	199.08	103		69.8	102.5	78.9
S9		316.8	301.09	245.54		197.72	140.96	147.28
S10		119.6	201.9	217.5		246.3	186.98	208.133
S11		499.1	534.7	589		235.08	224	221.07
S12		417.02	514.02	443.67		242.9	480.9	420.06
S13		215.39	205.83	295.36		358.01	333.94	304.69
S14		189.3	164.5	198.5		124.125	125.725	165.885
S15		364	314.8	375.8		178.88	0.6875	242.305
S16		472	469	527.4		369.8	298.03	284.63
S17		265.41	276.37	215.62		286.07	14.8775	196.55
S18		428.6	484	517		347.46	227.53	274.63
S19		464	364.2	642.8		110.005	214.68	27.745
S20		458.23	309.88	197.01		304.68	287.4	146.5
S21		331.06	334.7	689.4		63.5	224.25	401.27
S22		98.07	121.63	189.4		54.9	99.76	236.8

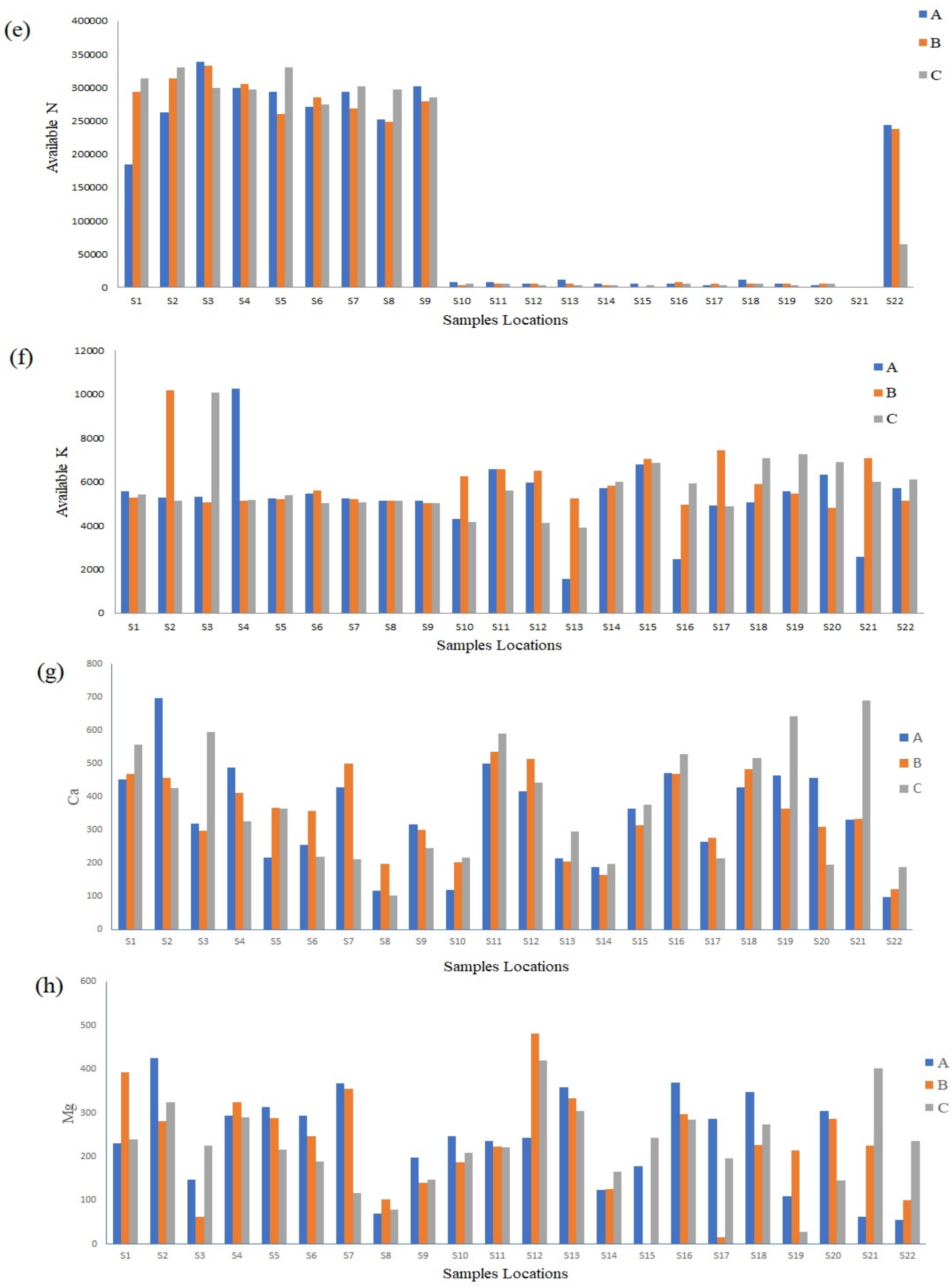


Fig.6.3. Diagrammatic representation of different parameters with depth **e)**available nitrogen, **f)** available Potassium, **g)**calcium, **h)** magnesium.

6.4.10. Total Sulphur

Sulphur is the most common abundant element in the earth and its transformations are of geochemical, pedological, biological and ecological importance. In aerated soils, the oxidation of elemental sulphur, alteration of sulphide and organic sulphur compounds to sulphate and the reduction of sulphate and incorporation of sulphur into plant and microbial tissues are the main process taking place. The main product of anaerobic transformation of sulphur is H_2S derived from the sulphate reduction (Timar,1964 and Postgate,1965). Sulphate reduction proceeds slowly in submerged acid sulphate soils and lime accelerates the reduction (Nhung and Ponnamperuma,1966).

The total sulphur was found to be below the detectable limit in the locations S9, S14, S17, S21.There was a gradual decrease in the S content with depth in 50% of the samples. The content of sulphur was found to have increased with depth in the locations S1, S8, S13 and S22 (Table 6.6 and Fig 6.4i). Based on the range chart, total sulphur deficiency was prevalent in the entire Kole lands.

Tandon (1991) reported that sulphur deficiencies in India are widespread. Intensification of fertilizers along with the restricted or no use of organic manures have accrued in depletion of the soil sulphur reserve (Paritosh et al.,2012).

6.4.11. Available Sulphur

The reduction of sulphate in the submerged soils have implications for the rice cultivation. The insufficient sulphur supply can immobilize Zn and Cu and there by H_2S toxicity may arise in soils with low iron. The available sulphur in the top layer of the soil ranged from 0 to 512 ppm, middle layer 0 to 0.887ppm and in the bottom layer the contents ranged from 0 to 0.475 ppm (Table 6.6 and Fig 6.4j).

Table 6.6. Soil parameters total sulphur and available sulphur from different locations - top layer (A), middle layer (B) and bottom layer (C)

Locations	Total Sulphur			Available Sulphur		
	A	B	C	A	B	C
S1	0	1.102	1.218	0.0375	0.0125	0.0375
S2	1.158	1.154	1.134	0.0375	0.025	0.0375
S3	1.143	0	0	0	0	0
S4	1.602	0	0	0	0	0
S5	1.681	1.681	0	0.0125	0	0.0125
S6	1.601	0	0	0	0.025	0
S7	1.601	0.41	0	0.0125	0.0375	0.0125
S8	0	1.693	1.741	0.4125	0.5875	0.4125
S9	0	0	0	0	0	0
S10	1.693	0	0	0	0.225	0
S11	0.357	0	0.362	0	0.4625	0
S12	0.338	0	0	0	0.35	0
S13	0	0.413	0.666	0	0	0
S14	0	0	0	0	0	0
S15	0.841	0	0	0.5125	0.425	0.5125
S16	0	0.358	0	0	0.0125	0
S17	0	0	0	0.4375	0.525	0.4375
S18	0.618	0.335	0.308	0	0.8875	0
S19	0.335	0	0	0.0125	0.55	0.0125
S20	0.92	0.973	0	0	0.7125	0
S21	0	0	0	0.0125	0.3625	0.0125
S22	0.655	0.657	1.101	0	0	0

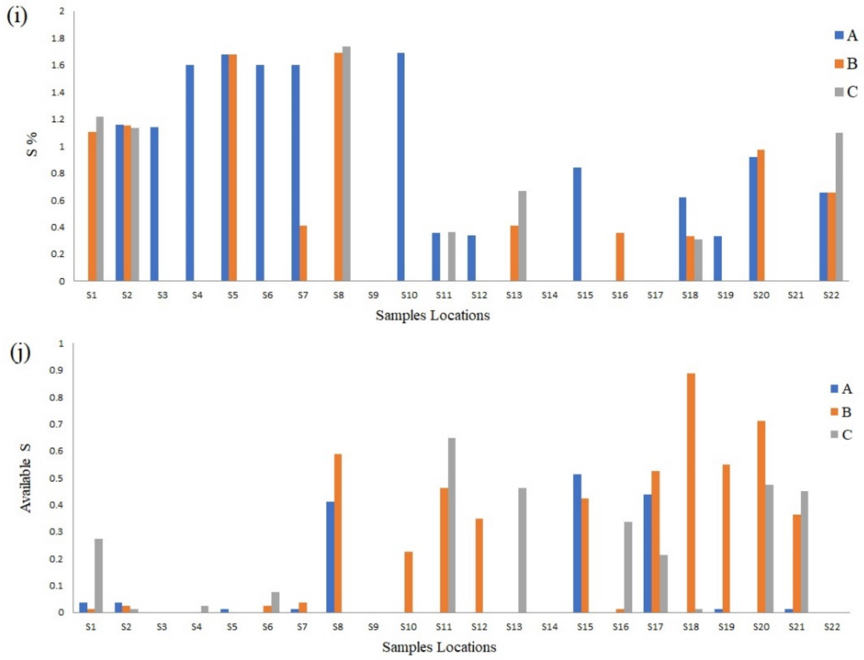


Fig.6.4. Diagrammatic representation of different parameters with depth **i)** total sulphur, **j)** available sulphur

6.5. Micronutrients

Micronutrient availability in the rhizosphere depends on the complex microbe plant micronutrient interactions (Rengel,2015). Micronutrients at a concentration less than 0.5 g/kg plant dry matter such as Cu, Fe, Mn and Zn are considered as essential micronutrients. The fluctuation in micronutrient deficiency level in soils is a global phenomenon (Monreal et al., 2016).

6.5.1 Copper

Cu is an important constituent of several enzymes, plant proteins, plastocyanin and actively takes part in electron transport system (Hochmuth et al., 1991). The maximum copper content in the top and middle layer was found to be 2.05 ppm and the maximum Cu content in the bottom layer was 1.175 ppm (Table 6.7 and Fig 6.5a).

Copper become a limited factor when pH increases. Soils with high organic matter has a tendency to hold Cu more tightly and thereby reducing its availability. This trend found commonly in the soils of Thrissur Kole wetland. Dhaliwal et al.,(2019) reported that the addition of organic matter to the soil lowers the redox potential, as a result the availability of Cu increases.

6.5.2 Iron

The most important chemical change that takes place under submergence is the reduction of iron and thereby increasing its solubility. Rice benefits from the availability of iron and it may be toxic when in excess. The chemical analysis showed that iron content was very high in all samples. It ranged from 188.06 to 697.42 ppm in the top layer and 197.32 to 669.7 ppm in the middle layer and 210.35 to 687.46 in the bottom layer (Table 6.7, Fig 6.5b).

Rice suffering from Iron toxicity may show purplish brown discoloration and would have retarded growth and sterility reducing yield. The study conducted by Santhi et al., (2017) on the available iron content in the Kaipad soils varied from 702 to 1250 mgkg-1 which was in toxic levels. Similar trend on iron was reported by Shylaraj et al., (2013) in Pokkali soils. Soil minerals such as pyrites, jarosite etc. contribute high content of iron in these soils (Iyer, 1989).

6.5.3. Manganese

Acid soils with high Manganese content and organic matter contents can build up water soluble Mn. Most flooded soils contain sufficient water-soluble Mn for the growth of rice. (Zhu et al., 2002). Submergence brings various changes in soils i.e., physical, biological and chemical, which are usually advantageous for the growth and nutrition of rice. Flooded conditions cause higher valent forms of Mn like MnO_2, Mn_2O_3 and Mn_3O_4 to get reduced to Mn_2^+ form which becomes easily accessible to plants (Ponnamperuma, 1972). Green manuring is another way to enhance the Mn availability in soils. The Mn in Kole land soils was found ranged from 0 to 164.25ppm in top layer, 0 to 223.7ppm in the middle layer and 0 to 105.8 ppm in bottom layer (Table 6.8 and 6.5.c). Mandal and Mitra (1982) reported that the low manganese availability is due to the presence of high organic matter. Malvi (2011) stated that the interaction of iron with manganese is antagonistic in nature and found in Kaipad soils where the toxic levels of iron content might have adversely affected the manganese content.

6.5.4. Zinc

Zinc, a vital micronutrient, released during the mineral weathering process. Suspended organic matter exhibit an important role in inducing partitioning of Zn and thus on biogeochemical cycling of Zn. The top layer of the soil contained a maximum of 24.25 ppm, 22.25 ppm in middle layer and 23 ppm in the bottom layer (Table 6.8 and fig 6.5d).

The study carried out on Kaipad revealed that available zinc content was adequate (Santhi et al.,2011). Zinc forms chelate with the organic matter present in the soil. Chelated forms of zinc do not move through the soil and is not subjected to leaching losses (Schulte and Kelling, 2017).

Table 6.7. Soil parameters copper and iron from different locations - top layer (A), middle layer (B) and bottom layer (C)

Locations	Copper			Iron		
	A	B	C	A	B	C
S1	0.125	0.05	0.05	535.9	541.65	541.65
S2	0.075	0.05	0.05	358.1	374.62	378.56
S3	0.025	0.175	0.15	468.9	456.2	478
S4	0.1	0.25	0.225	697.42	633.8	687.36
S5	0.4	0.4	0.325	492.4	425.8	497.6
S6	0.55	0.575	0.65	528.3	530.89	530.08
S7	0.575	0.525	0.775	463.01	470.9	482.3
S8	1.35	1.2	1.225	398.3	402.6	408.6
S9	1.125	1.325	1.25	438.9	422.8	442.8

S10	0	0	0	448.04	550.09	552.8
S11	0.4	0.325	0.35	429.05	428.6	469.08
S12	0.15	0.125	0.15	447.65	478.25	478.25
S13	2.05	2	0.175	188.06	197.32	210.35
S14	0.1	0.225	0.15	389.7	412.82	421.09
S15	0.225	0.1	0.125	423.18	417.53	438.91
S16	0.35	1.4	1.175	476.9	479.4	483.52
S17	0.2	0.7	0.075	653.25	669.7	687.46
S18	2.175	2.05	0.2	637.13	637.5	649.24
S19	0.05	0.05	0.05	486	444.31	479.8
S20	0.175	1.4	1.25	569.8	514.9	571.39
S21	1.625	1.95	0.175	338.7	329.86	358.04
S22	0.075	0.775	0.1	398.57	478.13	444

Table 6.8. Soil parameters Manganese and Zinc from different locations - top layer (A), middle layer (B) and bottom layer (C)

Locations	Manganese			Zinc		
	A	B	C	A	B	C
S1	77.15	87.275	66.575	18.75	18.5	23
S2	32.9	48.975	54.925	24.25	19	4.5
S3	9.85	15.4	15.525	6.25	5.25	3.75
S4	7.975	7.475	9.025	3.75	16.25	3.25
S5	107.225	8.075	105.8	23	22.25	21.25
S6	16.05	5.9	5.525	0.1675	5.75	12.25
S7	9.375	7.85	5.65	4.87	0.545	8.7125
S8	73.125	56.55	6.05	10.75	8.25	8.25
S9	0.9	38.975	1.875	8.25	7.75	8
S10	16.8	18.2	18.025	9.75	8	8.25
S11	2.05	12.75	95.95	0	12.5	0
S12	2.45	13.025	25.525	8.25	7.5	8
S13	85.025	223.7	99.625	8	7.75	7.575
S14	143.1	71.575	90.875	8	8.25	7.75
S15	2.175	31.75	39	7.75	9	8.25
S16	0	0	39.55	8	8.5	8
S17	224	200.025	90.5	8.25	8	8
S18	2.325	39.5	0	7.75	7.25	8.25
S19	164.25	196.275	59.025	8	7.75	7.25
S20	60.95	146.75	2.4	1.75	3.75	6.25
S21	61.05	89.55	36.95	7.25	7.75	8
S22	14.675	6.475	11.4	9.75	8	4.25

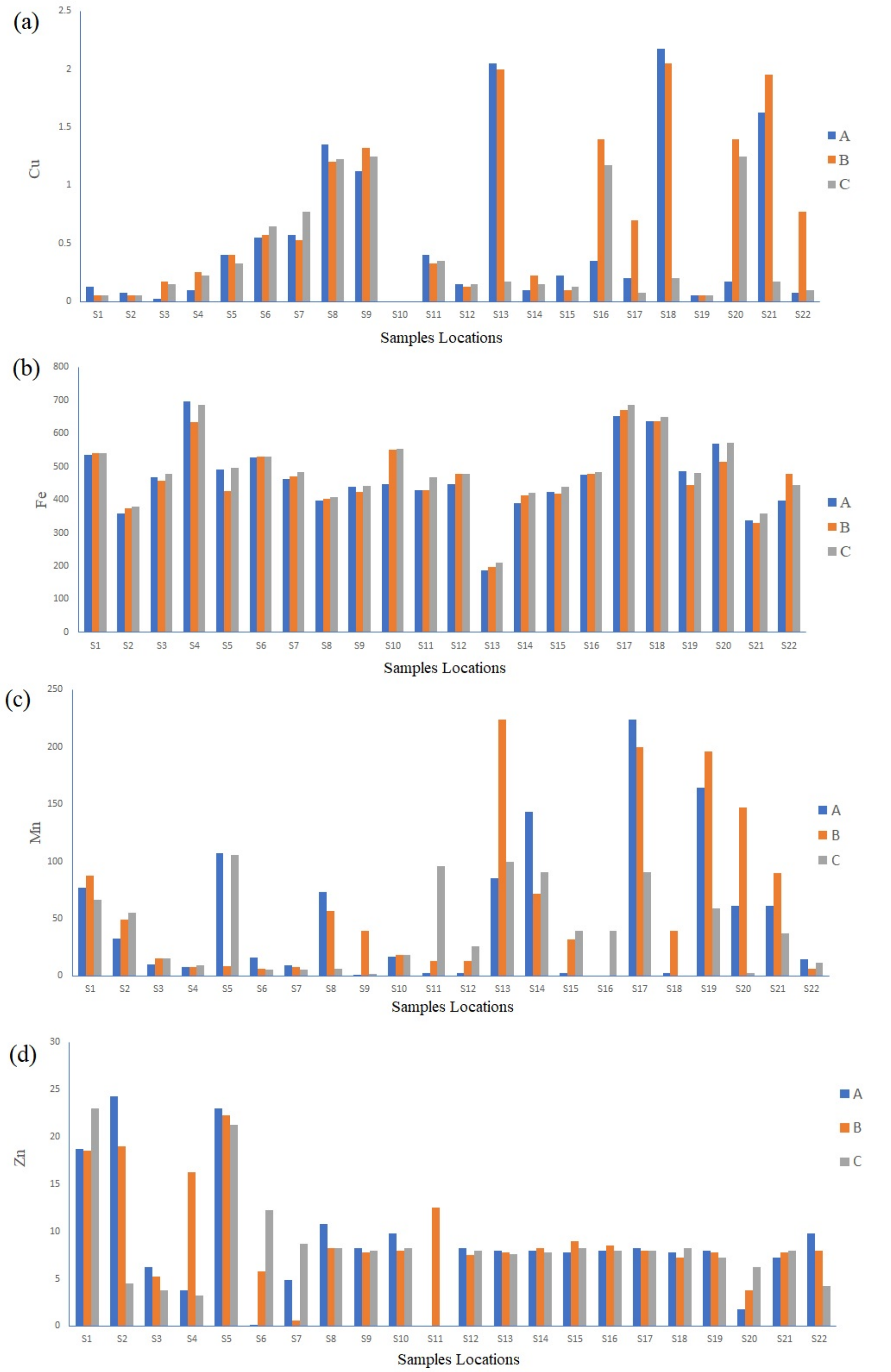


Fig.6. 5. Diagrammatic representation of micronutrients with depth **a)**copper, **b)**iron, **c)**manganese, **d)** zinc.

6.6. Aluminium (Al)

In paddy soils Al toxicity is observed in very high acidic conditions. Al concentration is directly related to soil pH and toxicity occur only at pH values below 5. The Al content in the top layer was found to be a maximum of 0.964 ppm, middle layer 1.2 ppm and bottom layer 0.9 ppm (Table 6.9 and Fig 6.6a). Santhi et al., (2017) reported that the high aluminium content may be due to the acidic pH prevailing in Kaipad wetland soils and similar findings was reported by Kochian (1995)

6.7. Boron (B)

Boron a non-metal micronutrient essential for normal growth and development of rice (Gupta,1979). Minerals and rocks are the important sources of boron in soils. Boron commonly seen associated with surface of clay, hydroxide iron, aluminium oxides and organic matter and these factors directly affecting the plant availability of boron. Boron deficiency reduces the paddy yield and grain quality (Rashid et al., 2004). Rice grown in saline soils and / or with sodic irrigation water faces B deficiency due to negative interaction between soil B availability and high SAR (Wimmer et al., 2003)

Top layer of the soil contained boron with a maximum value of 0.163 ppm, middle layer with 0.194 and bottommost layer with 0.353 (Table 6.9 and Fig 6.6b). The locations were found to be deficient with boron in the study area.

Table 6.9. Soil parameters aluminium and boron from different locations - top layer (A), middle layer (B) and bottom layer (C)

	Aluminium			Boron		
Samples	A	B	C	A	B	C
S1	0.009	0.83	1.001	0	0.008	0.038
S2	0	1.2	0	0.008	0.017	0
S3	0.9	0.93	0.87	0.072	0.037	0
S4	0.341	0.297	0.297	0.01	0	0
S5	0.657	0.782	0.796	0.057	0	0
S6	0.964	0.964	0.98	0	0.037	0
S7	0.647	0.68	0.801	0.037	0.049	0.049
S8	0.189	0.201	0.254	0	0	0
S9	0	0.01	0.57	0	0.025	0.053
S10	0.672	0.582	0.736	0.163	0.008	0
S11	0.091	0.057	0.092	0	0.041	0
S12	0.073	0	0	0.016	0	0
S13	0	0.089	0.56	0	0.009	0.001
S14	0.872	0.579	0.901	0.002	0	0.001
S15	0	0	0.597	0.003	0.194	0
S16	0.421	0.83	1.9	0	0	0.004
S17	0	0	0	0	0.012	0
S18	0	0	0	0.024	0	0.012
S19	0	0	0	0	0.016	0
S20	0	0	0	0	0.044	0
S21	0	0	0	0.025	0.008	0.044
S22	0.118	0.564	0.962	0.085	0	0

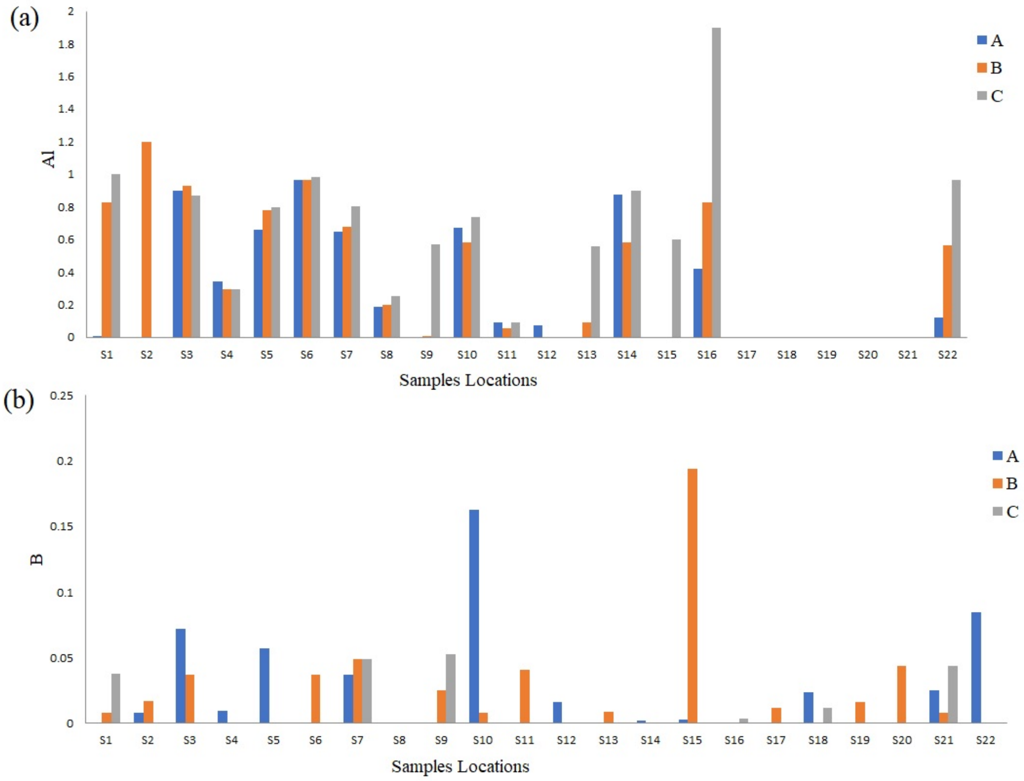


Fig .6.6 Diagrammatic representation of different parameters with depth **a)** aluminium **b)**boron

6.8. Heavy metals

Heavy metals are distributed between the aqueous phase and the suspended sediments. Human activities have led to accumulation of toxic heavy metals in aquatic sediments (Heyvaert et al. 2000). Many researchers have used sediments to study the behavior of metals over time of sedimentation (Bellucci et al. 2003 and Bertolotto et al. 2003). The occurrence of elevated levels of trace metals especially in the sediments can be a good indication of man induced pollution. High level of heavy metals can often be attributed to anthropogenic influences, rather than natural enrichment of the sediment by geological weathering.

In long-term, the contaminated sediments could be a second source of pollution to the overlying water when the environmental conditions to which the sediment is exposed are altered. Concentration of trace metals in coastal estuaries can be elevated due to high inputs from natural as well as anthropogenic sources. Hence understanding the transport and distribution of trace metals in estuaries is a goal of environmental chemists.

The concentration of cadmium, nickel, lead and chromium were determined and are given in Table 6.10.

6.8.1 Cadmium (Cd)

Cd is a non- essential trace element, and does not play any identified role in the growth and development of human, plants and animals. Addition of organic matter to soil improves its chemical, physical and biological qualities by increasing the contents of organic matter, changing its pH, providing essential nutrients, improving the water holding capacity, and altering the bioavailability of heavy metals. Soil pH is the most influential factor affecting the Cd uptake by plants grown on Cd contaminated soil (Liu et al., 2015). Cd in wetland soils was associated with underlying geology and hydrology and with concentrations of P and Zn, suggesting a link with agricultural land use surrounded by the wetlands (Jacob et al., 2013).

The Cd in the top layer of the Kole land was found to be a maximum of 5.75 ppm, 2.225 ppm in the middle layer and 1.75 in bottom layer (Table 6.10 and Fig 6.7a). Similar results were reported by Vinodkumar et al., (2021) in wetlands of Kannur district.

6.8.2 Nickel

Nickel (Ni) is an important heavy metal, and pollution by Ni has gained importance due to the greater understanding of its persistence and toxicity in the ecosystems (Alemayehu and Lennartz, 2010). The effects of Ni exposure vary from skin irritation to damage of the nervous system and it is also a known carcinogen. Nickel may enter and accumulate in agricultural soils through the application of phosphate fertilizers, pesticides and other waste materials from industries like nickel-cadmium batteries, nickel electroplating, paints formulation, vegetable fat production, etc.

The Ni in the Kole land soil found to contain a maximum of 15.3 ppm, 5.925 ppm and 22.25 ppm in the top, middle and bottom layer respectively (Table 6.10 and Fig 6.7b).

6.8.3 Lead

The staple food of the local population is rice and concentration of pb in the soils of rice fields contributes a major part to the total daily intake of this element. The Pb in the top layer of the soil was found to be a maximum of 2.56 ppm, 1.8 ppm in the middle layer and 2.87 in bottom layer (Table.6.10 and Fig 6.7c). Kannan et al., (2014) reported that the lead concentration was very high in the soils of Kuttanadu wetland and had caused serious health issues. The accumulation of pollutants in the system is mainly due to the restriction of natural flooding and increased input.

Table 6.10. Soil parameters cadmium, nickel and lead from different locations - top layer (A), middle layer (B) and bottom layer (C)

	Cd			Ni				Pb		
Samples	A	B	C	A	B	C		A	B	C
S1	0.425	0.55	0.15	0.05	0.125	0.7		0	0.742	0.251
S2	0.275	0.125	0.9	0.175	0.35	2.425		0.245	0.178	0.65

S3	0.675	0.275	0.5	0.225	0.225	0		0.652	0.364	0.149
S4	0.525	0.675	0.325	0.35	0.575	8.7		0	0.613	0.098
S5	2.75	0	0	0.125	0.2	8.75		0.952	1.8	0.997
S6	0.2	0.6	0	1.225	2.45	1.175		0.67	0.458	0
S7	0.035	0.125	0.175	0.6	0	0		2.56	0.8	1.01
S8	0.15	0.125	0.35	0.15	6.95	1.45		2.5	1.003	1.003
S9	0.1	0	0.55	1.175	1	0		0.438	0.58	0.96
S10	0.025	0.125	0	0	0	0		0	0	0
S11	0	0	0	15.3	0.2	1.825		1.56	1.02	0.59
S12	0.025	1.275	0.075	2.1	1.85	1.85		2.3	0	1.88
S13	0.2	0.125	0.025	0.2	0.2	0.125		0.95	0.451	0
S14	0.05	0.1	0.175	0	0	0.15		1.09	1.11	0.604
S15	0.35	0.6	0	0.35	0.6	0.225		0.681	0.992	0.862
S16	0.25	0.225	1.75	0.175	1.125	22.25		0	0	0
S17	0.15	0	0	0.175	0.125	0.05		1.46	1.02	0.984
S18	0.175	0.575	0.075	0.1	1.175	1.9		1.94	0.951	2.87
S19	0.225	0	0	0.2	5.925	0.225		1.9	1.6	0
S20	0.025	0.175	1.525	1.95	1.125	13.5		0.845	1.5	1.5
S21	5.75	2.225	0.075	1.05	0.95	7.175		0	0.741	0.956
S22	1.125	0.9	0.3	1.15	0.1	2.125		1.2	1.2	2.4

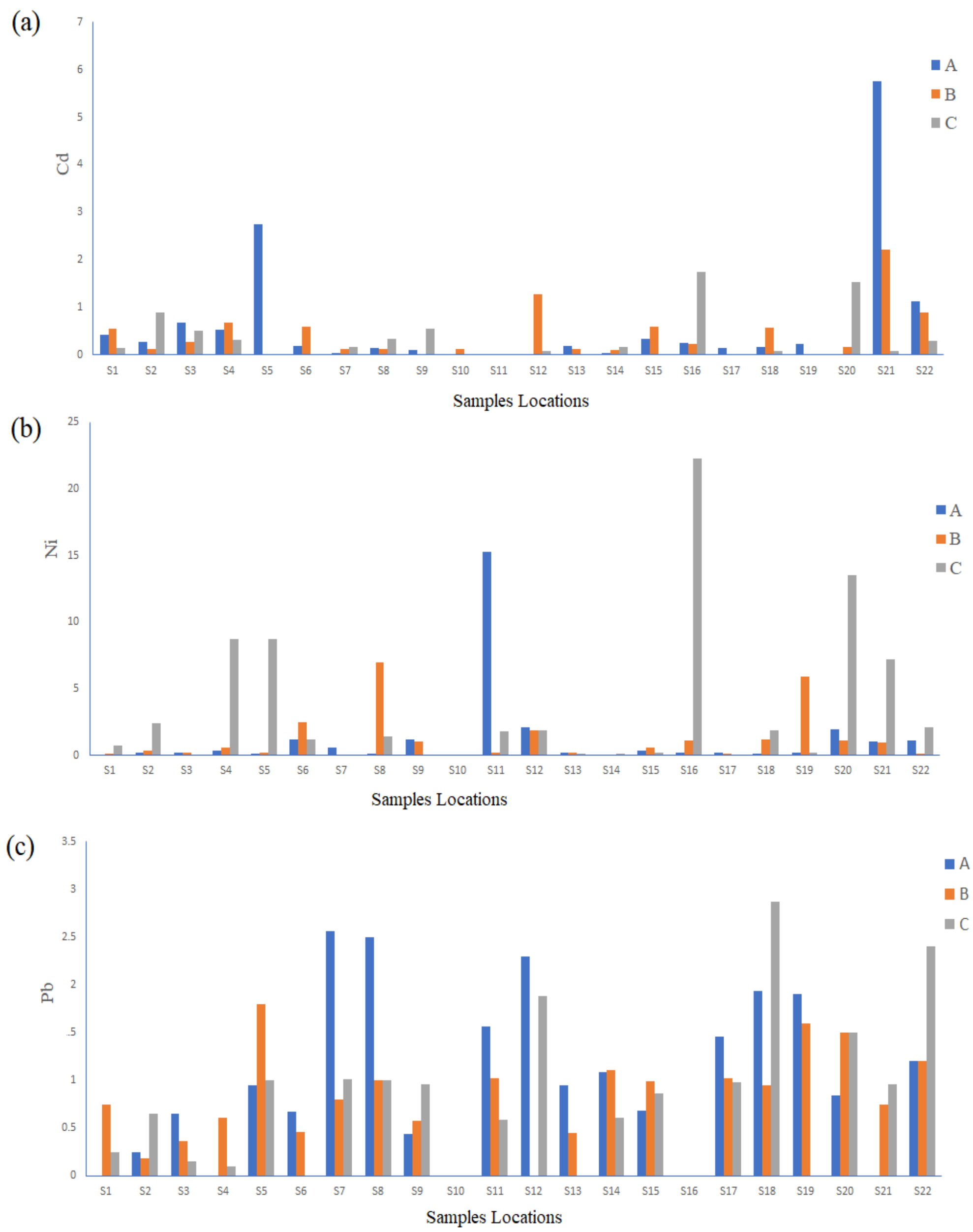
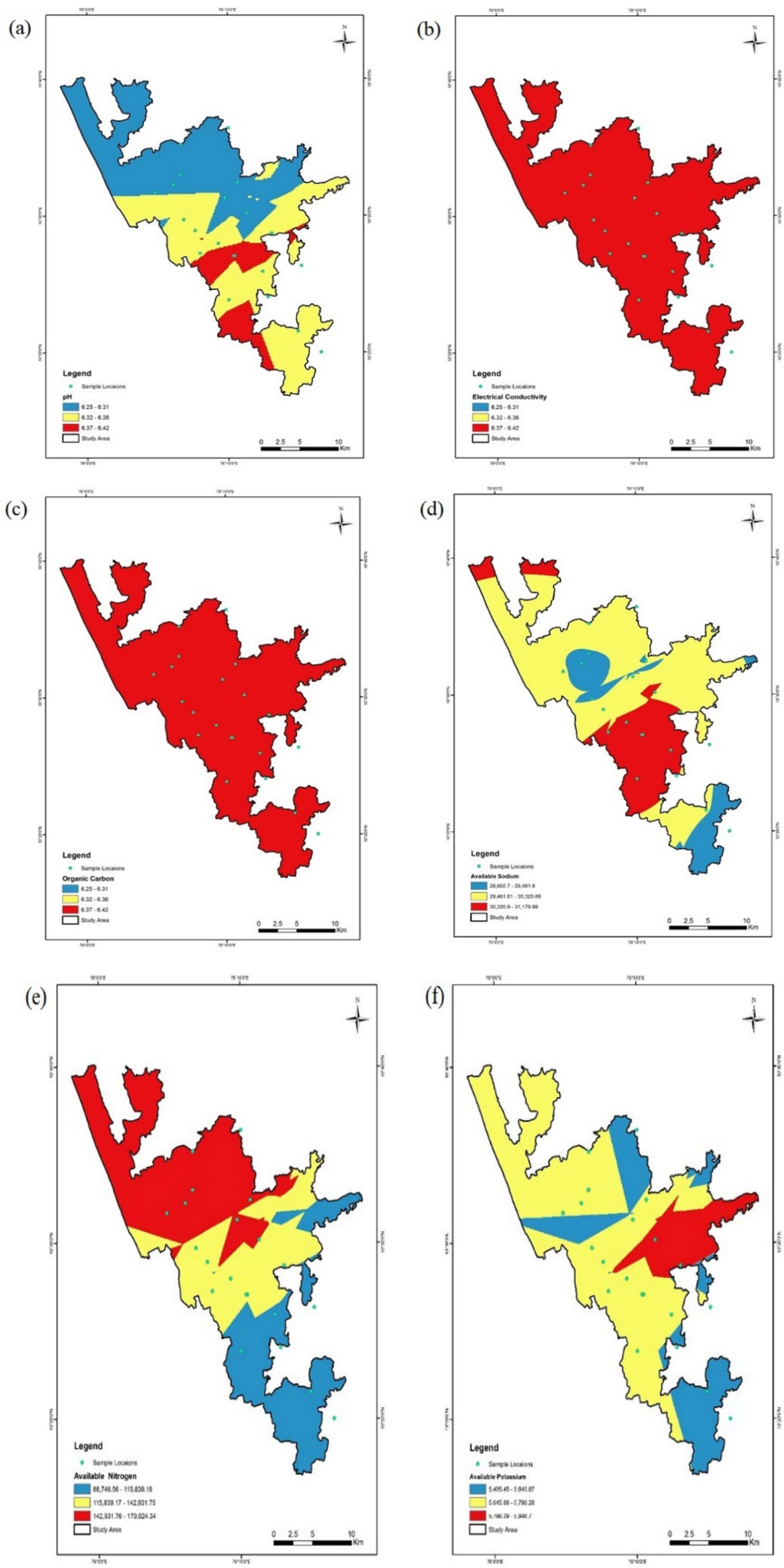


Fig 6. 7. Diagrammatic representation of different parameters with depth **a)** cadmium, **b)** nickel, **c)**lead.

6.9. Interpretation of soil parameters by Interpolation technique – Kriging

For the interpretation of different soil parameters, the spatial variability of soils of Kole wetlands was investigated using geostatistical tools. pH of the soil samples was slightly acidic after submergence. From the maps generated by Kriging (fig.6.8 to fig.6.11) it with found that the electrical conductivity, organic carbon, sodium and potassium content in the Kole lands were very high. Generally, the Ca in the Kole land soils were low. The lowest calcium content is noticed in NW and SE area of the wetland. Mg was highly loaded in NW and Southern tip of Kole land, indicating the intrusion of saline water into the fresh water zones. The sulphur content was in adequate in NW area of the study area. The aluminium toxicity was observed in the middle part of the wetland and boron toxicity observed in NW of Kole lands.

The distribution of micronutrients such as Cu was high in parts of NW and SW area. The iron toxicity was observed in the middle and South part of the study area and Mn distributed in East and south part of the Kole wetlands. The distribution of Zn was observed in the entire study area. Distribution of heavy metals such as lead was high in the southern tip area of the Kole wetland, Ni in entire area and Cd in the NW area of the Kole lands.


(a)
Legend
Sample Locaions
pH
6.25 - 6.31
6.32 - 6.36
6.37 - 6.42
Study Area
0 2.5 5 10 Km
(b)
Legend
Sample Locaions
Electrical Conductivity
6.25 - 6.31
6.32 - 6.36
6.37 - 6.42
Study Area
0 2.5 5 10 Km
(c)
Legend
Sample Locaions
Organic Carbon
6.25 - 6.31
6.32 - 6.36
6.37 - 6.42
Study Area
0 2.5 5 10 Km
(d)
Legend
Sample Locaions
Available Sodium
28,602.7 - 29,461.8
29,461.81 - 30,320.89
30,320.9 - 31,179.99
Study Area
0 2.5 5 10 Km
(e)
Legend
Sample Locaions
Available Nitrogen
88,746.56 - 115,839.16
115,839.17 - 142,931.75
142,931.76 - 170,024.34
Study Area
0 2.5 5 10 Km
(f)
Legend
Sample Locaions
Available Potassium
Study Area
0 2.5 5 10 Km

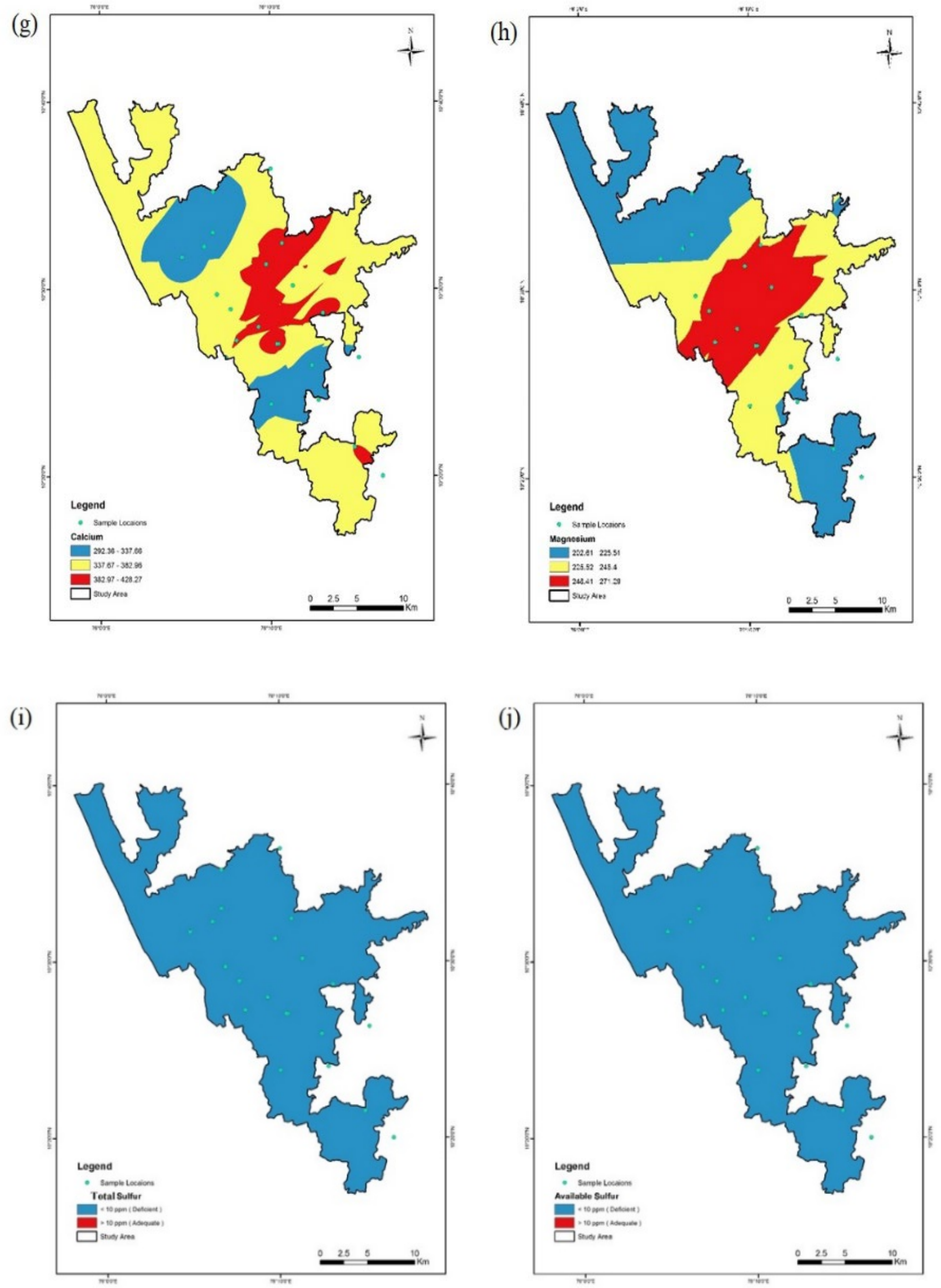


Fig.6.8. Spatial distribution of various parameters **a)**, pH **b)** EC, **c)** OC, **d)** available sodium, **e)** available nitrogen, **f)** available potassium, **g)** Ca, **h)** Mg, **i)** total sulphur, **j)** available sulphur

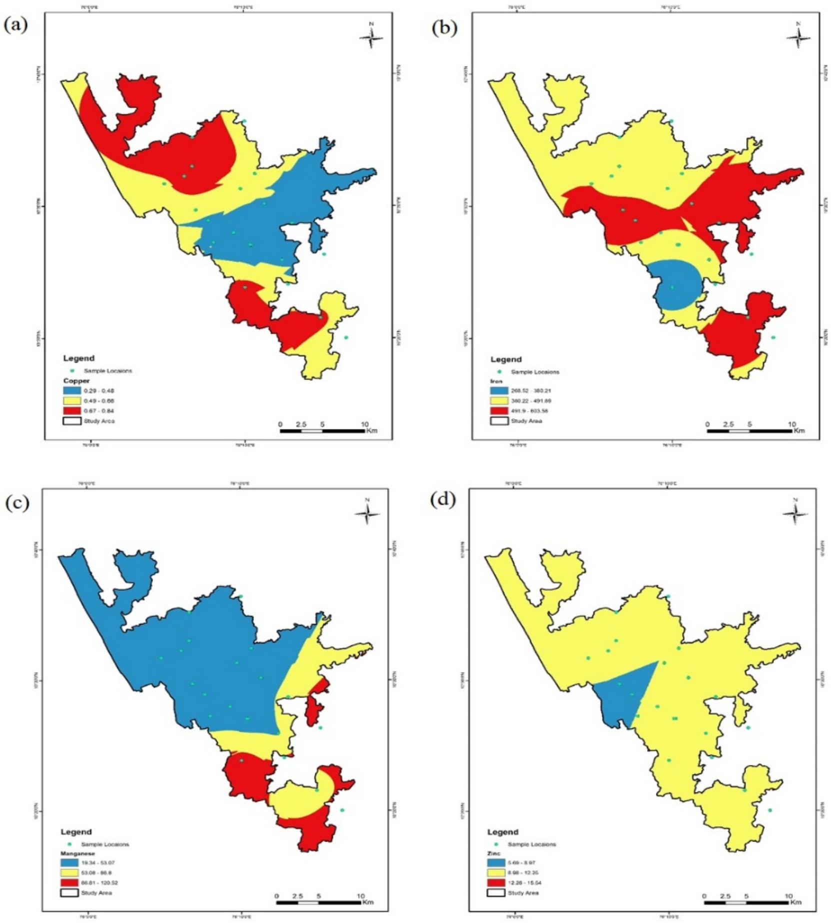


Fig.6.9. Spatial distribution of various parameters **a)** copper, **b)** iron, **c)** manganese, **d)** zinc

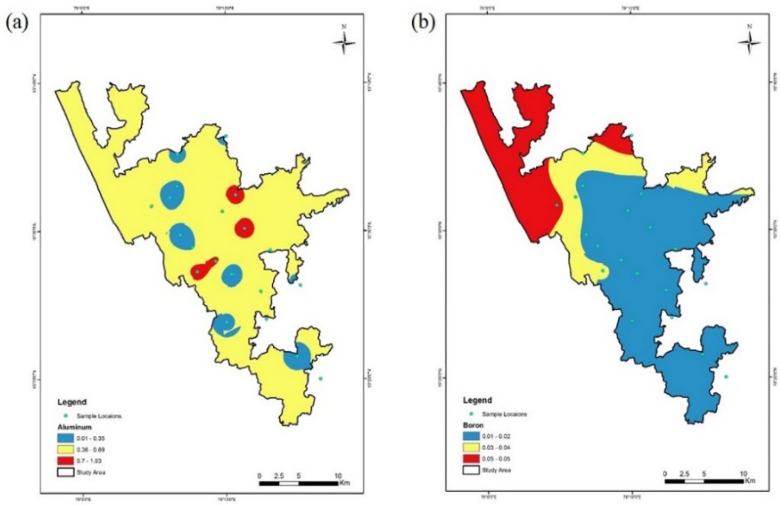


Fig.6.10. Spatial distribution of **a)**, aluminium **b)** boron

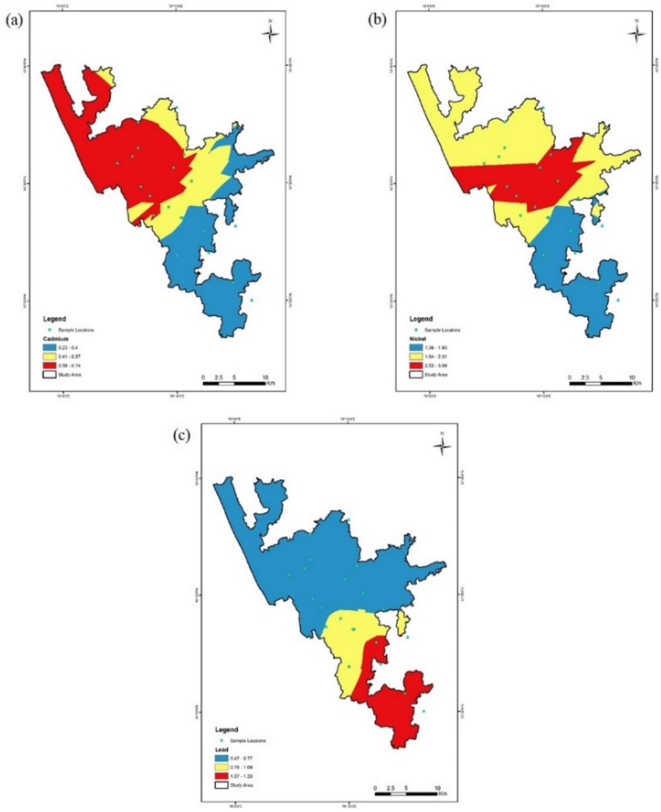


Fig.6.11. Spatial distribution of heavy metals **a)** cadmium **b)** nickel, **c)** lead

6.10. Soil health status of Thrissur Kole wetlands in post flood scenario

Kerala received a heavy monsoon rainfall, which was about 75% more than usual in the State. The wetlands are located in low lands, the flood plains of the rivers Karuvannur and Keechery. Soil samples were analysed to understand the post flood status of soil. Soil properties of soil before flood and after flood is presented in the Table 6.12 and table 6.13 respectively and sample locations in table 6.11. The variation of different parameters in soil samples is illustrated in Fig.6.12 and fig 6.13. Flooding was severe in Chalakakudy and Karuvannur river basin, Kole land areas and Canoli canal areas (plate 6.3).

Generally, pH of the soil samples became more acidic after flood. The conductivity of the samples S1 and S2 showed high values than pre flood data and indicated the deposition of salts in the top soil. The rest of the locations showed relatively low EC values which indicated the leaching of top soil. OC values in samples ranged from 0.6 to 2.9. General trend shows a decline of OC after flooding. The Ca shows high value of 971.3 mg/kg at S3. Fifty percent of the soil samples enriched with Ca while the rest of the samples were found to be leached. The Mg concentration of the post flood samples found to be lowered when it compared with the pre flood samples. The maximum Iron content was found in sample S2, 1090.8 mg/kg. The values of all the nutrient parameters NPK showed significant depletion after the great flood. The presence of available nitrogen was very high before the flood and it was observed in much depleted manner after the flood. The available sulfur was very low in samples in the base data, but the deposition of sulfur was found to be high after flood. The copper and manganese found to be high in post flood samples than in preflood time. The concentration of the zinc in the soil was reduced after the flood. The aluminium toxicity in pre flood samples was found reduced in post flood situation. Boron concentration showed an upward trend after flooding. The concentration of sodium content was depleted after flooding. The graphical representation of the comparison of pre and post flood samples given in fig 6.12.

Table 6.11 Sample locations of post flood samples

Loc	Site	Lattitude	Longitude
S1	Kanimangalam	N10^0 28' 42.6"	E 076^0 13' 05.1"
S2	Pullazhi	N10^0 31' 18.8"	E 076^0 09' 45.2"
S3	Perumpuzha	N10^0 28' 54.7"	E 076^0 07' 39.4"
S4	Annakara	N10^{0}33' 00.7"	E 076^{0}06' 37.5"
S5	Pullu	N10^0 27' 3.1"	E 076^0 10'23.1"
S6	Karuvannur	N10^0 24' 3.58"	E 076^0 12'48.61"
S7	Adattu	N10^{0}32' 26.1"	E 076^0 10' 41.4"
S8	Amballur	N10^{0}26' 20.0"	E 076^0 15' 11.3"
S9	Muriyad	N10^{0}21' 32.2"	E 076^0 14' 56.1"
S10	Thazhekkad	N10^{0}20' 00.3"	E 076^0 16' 34.8"
S11	Mullassery	N10^{0}32' 15.5"	E 076^{0}06'06.8"
S12	Cherpu	N10^0 25' 55"	E 076^0 12'26.1"

The wetland system is a good recharging area of rain water. The spread of the wetland area is shrinking day by day by imprudent mining, conversion for agriculture and settlements. The water table level in the adjoining wells registered a fall particularly after 2018 flood. Combination of heavy rainfall and breaching of check dams and irrigation bunds had crossed the limit of usual river discharge.During normal monsoon nutrients are added to the flood plains which helped in paddy cultivation. Turbulent flow due to increased discharge had caused extensive leaching of the top argillaceous silty layer and this will badly affect the water retention capacity of the soil and in turn crop productivity.

Table 6.12 Pre flood soil properties of samples

Sample name	pH	EC	OC (%)	N (kg/ ha)	K (kg/ ha)	S (mg/ kg)	Na (mg/ kg)	Ca (mg/ kg)	Mg (mg/ kg)	Cu (mg/ kg)	Zn (mg/ kg)	Mn (mg/ kg)	Fe (mg/ kg)	Al (cmol/ kg)
S1	6.22	44	22.8	264133.3	5418	0.108	31953	492.3	862.6	0.075	20.1	77	540	0.613
S2	6.31	91	26.1	302400	6869	0.025	32307	526.9	343.3	0.058	15.9	45.6	370	0.4
S3	6.295	84	25.9	300533.3	6856	0.008	27093	409	302.8	0.191	7.75	8.16	673	0.312
S4	5.98	86	22.9	266000	5131	0.333	30447	140.2	83.73	1.258	9.08	45.2	403	0.215
S5	6.95	151	0.4	466.7	5529	0.117	29893	458.2	381.3	0.142	7.92	13.7	468	0.024
S6	6.80	55	0.32	3733.3	5842	0	30327	184.1	138.6	0.158	8	102	408	0.784
S7	6.61	68	0.56	6533	4446	0.117	26153	489.5	317.5	0.975	8.17	13.2	480	1.050
S8	5.97	58	0.32	3733	5738	0.392	26427	252.5	165.8	0.325	8.08	172	670	0
S9	5.94	72	0.64	7467	6008	0.3	32033	476.5	283.2	1.475	7.75	13.9	641	0
S10	6.33	61	0.4	4667	6096	0.188	24747	490.3	117.5	0.05	7.67	140	470	0
S11	6.3	177	0	0	5225	0.275	21407	451.7	229.7	1.25	7.67	62.5	342	0
S12	6.15	68	15.7	182000	5650	0	32687	136.4	130.5	0.317	7.33	10.9	440	0.548

Table 6.13. Post flood soil properties of samples

Sample Name	pH	EC	OC (%)	N (kg/ ha)	P (kg/ ha)	K (kg/ ha)	S (mg/ kg)	Na (mg/ kg)	Ca (mg/ kg)	Mg (mg/ kg)	Cu (mg/ kg)	Zn (mg/ kg)	Mn (mg/ kg)	Fe (mg/ kg)	Al (cmol/ kg)
S1	4.96	48	2.6	188.2	10.4	194.9	115.3	324.0	252.5	47.6	3.0	6.1	19.2	568.5	0.1
S2	6.3	110	6.0	338.7	10.3	237.4	89.6	418.0	528.0	60.1	5.0	6.0	42.3	1090.8	0.1
S3	5.55	30	2.7	213.2	5.4	293.4	92.0	511.0	971.3	114.8	1.0	8.1	36.0	467.5	0.0
S4	5.4	32	2.9	301.1	17.7	133.3	50.9	162.0	179.5	29.0	47.6	17.5	37.9	759.5	0.1
S5	6.26	44	2.5	200.7	9.3	269.9	112.2	467.5	556.3	86.9	12.1	1.0	43.9	562.5	0.0
S6	6.7	16	2.1	225.8	12.0	191.5	6.0	283.5	272.5	42.3	11.4	4.0	14.9	522.5	0.0
S7	6.26	18	1.4	163.1	19.6	169.1	22.5	221.5	241.8	40.1	10.3	2.4	25.3	384.5	0.0
S8	5.45	22	2.2	225.8	8.6	231.8	15.5	353.0	233.5	67.9	12.2	2.3	42.9	729.0	0.1
S9	6.33	20	1.2	138.0	43.8	290.1	15.3	321.5	127.0	18.9	2.8	1.3	6.2	188.5	0.0
S10	4.6	30	0.6	62.7	179.4	67.2	37.1	46.5	140.3	18.7	2.4	0.1	2.2	153.5	0.1
S11	4.1	76	0.7	87.8	51.7	66.1	156.8	84.5	141.5	18.2	1.2	0.2	5.4	191.5	0.0
S12	5.39	56	2.4	163.1	63.5	144.5	132.2	187.0	177.8	25.7	3.8	2.0	2.7	343.0	0.0

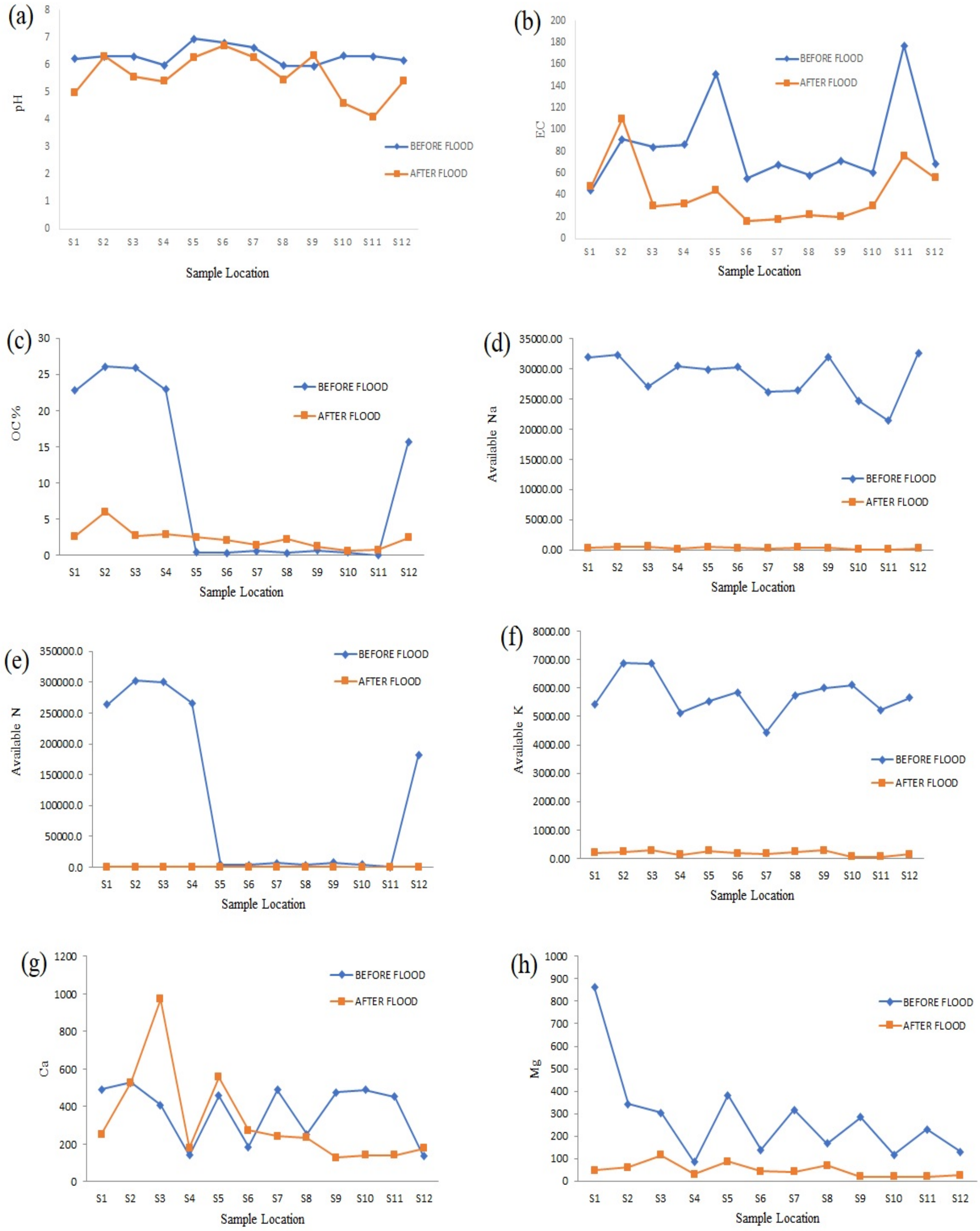


Fig.6. 12. Comparison of pre flood and post flood soil samples **a)** pH, **b)** EC, c**)** OC, **d)** available sodium, e**)** available nitrogen, **f)** available potassium, **g)** Ca, **h)** Mg

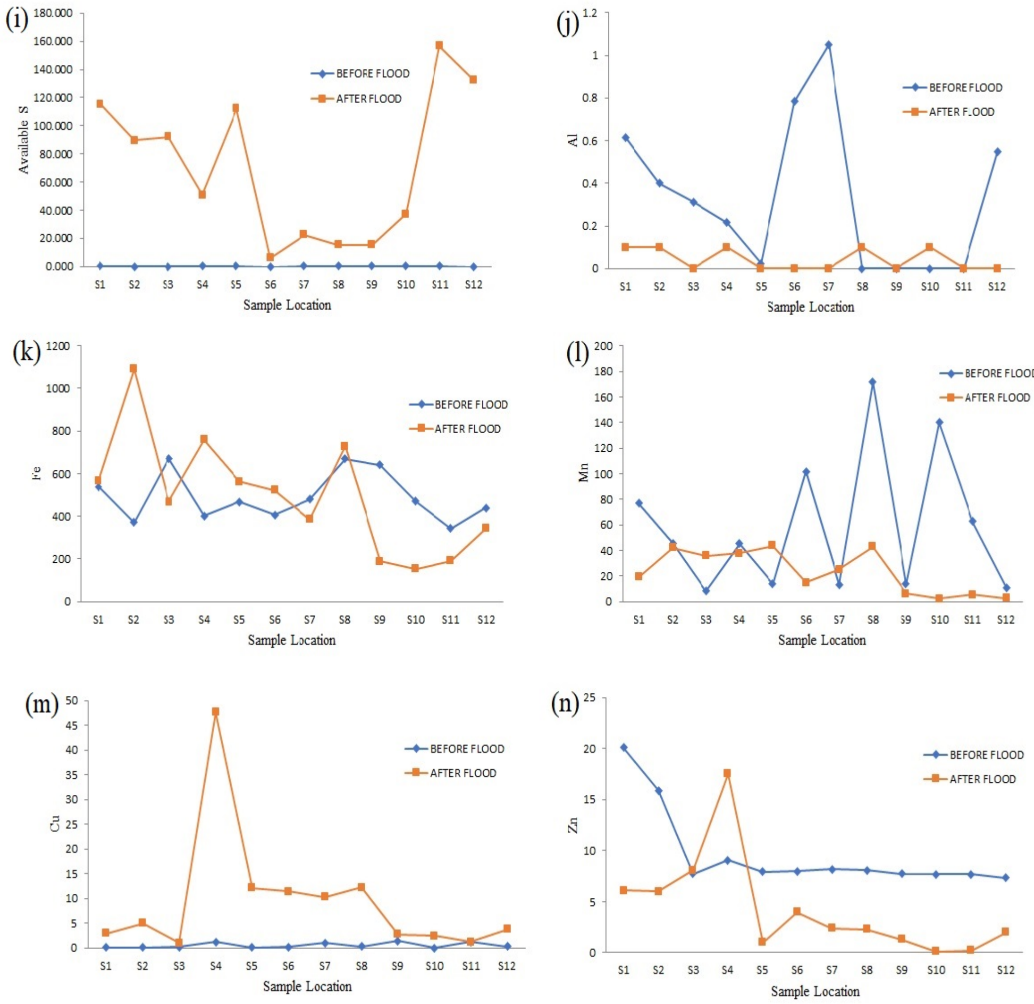


Fig.6. 13.Comparison of pre flood and post flood soil samples, **i)** available sulphur, **j)** aluminium, **k)** copper, **l)** iron, **m)** manganese, **n)** zinc

6.11. Conclusion

The soils of Kole wetland were found to be acidic. Soil acidity mainly influences the solubility of various elements in the soil, particularly some plant nutrients that influence productivity of wetland environments. At low pH values (<5.8) the availability of certain plant nutrients— such as phosphorus, nitrogen, calcium, and magnesium- may be limited. Microbial activity is also diminished when soil acidity is high. On the contrary, aluminium and manganese availability usually increase with lowering of pH and may reach levels of toxic nature to some plants. Majority of the soil samples fall within the slightly acidic category after the paddy cultivation. The electrical conductivity of the soils ranged from 17.42 to 437 µs/m in the top layer, 24.52 to 200 µs/m in the middle layer and 27.22 to 1530 µs/m in the bottom layer. In Kole wetlands electrical conductivity of soil is found influenced by saline water intrusion.

Among 22% of the locations, OC% was found to be increased with depth and 40% showed gradual decrease with the depth. Forty-five percentage of the locations coming under the low OC category. Fifty % of the locations were found to have lower sulphur content with decrease in depth while 18 % showed increasing trend downwards. The available nitrogen content in most of the locations was found to decrease with depth. The presence of available phosphorous was found below the detectable limit. The higher limit of potassium in all locations in the study area due to the application of the fertilizer. The Ca and Mg content in the Kole wetland soils indicated the presence of intrusion of saline water. Among the micronutrients, Fe, Mn and Zn showed high concentration while Cu recorded low concentration. Rice suffering from Iron toxicity may show purplish brown discoloration called bronzing or yellowish to orange discoloration. The retarded growth, and sterility results poor yield in some plants. Acid soils with high Mn concentration and high organic matter found to contain water soluble form of manganese. The Al toxicity is very high in acidic soils and was found to increase with depth. The boron deficiency was observed in Kole wetland soil. The heavy metal concentration was found to be low in all samples. After flood, the parameters pH, EC, available nitrogen, potassium, sodium, aluminium, manganese and magnesium showed a declining trend and iron, sulphur and boron showed an upward trend. Calcium showed an upward trend in locations S2 to S6 and zinc showed a declining trend except in location S4.

CHAPTER 7

CARBON - NITROGEN STORAGE POTENTIAL OF THE KOLE WETLAND SOIL

CARBON - NITROGEN STORAGE POTENTIAL OF THE KOLE WETLAND SOIL

7.1 Introduction

Soil is the weathered consolidated surface material which is the habitat of microorganisms and other living biota with organic detritus, water and air. Wetland soils are dominated by anaerobic conditions induced by soil saturation and flooding and have specific characters than upland soils with abundance of organic matter. The soil bulk density and soil organic matter are the two important factors which describe the physical and biological structures of soil in terrestrial and wetland ecosystem (Mitsch and Gosslink,2015).

Bulk density is dependent on soil organic matter, soil texture, the density of soil mineral and their packing arrangement (Pravin et al.,2013). Bulk density influence key soil processes, productivity, infiltration, rooting depth/restrictions, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity. Available water capacity is varied by texture and is reduced when compaction occurs. Bulk density can be managed using measures that limit compaction and build soil organic matter. Generally, loose, well aggregated, porous soils rich in organic matter have lower bulk density. Sandy soils have relatively high bulk density since total pore space in sands is less than silt or clay soils. Bulk density typically increases with soil depth since subsurface layers are more compacted and have less organic matter, less aggregation, and less root penetration compared to surface layers, therefore contain less pore space.

Organic matter in soil can absorb and store much more water than inorganic fractions, acts like a sponge, taking up water and releasing it as required by plants. It also helps bind soil particles into larger aggregates, or crumbs. Soils with this kind of structure are very resistant to erosion and vice versa (Herbert, 2015). Soil organic carbon is sensitive to climatic change, and it can be expected to manifest measurable responses to global warming. Nutrients washing into wetlands promote substantial annual growth of wetland vegetation. In humid climatic zones, carbons deposited through decaying vegetation into the beds of wetlands progressively turn to peat and eventually coal. The wetlands also receive significant amounts of carbon in the form of charcoal from fires occurring within the landscape. The carbon accumulated in the wetlands by sedimentation act like an activated carbon filter, extracting nutrients and impurities from the water. These vital functions remove the carbon from the atmosphere for a long term. Burning of drained wetlands releases substantial quantities of carbon dioxide and carbon monoxide back into the atmosphere (www.environment.gov).

The role of wetlands in carbon sequestration and storage has generally been under estimated. Wetlands cover approximately six to nine percent of the Earth's surface and contain about 35 per cent of global terrestrial carbon. However, under anaerobic conditions, wetlands can also produce greenhouse gases such as methane and nitrous oxide, though this is limited in saline conditions. Clearing or drainage of wetlands can lead to large losses of stored organic carbon to atmospheric carbon dioxide (www.environment.gov).

The carbon sequestration process is linked to methane emission from wetlands. This emitted methane mitigated by the removal of carbon dioxide present in the atmosphere and stored in peat. The balance of methane and carbon dioxide exchange can provide an index of a wetland's contribution to the atmosphere (Gary and Jeffrey, 2001). Water logging of wetland soils limits oxygen diffusion into sediment profiles creating anaerobic conditions. These conditions also slow decomposition rates, leading to the build-up and storage of large amounts of organic carbon in wetland sediments. However, anaerobic conditions are conducive to the production of greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O). In periodically inundated systems, such as those on floodplains, methane emissions can be highly variable. When the wetlands are inundated and anaerobic conditions exist, methane may be produced. When these wetlands are dry, they may act as methane sinks. Salinity also inhibits production of methane, so coastal wetlands may have lower methane emission rates than freshwater wetlands. Production of nitrous oxide in undisturbed wetlands is generally low compared with terrestrial soil environments (Page and Dalal, 2011).

The hydrological connections between water courses and their associated floodplains are important for the exchange of carbon and nutrients (Thomas, 2003). Drainage and subsequent oxidation of wetland soils can both decrease methane production and lead to large net losses of sediment organic carbon. However, while decreases in methane production may occur from drained wetland sediments, drainage channels may be net emitters of methane. The connectivity is considered essential for the functioning and integrity of floodplain-river systems. Wetlands may therefore be either sources or sinks of carbon, depending on their type, and can switch between being sinks of carbon to becoming net sources. This switching can be a natural process due to seasonal or other factors or can be affected by human management. Negative feedback mechanisms due to climate change may undermine the sequestration potential of wetlands, for example, by increasing the incidence and severity of fires and droughts

(Dudley et al., 2010). The role of wetlands in the global carbon cycle requires further research, particularly on different wetland types and their function as both sources and sinks of greenhouse gases (CBD Secretariat, 2007).

Birol et al., (2009) studied on carbon sequestration and fluxes in natural and constructed wetlands located around the world. All facets of carbon (solid and gaseous forms) have been covered. Their findings indicate that wetlands can be both sources and sinks of carbon, depending on their age, operation, and the environmental boundary conditions such as location and climate. If the organic C content is greater than 12% to 18%, depending on the clay content, the soil material is considered organic. Soils dominated by organic soil materials have a low bulk density, high porosity, and a high-water holding capacity. The water movement through organic soil materials is generally slow.

The level of soil organic carbon in a particular soil is determined by many factors including climatic factors such as temperature and moisture regime; edaphic factors like soil parent material, clay content and cation exchange capacity. Soil carbon sinks resulting from sequestration activities are not permanent and will continue only for as long as appropriate management practices are maintained. If a land management or land use change is reversed, the carbon accumulated will be lost, usually more rapidly than it was accumulated (Smith et al., 1996).

The role of aquatic microbes in carbon mineralization is important in the case of both carbon fixation and carbon release. Methanogens, sulfur reducing bacteria and other anaerobic microbes play an important role in carbon assimilation. The source of methane is important in the case its origin, because most of methane is produced from paddy fields. Methane production from estuarine sediments is also an indicator of Carbon metabolism by Methanogens (www.environment.gov.au).

The photosynthesis and respiration are the two main transformations of carbon in nature and the balance between these occurred mainly depend on the amount of organic matter that accumulates in the soils and sediments and the quality of the water bodies (Ponnamperuma, 1972). In the submerged soils, the respiration is the main transformation occurred. The decomposition of the organic matter in the submerged soils is slower and end products are hydrogen, methane, ammonia, amines, mercaptans, hydrogen sulphide and partially humidified residues by the activity of facultative and obligate anaerobes. The drained soils favour the decomposition by soil aerobic microorganisms and end products are CO_2, nitrate, sulphate and humus.

Soil is the primary resource for plants to grow and the main two parameters that support growth are carbon and nitrogen. The linkages between C and N biogeochemical cycles are through organic matter transformation, N assimilation, N mineralization and denitrification (Yano et al., 2000). This makes the C and N ratio (C: N ratio) an important indicator of N availability and also a determinant of organic matter source in ecosystems. Soil organic matter is the main reservoir of major nutrients including N and as such mineralization of C and N is essential for the maintenance of ecosystem functions, particularly agricultural production and its sustainability. Temperature and moisture are, therefore, important environmental factors that affect C and N mineralization in soils. Soil pH also effects C and N mineralization. Generally, near–neutral pH values are optimal for enhanced mineralization. Values on either side of neutrality restrict microbial activity and growth and consequently suppress mineralization (Weier et al., 1993).

In wetlands, ammonification is an important process regulating bioavailable N in both soils and the overlying water column. During decomposition of plants, particulate organic N in the detritus pool undergoes decomposition and producing dissolved organic N. Additionally, organic N forms such as proteins and amino acids can be sequestered in the microbial biomass, after cell death released to the soil there by creating a dissolved organic N pool (White and Reddy, 2000). The extracellular enzymatic activity breaks down the organic forms to inorganic N (Wright and Reddy, 2001). The humic compounds and complex proteins are the largest storage of N in wetlands accrete slowly with time (Reddy and De Laune, 2008). Ammonification transforms organic N to bioavailable inorganic forms. The ammonification causes an accumulation of $NH4 +$ in wetland soils rather than as $NO3 -$ due to the anaerobic status of flooded soils and limitations to diffusion (Reddy and Patrick, 1984; Reddy and Graetz,1980).

Plants require nitrogen in large quantities but plant available form of nitrogen present only in small percentage, 98% of the nitrogen in organic form. Nitrogen present in the soil undergo various changes or transformations. The main processes process of organic transformation through the biogeochemical cycles were N assimilation, N-mineralization and denitrification (Yano et al.,2000). Organic N that's present in soil organic matter, crop residues and manure is converted to inorganic N through the mineralization process. The process of conversion of organic matter by the microbial decomposition into inorganic compounds is termed mineralization (Gregorich et al., 2001). Mineralization of organic N and immobilization of mineral N are two rival processes occurring concurrently in soils. These two processes affected by the quantity and the decomposition of carbonaceous compounds by microorganism which act as a source of energy. The presence of surplus amount of readily decomposable carbon, favors the immobilization of mineral N proceeds to a greater extent than the mineralization of organic N, which constitute net immobilization. Immobilization rates decrease gradually with the decomposition of the carbon compounds. When equilibrium occurs, the rates of mineralization and immobilization are equal and there is neither net mineralization nor net immobilization. With the further utilization of carbonaceous material, the rate of mineralization exceeds the rate of immobilization and net mineralization (Zhu ,1997). The organic and mineral N which involved in the transformations can be either soil N or added N. Bioavailability of soil organic N is strongly coupled to SOM cycling and is a crucial parameter determining crop yield. Anaerobic conditions inhibit N mineralization, with a high risk of gaseous N losses.

C: N, the soil Carbon-Nitrogen ratio is an indicator of the nitrogen availability and a determinant of organic matter source. C-N ratio used as an index for turn over period of N to the soil. However, C-N dynamics of the wetland soils are still poorly understood. C-N mineralization depending on organic matter added to the soil and other environmental factors.

The nitrogen and phosphorus are the most common nutrients limiting plant growth and soil carbon storage (Liu et al., 2017). Changes in the sources and sinks of soil organic carbon and total nitrogen in wetland soils act as indicators of soil quality and climate change have received attention worldwide (Wang,2016). Mitsch and Gosselink (2015) reported that any variations in the distributions and abundances of soil C and N exert important effects on the carbon and nitrogen cycles at regional or global scales. The accurate estimations of soil organic carbon and total nitrogen are essential for the detection of potential carbon and nitrogen sequestration and emissions in wetlands.

Flooding of soil at the time of land preparation for wetland rice triggers several physicochemical and microbiological processes. The resultant soil-water atmosphere system is highly complex and heterogeneous in nature (De Datta, 1995; Reddy and Patrick, 1978; Ponnamperuma, 1972). The greatest losses of N are reported to occur when the fertilizer treatment leads to a high concentration of ammoniacal N in the floodwater. Results from the studies using micrometeorological technique suggest that ammonia volatilization may be the most important loss process in wetland rice ecosystems. Directly measuring denitrification in the field proved more difficult than measuring NH_3 volatilization due to difficulty in distinguishing the main end product of denitrification (N_2) against a large background of atmospheric N_2 (De Datta,1995).

7.2 Methodology

The soil samples were collected as mentioned in the section 6.3.1. The sieve analysis of the soil samples were carried out and categorized under different classes. Bulk density was analysed by core sampler method (Jackson 1957) using following equation. Bulk density (g/cm^3) = weight of dried soil (g) /Soil volume (cm^3). Soil texture Hydrometer method (Bouyoucos ,1962) was used for the determination of particle size distribution. Hydrometer method was based on the dispersion and sedimentation applied to a given weight of the soil sample. The carbon content and nitrogen in the soil samples were analysed using CHNS analyzer (Eurovector, Italy. Model: EA 3000). Maps of carbon and nitrogen were prepared using interpolation technique in ArcGIS version 10.3 in section 3.4.

7.3. Result and Discussion

7.3.1. Textural analysis of Kole land soil

The textural analysis of Kole land soils revealed wide variation in particle size, ranging from sandy loam to clay (Table 7.1). The surface and subsurface layers of the profiles have more or less same texture indicating poor profile development. The texture analyses show variation in the texture, ranging from sandy loam to clay from the fourteen samples. Similar results observed in the study on the Kole land soils by Sheela (1988) and Abdul Hameed (1975). According to Abdul Hameed (1975) all locations including Pullazhy and Muriyad is predominantly composed of clay. From the soil profile for Muriyad wetland, the top zone was composed of sand-silt particles and thickness varies from 0.25 m to 0.75m. Plastic clay horizon of thickness 2 to 3 meters occurs just below this zone. In certain areas, sand horizon of varying thickness from 0.6 m to 1.25 m was observed. This horizon is horizontally impersistent where the sand horizon is absent plastic clay zone directly rests on peat + carbonaceous sandy clay zone (Thomas, 2003).

Table. 7.1. Mechanical composition of soil

Sl.no	Locations	Average value of 0-30 cm				Grade
		Coarse sand	Fine sand	Silt	Clay	
1	Pullazhi	14.88	4.1	41.9	38	Clay
2	Aranattukara	68.9	5.9	18	4.3	Sandy loam
3	Perumpuzha	63.1	24.8	6.2	4.6	Sandy loam
4	Manaloor	34.9	22.8	28.2	13.4	Sandy loam
5	Venkitangue	37.4	16.3	36.4	7.1	Sandy loam
6	Mullassery	59.3	11	23.7	4.8	Sandy loam
7	Anthikkad	57.8	12.7	21.3	6.6	Clay loam
8	Ammadam	27.9	17	34.8	19.2	Sandy clay loam
9	Alappad	54	22.8	19.4	3.1	Sandy clay loam
10	Pullu	5.7	5.2	23.4	63	Clay
11	Vellani	22.6	17.9	23.6	34.5	Clay
12	Cherpu	15.5	18.3	26.3	38.4	Clay
13	Muriyad	18.7	6.8	23.8	42.4	Silty loam and clay
14	Thazhekkad	17.6	7	24.6	44.6	Silty loam and clay
15	Kacheri	60.8	12.4	22.1	4.9	Sandy loam
16	Kanimangalam	16.99	4.5	41.9	38	Clay

7.3.2. Bulk density of Kole land soil

The bulk density ranged from 0.04 g/cm^3 to 0.81 g/cm^3 in top layer, 0.04 g/cm^3 to 0.90 g/cm^3 in middle layer and 0.007 g/cm^3 to 0.82 g/cm^3 in bottom layer in the Kole land soil. The bulk density of different locations with varying depth A, B, C is presented in Table 7.2. The Bulk density increased with compaction and tends to increase with depth. Soils with more sand content was found to have high bulk density than other types. The low bulk density of Kole land soils may be due to the following reasons; consistently plowing or disking to the same depth, allowing equipment traffic, especially on wet soil; using a limited crop rotation without variability in root structure or rooting depth; incorporating, burning, or removing crop residues; overgrazing forage plants, and allowing development of livestock loafing areas and trails, and using heavy equipment for building site preparation or land smoothing and leveling (www.soilquality.org/indicators/bulk_density).

Table. 7.2. The bulk density of paddy soils at different depth layers

S. No	Bulk density g/cm^3		S. No	Bulk density g/cm^3		S. No	Bulk density g/cm^3
S1A	0.31		**S9A**	0. 63		**S17A**	0.59
S1B	0.46		**S9B**	0. 90		**S17B**	0.59
S1C	0.44		**S9C**	0.70		**S17C**	0.34
S2A	0.72		**S10A**	0.31		**S18A**	0.04
S2B	0.45		**S10B**	0.07		**S18B**	0.04
S2C	0.40		**S10C**	0.21		**S18C**	0.38

S3A	0.61	**S11A**	0.55	**S19A**	0.42
S3B	0.76	**S11B**	0.62	**S19B**	0.42
S3C	0.81	**S11C**	0.47	**S19C**	0.17
S4A	0.33	**S12A**	0.66	**S20A**	0.20
S4B	0.40	**S12B**	0.57	**S20B**	0.60
S4C	0.007	**S12C**	0.48	**S20C**	0.14
S5A	0.64	**S13A**	0.43	**S21A**	0.66
S5B	0.64	**S13B**	0.41	**S21B**	0.66
S5C	0.27	**S13C**	0.39	**S21C**	0.52
S6A	0. 44	**S14A**	0.72	**S22A**	0.11
S6B	0. 29	**S14B**	0.70	**S22B**	0. 84
S6C	0. 21	**S14C**	0. 71	**S22C**	0. 63
S7A	0.60	**S15A**	0.65		
S7B	0.52	**S15B**	0.72		
S7C	0.67	**S15C**	0.18		
S8A	0.57	**S16A**	0.60		
S8B	0.69	**S16B**	0.25		
S8C	0.61	**S16C**	0.82		

7.3.2. C - N balance of wetland soils

Soil organic matter is the main reservoir of major nutrients including N, mineralization of C and N is essential for the maintenance of ecosystem functions, especially agricultural production and its sustainability. This process depends on a number of factors such as the quality of organic matter added to the soil and other environmental factors. The carbon balance in wetlands depends on the topography, geological position, hydrological regime, the type of vegetation, temperature, moisture, pH and morphology. Thus, the carbon accumulation in wetlands is a complicated process influenced by many factors (Shalu et al., 2009). Several earlier studies express the carbon content in soils of wetlands on a percentage basis, making it too difficult to derive the carbon storage per unit area if the depth of the organic matter is unspecified. The carbon content and the total nitrogen in soil layers of the Kole land are tabulated and given in Table 7.3.

The carbon content in the Kole wetland ranged from 0.64 % to 5.01 %. The Kole wetland top soil had a range of 1.89 to 4.11%. Carbon in the middle layer found have carbon contents varying from 1.69 to 3.69%. The bottom layer of soil was found to be higher carbon content in the range of 1.14 to 5.01 %. The carbon content was found have be increasing with depth. The figures 7.1 show the diagrammatic representation of carbon in different locations of the Kole wetlands.

The total nitrogen content in the wetland soils ranged from 0.598 % to 1.867 %. The nitrogen content was found to be in the range of 0.64 to 1.54% in top layer. The middle layer had a nitrogen content which range from 0.59 to 1.07%. The bottom layer found to be 1.46 to 1.77%. The general trend showed an accumulation of nitrogen in the lower layers (Fig.7.1).

Organic N mineralization is dependent on several environmental factors including temperature, O2 availability, the C/N ratio of the soil organic matter, detritus the size and heterotrophic activity of the microbial pool and limiting nutrients (Roy and White, 2013).

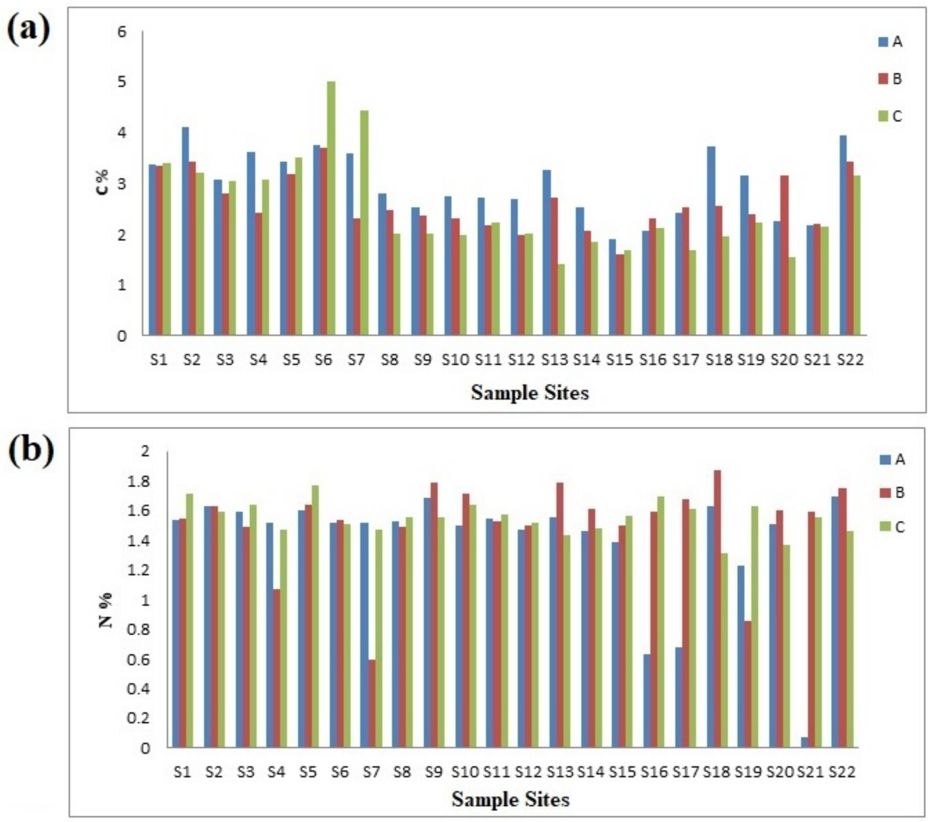


Fig: 7.1. Depth vise distribution of (a) carbon (b) nitrogen in soil

Soils dominated by organic soil materials have a low bulk density, high porosity, a high-water holding capacity and the water movements through organic soil materials are generally slow. Although the nutrient content of the organic soil materials is high, is not in available forms and the pH of organic soil materials is generally low. The prolonged saturated and anaerobic conditions in wetland soils and slow organic matter decomposition lead to organic matter accumulation. Organic matter, specifically humus, in a mineral soil promotes aggregation and structural stability, lowers bulk density, increases porosity, and leads to higher infiltration and percolation rates. Organic matter also contains significant amounts of plant nutrients in unavailable forms, which can be converted to available forms during organic matter decomposition. (Jackson et al., 2014).

Table 7.3: The Carbon and Nitrogen content in soil layers

Sl. No	C%	N%	S. No	C%	N%	S. No	C%	N%
S1A	3.36	1.54	**S9A**	2.52	1.68	**S17A**	2.42	0.68
S1B	3.34	1.55	**S9B**	2.37	1.79	**S17B**	2.52	1.67
S1C	3.39	1.71	**S9C**	2.02	1.56	**S17C**	1.68	1.61
S2A	4.11	1.63	**S10A**	2.74	1.49	**S18A**	3.71	1.62
S2B	3.42	1.63	**S10B**	2.32	1.71	**S18B**	2.54	1.86
S2C	3.22	1.59	**S10C**	1.98	1.64	**S18C**	1.94	1.31
S3A	3.08	1.59	**S11A**	2.71	1.54	**S19A**	3.17	1.23
S3B	2.81	1.49	**S11B**	2.16	1.53	**S19B**	2.38	0.85
S3C	3.06	1.64	**S11C**	2.22	1.57	**S19C**	2.23	1.63
S4A	3.62	1.52	**S12A**	2.69	1.4	**S20A**	2.24	1.5
S4B	2.43	1.07	**S12B**	1.98	1.5	**S20B**	3.16	1.60
S4C	3.08	1.47	**S12C**	2.01	1.51	**S20C**	1.56	1.37
S5A	3.43	1.6	**S13A**	3.25	1.56	**S21A**	2.17	0.07
S5B	3.18	1.64	**S13B**	2.71	1.79	**S21B**	2.21	1.59
S5C	3.50	1.77	**S13C**	1.41	1.43	**S21C**	2.14	1.56
S6A	3.70	1.52	**S14A**	2.54	1.46	**S22A**	3.9	1.69
S6B	3.69	1.53	**S14B**	2.07	1.61	**S22B**	3.42	1.75
S6C	5.01	1.52	**S14C**	1.85	1.48	**S22C**	3.14	1.46
S7A	3.58	1.52	**S15A**	1.89	1.39			
S7B	2.29	0.59	**S15B**	1.61	1.49			
S7C	4.42	1.47	**S15C**	1.68	1.57			
S8A	2.81	1.52	**S16A**	2.06	0.64			
S8B	2.47	1.49	**S16B**	2.31	1.59			
S8C	2.01	1.55	**S16C**	2.11	1.69			

7.3.4. Regression analysis

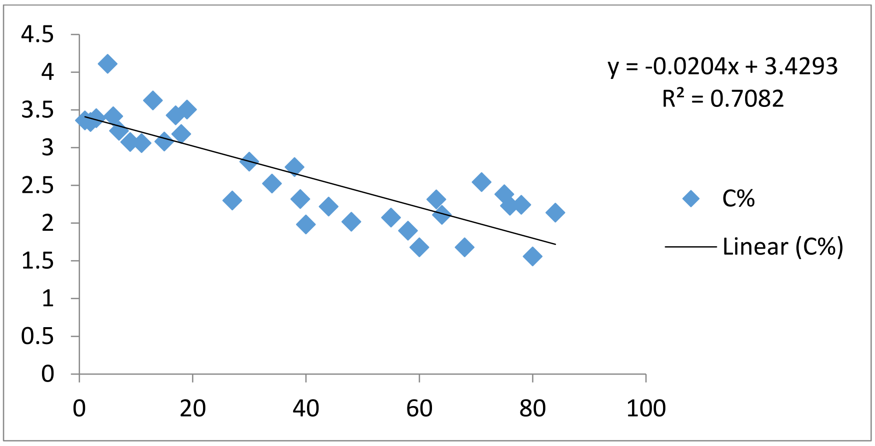


Fig.7.2. Correlation between bulk density and carbon

The correlation between bulk density and carbon percent showed R value 0. 84.It showed that a strong correlation between them (Fig.7.2). The carbon –nitrogen storage in soil was found to be positive correlation but not a significant one.

Some parts of Kole wetlands (Konchira) soils are rich in carbonaceous clay with considerable quantities of vegetable matter and lacustrine in nature (Konchira series) and Anthikkad and Perumpuzha areas are enriched with weathered tree trunks and lime shells when dug deep (Johnkutty and Venugopal, 1993). Soil C: N ratio determines the decomposability of soil which is primarily dependent on organic matter and has an important role in producing available N for plant growth.

7.3.5. Soil quality analysis using kriging

The spatial distribution of carbon was done using GIS interpolation techniques. It was found that the wetland soils were highly enriched with carbon than the normal range (Table 7.3.). Soil carbon sequestrations indicate transferring of atmospheric CO_2 into soil of a land unit through its plants. The advantages of soil C sequestration include advancing food and nutritional security, increasing renewability and quality of water, improving biodiversity, and strengthening elemental recycling (Lal et al., 2002). The spatial distribution of nitrogen in Kole wetland was found to be in medium and higher range. The Figures 7.3 gives the interpolation of carbon and nitrogen of wetland soils.

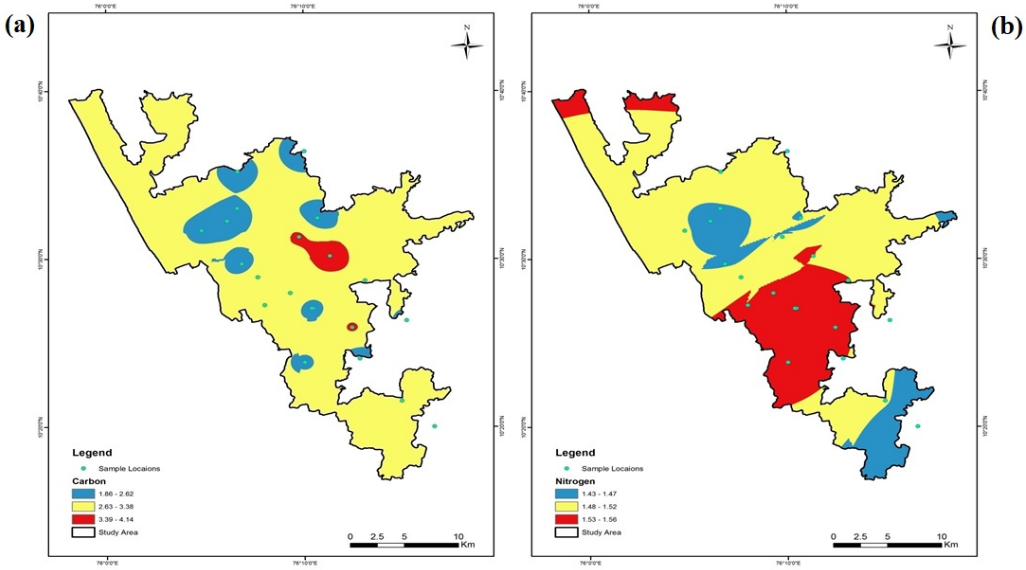


Fig: 7.3. Map of (a) carbon and (b) nitrogen in soil

7.4. Conclusion

The significant disturbances in land use practices cause initial decrease in the soil carbon level. The nitrogen and carbon content in the wetland soil were found to be high and general trend showed that they increase with depth. The low bulk density soils in this ecosystem were generally rich in carbon. Wetlands are an important C sink, playing a key role in climate regulation and these ecologically important sensitive areas should be maintained properly. Soil carbon sinks can be increased by adopting carbon enhancing land management strategies.

CHAPTER 8

CONCLUSIONS

CONCLUSIONS

8.1. CONCLUSIONS

The aim of the study is to understand the land use changes in Kole wetlands and to assess the soil and water quality status of Thrissur Kole wetlands. It is observed that there was a decline in the paddy field extent from 1980 to 2007. However, a significant increase in the area of paddy cultivation was noted from 2008 to 2017.The extent of agriculture land (coconut and settlement) showed a remarkable increase (41.96%) from 1980 to 2017. This showed that people have either shifted their agricultural practice from paddy to coconut cultivation or transformed the land for settlement. A reduction in the extent of mixed agriculture crops was also noticed from 1980 to 2017.

During pre monsoon, 90% of the surface water samples were acidic in nature while 71% of the water samples were acidic duirng postmonsoon. The electrical conductivity of all the surface water samples were above the acceptance limit in the pre monsoon indicating the intrusion of saline water into the waterbodies.The value of 90% of the water samples exceeded the permissible limit with regard to the sodium during pre monsoon season. Ninety six percent of the samples were contained iron which was above the permissible limit duirng post monsoon. Ca>Na or K >Mg in cationic and HCO_3 > Cl>SO_4 in anionic facies. During post monsoon Na/K> Ca>Mg in cationic and Cl>HCO_3>SO_4 in anionic facies. The classification of cation and anion facies in triangular fields of piper plot showed that majority of the surface water samples fall into Ca type in cationic and HCO_3 type in anionic during pre-monsoon. The map prepared using Kriging method clearly demarcate that the NW part of the wetland area is under the threat of saline intrusion during pre monsoon period. The proximity to the sea can be identified as the source for salinity.

In this study, surface water samples of the selected locations had higher Dieldrin concentration than the permissible limit. Presence of α- BHC was observed in certain locations. Dieldrin residue was found in the samples of rice and plants which exceeds the permissible limit.

Fifty percent of the of the ground water samples were acidic while only one sample (W3) remained alkaline during pre-monsoon whereas 20% of the samples were acidic and 15% were alkaline during post-monsoon. The electrical conductivity of 25% ground water samples was above the permissible limit during pre-monsoon and 50% of the samples were above the permissible limit during post monsoon. Examining the ground water chemistry, the order of cation abundance is Ca > Na/K>Mg in both seasons. The anionic abundance was $Cl>HCO_3>SO_4$ in pre-monsoon and $HCO_3>Cl>SO_4$ in post-monsoon. Based on the USSL diagram, 95 % and 50% of the ground water samples were categorized as bad quality for irrigation purposes during pre-monsoon and post-monsoon respectively. This indicated that wetland system was under the threat of salinity hazard. In the majority of the areas ground water was acidic in pre monsoon season and after monsoon the water in the northern segment remained acidic and the southern tip of the wetland area turned alkaline due to intrusion of saline water and its leachate.

In general, the soils of Kole wetland were found to be acidic. The organic carbon, available nitrogen and sulphur of the majority sample locations decreases with depth. The presence of available phosphorous was found to be below the detectable limit. The concentration of micronutrients such as Fe, Mn and Zn were very high while Cu low in samples. The boron deficiency and low heavy metal concentration were found in all samples. All samples in the study area were found to be above the higher limit of Potassium in the Kole wetland due to the application of the fertilizer. The Ca and Mg content in the Kole wetland soils indicated the presence of intrusion of saline water. pH of the soil samples became more acidic after flood. The sample locations showed high electrical conductivity after flood due to the deposition of salts in the upper parts of soil profile. and relatively low EC values which indicated the leaching of top soil. General trend shows a decline of OC, Na, Mg, N, P, K, Zn and Al after flooding. The soil samples enriched with Ca, sulphur, boron, Cu and Mn after the flood.

Soil carbon sinks can be increased by carbon enhancing land management practices. The significant disturbances in land use practices cause initial decrease in the soil carbon level. The nitrogen and carbon content in the wetland soil were found to be high with increase in depth. The low bulk density soils are rich in carbon. Kole wetlands are an important carbon sink, playing a key role in climate regulation. This fragile ecosystem should be maintained properly.

The conclusions are drawn on the basis of random sampling and their analysis. A comprehensive sampling is required for arriving at an accurate conclusion.

CHAPTER 9

RECOMMENDATIONS

RECOMMENDATIONS

9.1. Recommendations

The Kole wetland system is threatened in several ways like sand mining, reclamation, construction of permanent bunds, weed chocking, over use of chemicals and disposal of waste materials. The unscientific land use practices resulted in the shrinkage of total area of productive wetland to a great extent. This poses a threat to drinking water and food security of the people around. The need of the hour is to maintain at least the present status of the wetland and prevent any kind of further deterioration. The extreme climatic events due to global warming can invite frequent natural calamities such as floods and droughts in future. Wise use of the wetland system is the cheapest nature-based solution to reduce the risk from natural hazards. The aim of The Kerala Conservation of Paddy land and Wetland Act of 2008 was to check the degradation of wetlands. However, the periodic dilution of the laws defeats the purposes of law. The goal of the restoration management plan is to conserve its biological diversity and maintain the full range of ecosystem services derived from the wetland system in order to sustain livelihood of dependentant community. Fishing, paddy cultivation, medicinal plant collection are the income sources of the inhabitants in the fringes of the wetland. The study endorses the following recommendations for the protective management of productive Thrissur Kole wetland system.

9.1.1. Declaration as buffer zone

Declaration of buffer zone of 50 m wetlands as protected area prohibiting of any major industries that causes pollution of water bodies.

9.1.2. Pollution abatement

Dumping of waste from houses is one of main source of pollution. The segregation of waste must be done at the source itself. Biodegradable waste from each is to be utilized for biogas or making compost for manure. The non-degradable waste must be collected at house hold level by Haritha Karma Sena constituted by Local Self Government (LSG). All LSGs have these waste disposal system and public must co-operate with the administration in paying fee without fail.

The effluents from slaughter houses, farm, small scale industries and human sewage must be treated before entering the water. The over use of fertilizers and chemical fertilizers often contaminate water and soil in wetlands. To avoid the harmful effects of chemicals, organic farming must be promoted. The farmers must be given awareness regarding the judicious use of fertilizers and pesticides.

9.1.3. Scientific operation and maintenance of regulators

During the monsoon, rain water flows through the canal network and drain into the Arabian sea. The regulators at Enamakkal and Idiyanchira in the northern Kole region divert excess water into the Canoli canal which control inundation. When decided to start cultivation with the consent of Padasekhara Samithi (formation of group of farmers), the operation of regulators Idiyanchira and Canoli canal system must be carried out. In the recent past, the paddy fields are fragmented due to unscientific road construction and reclamation which often block the natural drainage resulting in unprecedent floods and water logging in Ayyanthole and Puzhakkal region. A systematic calendar for regulator operation is to be prepared every year to avoid conflict between fishery and agriculture existing in the area. The scientific operation of the regulators must be needed for maintaining water quality. Timely intervention by the District administrators for the construction and breaking of Valayakettu (Earth bank) in Enamakkal is needed. The regular annual maintenance of all bunds, irrigation canals and regulators should be carried out by the District Panchayath.

9.1.4. Rotational farming system

In the rotational farming system fish cultivated in the rice fields. It resulted in higher production of fish per unit area. The residues from fish culture, makes the soil richer for the rice crops while the residues from paddy encourage the growth of fish feed. Successful results are obtained in Chathan Kole padasekharam (Adat Gramapanchayath) by using rotational farming system. By popularizing this farming system in more areas, additional income can be generated for rural people.

9.1.5. Integrated farming system

Establishment of a low-cost organic farming method - fish, duck and azolla integrated with rice results in nutrient enhancement and biological control of weeds and pests.

9.1.6. Recharging of ground water

This is the most important function attributed to the paddy fields, preventing overland flow. The ponds and wells in the fringe areas should be conserved for the effective recharging of the ground water. Laterites are good aquifers which can hold rain water and guaranties fresh water availability in summer as it recharges the wells and ponds. The isolated lateritic mounts situated along the fringe area should be protected. The small hillocks in Urakam, Vallachira and Irinjalakuda areas in south Kole and Parappur, Adatt, Mullassery in the north Kole act as a good aquifer.

9.1.7. Utilization of abandoned deep mined areas

Extraction of sand and clay has resulted deep excavations in South Kole especially Konthipulam, Madappuram, Rappal and Thottippal padasekharam areas. These areas can be utilized by cage fish cultivation. Indian major carps, Common carps, Scampi, green chromide are suitable for cultivation. Installation of floating solar panels on the surface of waterbodies also an adaptive method for the utilization of these mined areas.

9.1.8. Promotion of cultivation in fallow land

Encourage paddy cultivation in fallow lands. Crop insurance may be decided based on the stage of crop and expected returns from the crop in the context of the climatic variability and frequent natural disasters, new schemes should be floated. Paddy farmers should be supported for the ecosystem services annually, for not converting paddy fields.

9.1.9. Ensure the soil health

Soils in the Paddy require special management practices for the problems to counteract the sustainable development. Preparation of Soil health card should be provided for the effective application of fertilizers.

9.1.10. Research needs

Regular monitoring and detailed analysis of water and soil quality is required for generating data base for risk evaluation. The biological studies and eutrophication studies must be conducted. The local environmental impact assessment should be carried before the construction of the new engineering structures such as bridges, roads, culverts and bunds.

9.1.11. Capacity building

Create awareness among people and local self-governments authorities about the importance wetlands conservation. Co-ordinate the activities of local self-governments which share the boundary of the wetland areas and also co-ordinate various engineering projects of line departments. Integrated river basin management of Keecheri and Karuvannur is required for the conservation of Thrissur Kole wetland region.

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Presentations & Publications

International paper presentation

1. **Sinta K B., Sreekumar, S., ‘‘Harilal C C.** Hydrochemical characteristics of Muriyad wetlands, Kerala-an appraisal”. International conference: Geology: Emerging methods and applications (GEM-2017). Christ College (Autonomous), Irinjalakuda-680125, Kerala.6-8 February,2017.
2. **Sinta K B., Sreekumar, S., ‘‘Harilal C C.** Flood induced changes in the chemical characteristics of soils – A Case study from Kerala, India. International conference: Geology: Emerging methods and applications (GEM-2017). Christ College (Autonomous), Irinjalakuda-680125, Kerala.17-19 January,2019.

National paper presentation

1. **Sinta K B., Sreekumar, S., ‘‘Harilal C C.** Water pollution with special reference to pesticide contamination in Kole wetlands, Kerala, India. National seminar on “Biopesticides, bioinsecticides and sustainable livelihood practices", Department of Botany, University of Calicut .23-25 March ,2022.

Publications

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Land degradation and water quality assessment of a part of Thrissur Kole wetland, Kerala, India –Ramsar site

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Abstract: **The Kole wetlands already been declared as complex Ramsar sites in Kerala, India. The study involves to assess the degradation of Vembanad kol wetland (Ramsar site), Kerala, India using Remote Sensing (RS) and Geographical Information Technology (GIS) and to monitoring the monthly water quality with special reference to salinity in surrounding areas of kole wetland system. By analyzing the data such as Survey of India toposheet (1969), LANDSAT image (2001) and IRS P-6 satellite image (2008) showed a significant degradation of Kole wetland from 61% to 28% during the period 1969-2008 respectively. It is inferred that Kole land area shrinked by 10 percent within a period of 32 years (1969-2001).Seven ground water samples were collected during the period of September 2007 to July 2008 and the quality of groundwater has been made through the analysis of physical and chemical parameters. The conductivity value ranged between 50µmhoscm^{-1} (Well-7) to 400 µ mhoscm^{-1} (Well-1) and showed the variation in peak season.(April, June and November). This is due to the saline water inflow in to inlet of Chettuva estuary during peak summer season. All parameters within the drinking water permissible limit prescribed by BIS except pH and Turbidity. The study confirm that the extent of salinity is confined in an area of inlet of chettuva estuary.**

Keywords: **Kole wetland, Vembanad Kole, Water quality, Salinity.**

1. INTRODUCTION

Wetlands are ecotones or transitional zones that occupy an intermediate position between dry land and open water. It is highly productive areas with rich biodiversity; they serve as a spawning and nursery ground for fishes, reptiles, birds, mammals etc. and hence can be used as an excellent area for conservation of rare and endangered species (Gopal, 1992). Wetlands are of great economic, cultural, scientific, and recreational value to human life. The wetlands are currently subjected to acute pressure owing to rapid developmental activities and indiscriminate utilization of land and water. During past Status and Trends studies the types of land use activities that most influence wetland conversions have been documented. These include Conversion of wetland in to agriculture, urban development rural development, forest plantation and other upland use (Dahl, 1993). Remote sensing and Geographical information Technology (GIS) have been used extensively by Status and Trends to monitor wetland acreage changes (Dahl, 1991). India has a wealth of wetland ecosystems distributed in different geographical regions. Twenty five wetlands in India are designated as Ramsar sites (WWF, 2006). State like Kerala is well known for its wetlands and these wetlands provide livelihood to the residents in the area in the forms of agriculture produce fish, fuel ,fiber ,fodder ,and a host of other day-to-day necessities .As much as one fifth of the State's total land mass is wetlands which include a vast network of backwaters, lagoons ,mangrove ecosystem, natural lakes, ponds, tanks, rivers and canals, manmade reservoirs, ponds et From Kerala, three wetlands were included in the list of Ramsar sites(2002)-Vembanad Kole wetlands, Ashtamudi lake, Sasthamkotta lake (WWF,2006).The Kole wetlands already been declared as complex Ramsar sites. The name "Kole" refers to the peculiar type of cultivation carried out from December to May and this Malayalam (mother tongue of state Kerala, India) word indicates bumper yield of high returns in case floods do not damage the crops (Johnkutty and Venugopal, 1993).The usually flooded areas of the Thrissur Kole wetland also suffered from salinity intrusion through the inlets at Chetwai and Kottappuram. Enammakkal barrage was constructed about five decades ago, to prevent salinity intrusion into the Kole lands from Chetwai. Regulator at Enammakkal and the minor one at Kottenkottuvalavu in the lower reach of the Karuvannur river act both as spillway for the flood waters from the Kole land and as a regulator of salt water entry (CED, 2007).The Kole wetlands with an extend of 13632 ha are spread over Thrissur and Malappuram districts in Kerala state (Johnkutty and Venugopal, 1993). It extends from the Northern bank of Chalakkudy River in Southern banks of Bharathapuzha River in North. Eastern side of the Kole wetlands is Thrissur town and Western side extend up to Arabian Sea.

2. STUDY AREA

The present study area covers the northern part of kole land which includes the boundaries of Panchayat Manaloor, Venkitangu, Mullassery, Elavally, Tholur, Adat and a part of Thrissur Corporation. The study area falls within the Latitude76^0 3'0"E to 76^0 15' 0"E and Longitude10^0 30' 0" N to 10^0 39'0" N (Fig.1). The study area covers an area of about 153.6sq.km. The Kole wetlands are low lying tracts located 0.5 to 1 meter below MSL and it remains submerged for about six months in year.

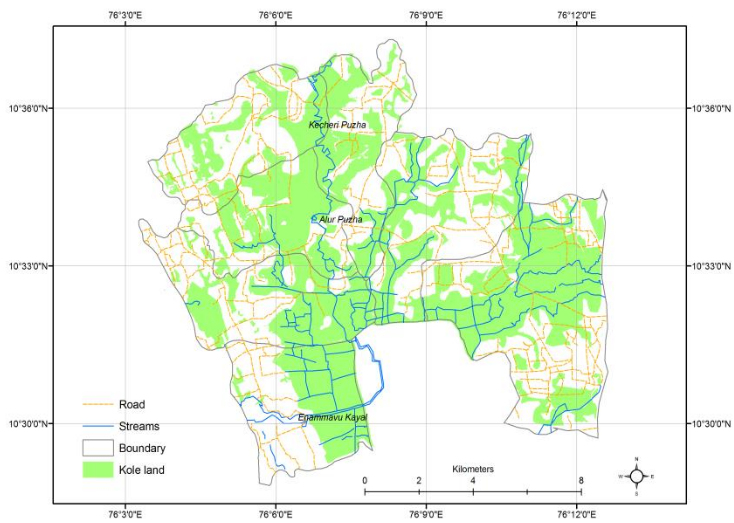

Fig 1: Study area

These lands were formerly shallow lagoons which gradually were silted up. Keecheri and Karuvannur rivers being the flood water into the wetlands which finally empty into Arabian Sea. These rivers in spate discharge the flood waters into the low lying Kole wetlands and raise the water depth to more 550cm.The Kole wetlands function as the flood basin for both the rivers. The climate is moderate and 4 different seasons-dry weather from December to February, hot weather from March to May, South-West monsoon from June to September and retreating or North East monsoon from October and November. About 60 percent of rainfall is obtained during South-West monsoon, 30 percent during North East monsoon and remaining 10 percent in summer. The average rainfall is 3200mm (James 1993) and there is temporal distribution of rainfall. At present the region appears as a saucer shaped basin flanked by laterite hills in the Western and Eastern margins. The valley fill material formed of gravel and sand of laterite composition mainly brought down laterite hills. Large quantity of nutrient rich alluvial soil gets deposited during the process of inundation making the wetlands highly fertile for paddy cultivation. One hundred and nine Padasekharams (section of paddy fields) exist in Kole wetlands. The present study aimed to assess the degradation of Vembanad Kole wetland (Ramsar site) using Remote Sensing (RS) and Geographical Information Technology (GIS) and to monitoring the seasonal water quality with special reference to salinity in surrounding areas of Kole wetland system.

3. MATERIALS AND METHODS

The spatial and temporal changes Kole-wetland are mapped using Survey of India-topographical maps and remote sensing data. This study done by using the GIS soft ware ArcGIS 9.2, Mapinfo9.2 and ERDAS IMAGINE 9.2.From the topographic sheet (1969), the boundary of Kole land with communication arteries and drainage network has been delineated (Fig.1). The study of topographic forms or geomorphologic units or land forms is the Science of Geomorphology. On screen visual interpretation of Land sat TM data has been carried out to identify various landforms taking into consideration the various images and terrain elements. A popular GIS package was used to mark the polygons of various landforms .The landforms, which are very important in wetland ecosystems are digitized and their distribution has been delineated from the remotely sensed data using standard image interpretation elements and characters. Reconnaissance and validation survey has been carried out for the present study. During reconnaissance survey GPS reading has been collected randomly from different places of the study area. These GPS readings were used to locate the places in the imager to get an overall idea about these places and this was helpful for the preparation of thematic maps. Three data such as Survey of India toposheet (1969), LANDSAT, IRS P-6 were used for assessing the change in kol wetland during the period 1969-2008. Details of data used in GIS as shown in the Table 1.

Table 1: Materials used for the study

Types Of Data	Details of the data	Source of the data
Survey of India(SOI)Toposheet	58B2,58B3 (1969)	Survey of India(SOI) Dheradhun
IRS P-6	1:50000,January,2008 Resolution-0.5m	NRSC Hyderabad
LANDSAT TM FCC	Resolution23.5 2001	NRSC Hyderabad

Seven ground water samples were randomly selected using statistical randomisation techniques (Levin, 1998) from different parts of study area. The more priority given to the areas where salinity intrusion facing the fringes of wetland. The sample collection done during the period of September 2007 to July 2008. The samples were collected in pre cleaned polythene bottles and were analysed according to methods prescribed by APHA (2005). The samples were treated on site and preserved by appropriate Method (APHA, 2005). pH analysed at the spot and other water quality parameters were analysed in the Environmental Laboratory, Christ College Irinjalakuda. The physico chemical and biological parameters analysed includes pH, conductivity, turbidity, total dissolved solids, total hardness and salinity etc. Table-2 showing the Locations of sampling site.

4. RESULT AND DISCUSSION

After analyzing different land use maps, the area of kol land was determined. The data obtained from the survey of India toposheet (1969) shows that there was an area of about 80.26 sq.km during that time (Table-2, Fig.2). The analysis of data from the LANDSAT TM image 2001, the kole land area drastically decreased in a faster rate. The analysis showed that during that period there was only 59.96 sq km kole land in the study area (Fig.3). The kole lands are mainly used for building purposes and road construction. The human settlements were traditionally concentrated around the wetland systems and the reasons are obvious.

Table 2: Locations of water sampling sites

SL no.	Sample	Location
1	Well -1 (W-1)	Manalur
2	Well -2 (W-2)	Mullassery
3	Well -3 (W-3)	Venkidangu
4	Well -4 (W-4)	Tholur
5	Well -5 (W-5)	Adat
6	Well -6 (W-6)	Thrissur
7	Well -7 (W-7)	Elavally

According to the census data (2001), the population of State Kerala doubled over five times in the last century (6 million in 1901 to 32 million in 2001) whereas India's population could grow slightly more than three times (238 million in 1901 to 1027 million in 2001).However, the trend has changed now and the population growth range in Kerala during the last decade works out to be 9.42 percent (for the whole India it is 21.34 percent), the lowest after the formation of Kerala State. According to the census data, the number of households in Kerala has increased from 55 lakhs in 1991 to 67 lakhs in 2001.The rapid urbanization and consequent development of infrastructure have taken a heavy toll to the wetlands.

The increase in the population and households and urban expansion thus becomes major driving forces for most of the wetland issues identified. The urban expansion requires more wetland areas to be converted resulting to ecosystem changes and biodiversity loss. The recent studies from IRS P- 6 showed that there was a rapid decline in Kole lands during 8 years, the area reduced to 54.39 sq.km. (Fig.4). In Adatt panchayat, a number of commercial and residential building works are done .A leading company Sobha developers reclaimed 55acres of Kole land for their building projects. Reclamation for various developmental activities is still going on in these areas. The change in the distribution of Kole land area from 1969 to 2009 is illustrated in Fig.5 &Table 2. From the analysis it is inferred that Kole land area shrinked by 10 percent within a period of 32 years (1969-2001).However the decline is much faster in the last 7 years (2001-2008) (Fig.5) than the previous three decades. The study conducted by U.S. Fish and Wildlife Service (USFWS) describes the process with the objective of using GIS to identify geographically discrete areas where significant wetland changes are taking place and data indicate that this usually occurs in areas where rapid land use changes are ongoing, either because of population changes, agricultural or silvicultural practices, or changes in land values. (Richard D.Young et.al, 1994).

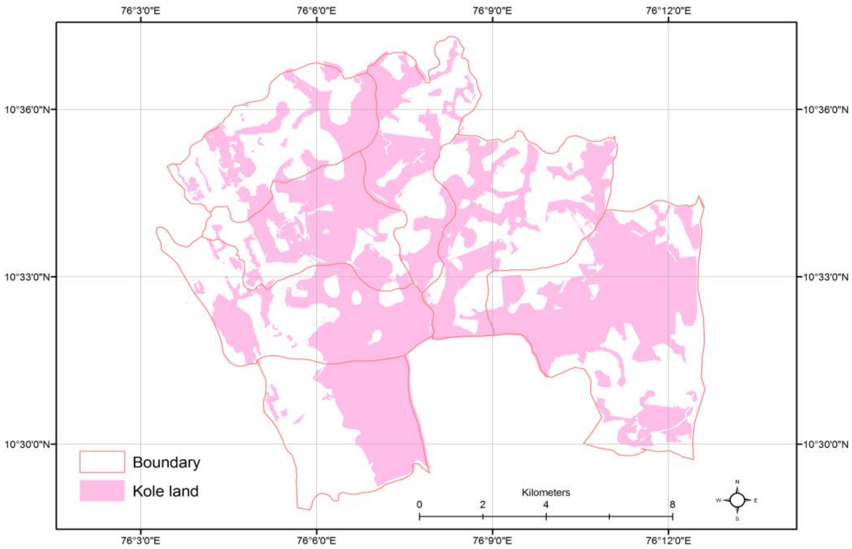

Fig 2: Kole land distribution in 1969

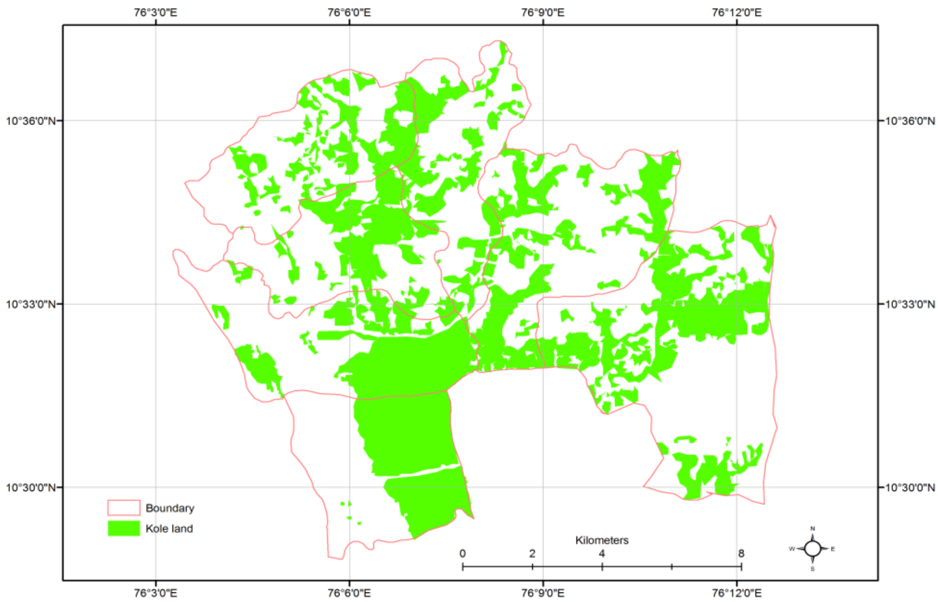

Fig 3: Kol land distribution in 2001

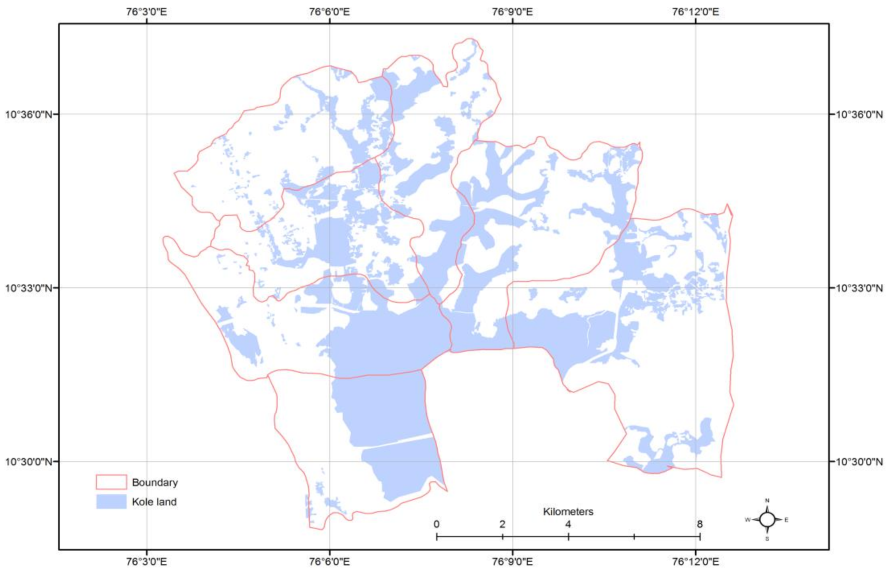

Fig 4: Latest distribution of Kole land as revealed from IRS P-6 2008

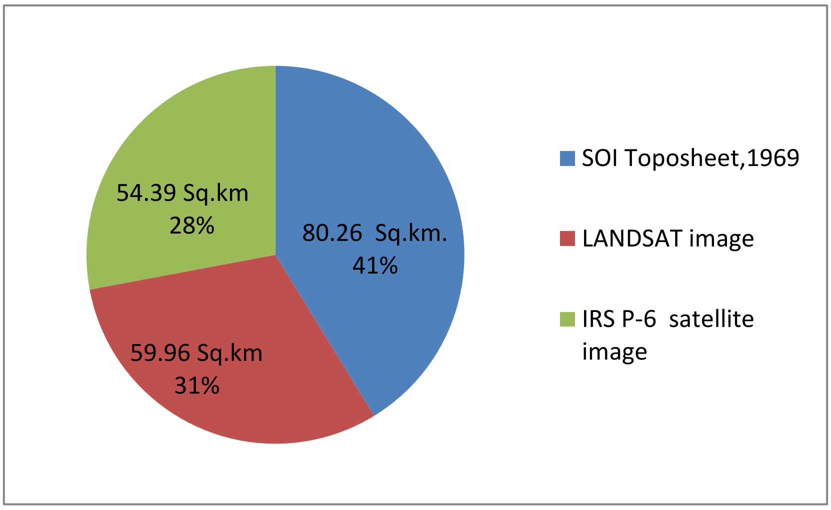

Fig 5: Change in Kole land area in different periods

Water quality characteristics with special reference to salinity:

The range and average values of various physicochemical parameters of the seven ground water samples as shown in Table 3&4. The physical and chemical water quality during the months of June 2008, April 2008 and November 2007 as shown in Table 5 and 6. From the analysis it was shown that pH of the water sample ranges from 6.20 (Well-5) to 7.8 (Well-1). According to BIS the desirable pH in drinking water is about 6.5-8.5. Average pH value of Well-5 is below the minimum value prescribed by BIS for drinking water. Samples showed both alkaline (Well-1, 2 and3) and acidic in nature (Well-4, 5, 6&7). pH showing slight decrease in July (monsoons) to April (pre monsoon).

Turbidity ranges from 0.34 (Well-7) to 10.66 (Well-1). According to BIS (1991) the desirable limits of turbidity is 5 NTU.Turbidity in Well-1 higher than limit prescribed by BIS. This well is located nearby site of the Enamavu Kayal in the north part of kole land area. Influence of Enamavu kayal affect the quality of wells which is the inlet of Chettuva Estuary.

Electrical conductivity value ranges from 50µmhoscm^{-1} (W-7) to 400 µ mhoscm^{-1} (W-1) .It has been suggested that the irrigation of water having conductivity lower than 250 µ mhos/cm does not contain enough salt to cause trouble. (Singh,1995). Conductivity more than 500 µ mhos/cm is not suitable for drinking purpose (Sharma B.K, 2007).The presence of salts and contamination with waste waters increase the conductivity of water (Trivedi and Goel, 1982). The well samples 1, 2 and 3 showing the high levels of conductivity value. The usually flooded areas of the Thrissur Kole suffered from salinity intrusion through the inlets at Chetwai and Kottappuram. (CED, 2007). These well sites are located on the inlets of chettuva estuary. Conductivity was maximum showed in the premonsoon period of April and minimum values showed in monsoon periods. From the present study it showed that conductivity value increased from monsoon to pre monsoon season. The inlets from chettuva estuary cause salinity intrusion in Thrissur Kole land are prone in pre monsoon season (Ahammed Ali K.*et al*, 1987). TDS content is usually the main factor, which limits or determines the use of groundwater for any purpose (Nordstrom, 1987). Since EC is directly related to TDS, the locations showing high contents of EC support higher TDS (N. Kannan, and Sabu Joseph, 2009).The TDS values ranges between 35 mgl^{-1}(Well-7) to 280 mgl^{-1}(Well-1).Average values of well waters shows within the permissible limit prescribed by BIS (500 mgl^{-1}).Salinity of the sample ranges from 0.05 (Well-4) to 0.2(Well-1). Salinity increases from monsoon (July) to premonsoon season (April). This is due to the saline water inflow in to inlet of chettuva estuary during peak summer season.When the dry summer month's advance, salt swings back to the surface soil again by capillary rise. The trapped salts will vertically oscillate between the perched ground water lens and the soil horizons for many years before being completely removed (Alex P M, 2005).

The hardness values of water samples ranges from 24.7 mgl^{-1} to 159 mgl^{-1} which is below the permissible limit prescribed by BIS (1992). According to BIS the permissible limit of hardness in the drinking water is 300 mgl^{-1}. High concentration of total hardness in water may cause kidney stone heart disease in human (Jain, 1996). The chlorides varied widely from 24.5 (Well-4) to 119.8 mgl^{-1} (Well-1) with a minimum average value of 25.9 mgl^{-1} and maximum average value of 78.67 were found below the acceptable limit of BIS. Naturally, chloride occurs in all types of waters. The contribution of chloride in the groundwater is due to minerals like apatite, mica, and hornblende and also from the liquid inclusions of igneous rocks (Das and Malik, 1988). The chloride values showed significant seasonal variation (well1, 2&3) and in the month of April showed higher values possibly due to leaching of salts adsorbed to the sand grains. Conductivity is related to chloride all months in well sample. Chloride values are comparatively low in well- 4, 5, 6&7. Significant variations are not showing in these samples. There is less possibility of high chloride value (W-1, 2&3) due to mineralogical origin. Salinity intrusion is the main factor of significant seasonal variation in well-1, 2&3.

Table 3: The range and average values of physico-chemical parameters of four well waters samples

Parameters	Well-1		Well-2		Well-3		Well-4	
	Range	Average	Range	Average	Range	Average	Range	Average
pH	7.70-7.80	7.74	7.21-7.67	7.48	7.20-7.37	7.29	6.45-6.95	6.64
Turbidity (NTU)	1.75-10.66	4.76	1.41-2.34	1.88	1.21-5.33	2.52	1.99-6.10	3.82
Conductivity ($\mu mhoscm^{-1}$)	134-400	241.9	66-155	112.2	97-210	147.3	42-59	52.3
TDS (mgl^{-1})	93.8-280	169.3	46.2-108.5	78.54	67.9-147	103.11	29.4-41.3	36.61
TH (mgl^{-1})	84.5-159	107.08	45.3-90.7	59.71	45.3-90.9	60.1	31.6-34.5	33.01
Chloride (mgl^{-1})	64.9-119.8	78.67	53.4-60.1	56.72	54-87.9	63.82	24.5-27.1	25.9
Salinity (ppt)	0.11-0.20	0.13	0.09-0.10	0.09	0.09-0.15	0.11	0.04-0.05	0.04

TH-Total Hardness TDS-Total Dissolved Solids

Table 4: The range and average values of Physico-chemical parameters of three well waters samples

Parameters	Well-5		Well-6		Well-7	
	Range	Average	Range	Average	Range	Average
pH	6.20-6.50	6.33	6.51-6.80	6.7	6.69-6.81	6.75
Turbidity (NTU)	1.50-2.10	1.84	1.10-1.64	1.31	0.34-1.67	1.01
Conductivity ($\mu mhoscm^{-1}$)	53-81	65.3	64-69	67.7	50-60	57.2
TDS (mgl^{-1})	37.1-56.7	45.71	44.8-48.3	47.36	35-42	40.04
Total Hardness (mgl^{-1})	25.5-29.2	27.09	24.7-27.4	26.81	34.5-36.9	35.59
Chloride (mgl^{-1})	42.4-45	43.68	33.3-35	34.14	31.2-36.9	33.88
Salinity (ppt)	0.07-0.074	0.072	0.05-0.058	0.056	0.05-0.06	0.056

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Table 5: Showing the physical and chemical water quality during peak monsoon, post monsoon and pre monsoon seasons (July, November, April)

Sample	Water quality Parameters											
	pH			Turbidity (NTU)			Conductivity (μ mhos cm^{-1})			Total Dissolved Solids (mgl^{-1})		
	July	November	April	July	November	April	July	November	April	July	November	April
W -1	7.8	7.72	7.7	1.8	3.44	10.66	134	154	400	93.8	107.8	280
W -2	7.7	7.63	7.25	1.5	1.77	2.34	88	90	155	61.6	63	108.5
W -3	7.3	7.31	7.2	1.5	1.65	5.33	97	122	210	67.9	85.4	147
W -4	7	6.7	6.51	2	2.95	5.99	45	51	59	31.5	35.7	41.3
W -5	6.5	6.36	6.2	1.5	1.82	1.99	55	66	81	38.5	46.2	56.7
W -6	6.8	6.8	6.6	1.1	1.25	1.57	65	64	68	45.5	44.8	47.6
W -7	6.8	6.71	6.69	0.6	1.23	1.56	50	59	59	35	41.3	41.3

Table 6: Showing the chemical water quality during peak monsoon, post monsoon and pre monsoon seasons (July, November, Apr

Sample	Water quality Parameters								
	Total hardness (mgl^{-1})			Chloride (mgl^{-1})			Salinity (ppt)		
	July	November	April	July	November	April	July	November	April
W -1	85	87.7	159	65	67.8	119.8	0.11	0.11	0.2
W -2	46	47.9	90.7	56	56.4	59.9	0.09	0.09	0.1
W -3	45	46.1	90.9	55	59.8	87.9	0.09	0.1	0.15
W -4	32	32.3	34.2	25	26.5	27.1	0.04	0.04	0.05
W -5	26	26.9	29.2	42	43.9	45	0.07	0.07	0.07
W -6	25	27.2	27.4	33	34.1	35	0.06	0.06	0.06
W -7	35	35.7	36.9	31	32.4	36.9	0.05	0.05	0.06

5. CONCLUSION

The Kole land area drastically decreased in a faster rate. The study carried out reveal that Kole land area shrinked from 41% to 28% during the period 1969-2008. Population pressure and urbanization have disturbed the desirable land use system of the area. The indiscriminate reclamation of wetlands, especially paddy fields, and their conversion for non-agricultural purposes, reduced the food crop production and degraded the ecosystem balance. In order to overcome the deteriorating scenario, agricultural intervention has to be planned considering the resource potential, its sustainability and environmental aspects, especially the aspects of land capability and suitability. Most of the government sponsored projects especially in urban areas are finding space for which large scale reclamation is going on. The unscientific land use and agricultural practices along with the forest clearing in uplands and in wetland areas exerts major pressure on wetlands leading to soil erosion. This causes siltation leading to vertical shrinkage and related problems like salinity intrusion, ecosystem change and biodiversity loss. The paramount consideration however, is the methodology described relies on the availability of timely, nationally-based GIS information to provide a cost effective approach to assessing areas of rapid wetland change The present study gives us sufficient data to confirm that the extent of salinity is confined in an area of inlet of Chettuva estuary. The wells in this zone become prone to saline on the pre monsoon period of April. Three well sample (W-1, W-2&W-3) showing significant seasonal variation in the water quality. Well water in all other areas remains within the permissible limits of drinking water standards. Immediate measures needed for the protection of Kole wetland to maintain the ecological balance.

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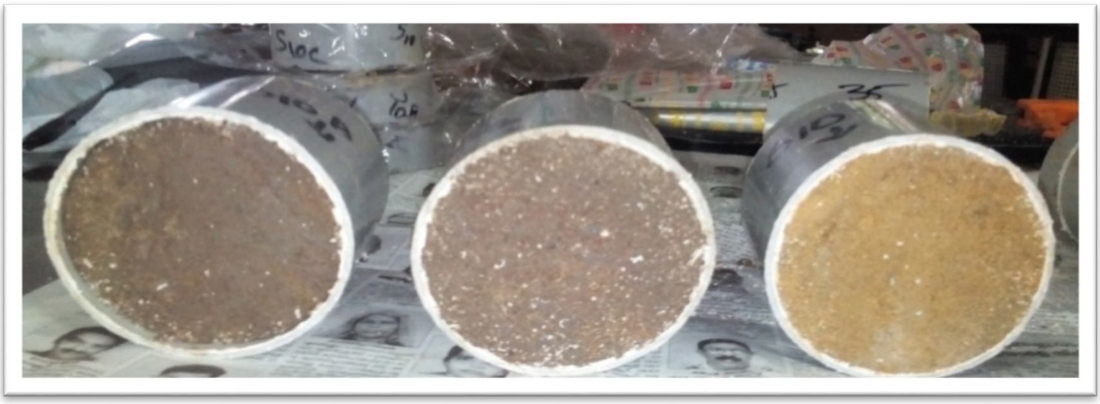

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