DYNAMICS OF BIOCENOSIS AND ITS SPATIO-TEMPORAL VARIABILITY IN MARANCHERY KOLE WETLAND, KERALA

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DYNAMICS OF BIOCENOSIS AND ITS SPATIO-TEMPORAL VARIABILITY IN MARANCHERY KOLE WETLAND, KERALA

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Environmental Studies

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Certificate

This is to certify that the thesis entitled **"Dynamics of biocenosis and its spatio-temporal variability in Maranchery Kole wetland, Kerala"** is an authentic record of research work carried out by Mrs. Rakhi Gopalan K. P (Reg. No. 4067), under my scientific supervision and guidance in the Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, in partial fulfilment of the requirements for the Degree of Doctor of Philosophy under the faculty of Environmental Studies and that no part of this has been presented before for the award of any other degree, diploma or associateship in any university.

It is also certified that all the relevant corrections and modifications suggested by the audience during the pre-synopsis seminar and recommended by the doctoral committee has been incorporated in the thesis.

Kochi
December 2017

Supervising Guide
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Declaration

I hereby declare that the thesis entitled "Dynamics of biocenosis and its spatio-temporal variability in Maranchery Kole wetland, Kerala" submitted by me is an authentic record of research work carried out under the supervision and guidance of Prof. (Dr.) S. Bijoy Nandan, Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology, in partial fulfillment of the requirement for the Degree of Doctor of Philosophy under the faculty of Environmental Studies and that no part thereof has been presented for the award of any other degree in any university.

Kochi

December 2017 **Rakhi Gopalan. K. P**

Dedicated for all those who encouraged me

to fly towards my dreams....

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ABBREVIATIONS

Km – Kilometer
ha – Hectares
m – Meters
Cm – Centimeters
mm – millimeters
Km^2 – Square kilometre
µ mol – Micro mol
ppm – Parts per million
ppt – Parts per thousand
gm – gram
mg – Milligram
µm – Micrometer
mm – Millimeter
L – Litres
ml – Milliliter
wt – Weight
°C – Degree Celsius
C – Carbon
% – Percentage
< – Less than
> – Greater than
m^2 – Square meter
m^3 – Cubic meters
No. – Number
Vis-à-vis – in relation to
N – North
KCl – Potassium Chloride

$MgCO_3$ – Magnesium Carbonate
E – East
v6 – Version 6
SD – Standard Deviation
TDS – Total Dissolved Solids
No. – Number
N – North
E – East
v6 – Version 6
SD – Standard Deviation
Ca. – Calcium
Mg. – Magnesium
DO – Dissolved Oxygen
BOD – Biological Oxygen Demand
GPP – Gross Primary Productivity
NPP – Net Primary Productivity
FFG – Functional Feeding Group
Chl. – Chlorophyll
Sp. – Species
Fig. – Figure
FAO – Food and Agricultural Organisation
ANOVA – Analysis of variance
et al. – And others
Min – Minimum
Max – Maximum

Chapter - 1

INTRODUCTION

1.1 Origin and evolution of concept

The term ecology is derived from two Greek words, *oikos* meaning 'home' and *logos* meaning 'study of' (Odum, 1971). The first principle of ecology is that each living organism has an ongoing and continual relationship with every other element that makes up its environment, since all organisms have their own specific surroundings (Hannan and Freeman, 1977). The emergence of ecology as a distinct field of knowledge dates back to the 19th century. Developmental activities aimed at the welfare of humans and their living partners, namely microbes, plants and animals, have had a certain measure of impacts on the ecological balance (Joseph and Nagendran, 2004). In the last few decades concerted efforts are being made in the field of science, engineering and technology to restore the balance. Thus, ecology is being recognized as an interface between environment and technology. The scope of ecology, thus appears to be an ever increasing feature in our understanding of the environmental structure and functions. The ecosystem is a structural and functional unit of ecology (Frankel and Soule, 1981).

Ecosystems have well defined sub structures and boundaries, which act as a medium and platform for various processes required to maintain a state of equilibrium. The ecosystem is defined as complex living organisms, their physical environment, and all their interrelationships in a particular unit of space. The ecosystem is composed of two entities, the biocenosis the entirety of life and the medium that life exists in the biotope. Biocenosis (alternatively, biocoenose or biocenose) termed by Karl Mobius in 1877, describes all the interacting organisms living together in a specific habitat (or biotope). Biotic community, biological community, and ecological community are more common synonyms of biocenosis. He was requested by managers to examine an Oyster bank by fisheries managers, but failed to rise to the expectations. Stating that the Oyster bank was a “ Bioco ¨ nose”, or a “social community”, he founded the basis of Ecology. He defined the biocenosis as a complex “superorganism” where animals and plants live together in an interdependent biological community. Biotic community, biological community and ecological community are common synonyms of biocenosis (Keller and Golley, 2000). Two decades later, Dahl, (1908) a colleague of Mobius, coined the new term ‘biotope’ to define complex of factors, which determines physical conditions and existence of a biocenosis. The biotope was related to biocenosis as ‘the biotope of a biocenosis’ (Troll, 1971). Followers introduced complementary notions describing the physical conditions and groups of plants and animals living there and finally suggested that the ecosystem was made up from the biotope (the abiotic environment) and the biocenosis (the biotic communities): ‘Biotope + Biocenosis = Ecosystem’(Ramade, 1978). Dajoz (1971) defines biocenosis as a group of living organisms with a definite spatial distribution dependent on external environmental factors and the interrelationship among species. Every biotope (desert, river, wetlands, isolated lakes, forest soils, etc) has a definite biocenosis. The living creatures of a biotope are in a definite inter-relationship with each other. The importance of concept of the biocenosis in ecology is its emphasis on the interrelationships among species living in a geographical area. These interactions are as important as the physical factors to which each species are adapted and responding. In a very real sense, a specific biological community or biocenosis which is adapted to conditions, prevails in a given place. The occurrence of several rare plant- animal species is connected with a definite biotope and its biocenosis.

How can macrophytes influence invertebrate communities? This question doesn’t leave simple answer. Probably this influence can act in several manners: vegetation has a positive effect on invertebrates because it brings refuge and food for detritivores, herbivores and indirectly deposit feeders. Different invertebrates use the structural components of their habitat selectively (Difonzo and Campbell, 1988). On the other hand, vegetation gives refuge for predators (mainly fish) and they can change the diversity, density, and size spectra of invertebrates near the plants (Brooks and Dodson, 1965; Pinel-Alloul et al., 1988). It is clear that these effects are associated to the plant’s architecture, so they should be “species-specific”. (De Neiff, 1983; De Szalay and Resh, 2000). Figure 1.1 shows a conceptual model for these relations (Momo et al., 2006).

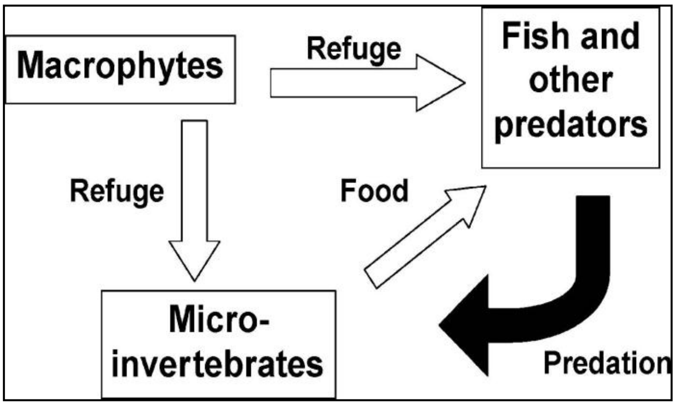

Fig.1.1. Conceptual model summarizing the relatinship between macrophyte and invertebrate communities. White arrows represent positive effects, black arrow represents a negative effect.

In a biotope two kind of ecosystems exist. They are natural ecosystems and artificial ecosystems. Natural ecosystems are self regulatory in nature and are solar driven. Wetlands, forests, grass lands, lakes, ponds, estuaries are natural ecosystems. Artificial ecosystems, also referred as human engineered, are not self regulated but depend on human interventions to meet their energy requirements. Examples include, agricultural fields, different plantations, etc (Geissen and Guzman, 2006).

1.2 Wetland ecosystem

Wetlands are one of the major ecosystems and different communities of organisms are living in it. Wetland is an ecosystem that arises when inundation by water produces soil dominated by anaerobic processes, which in turn, forces the biota, particularly rooted plants, to adapt to flooding (Keddy, 2010). Wetlands were considered as marginal waterlogged lands, harboring disease, hazardous and also the source of immense human distress. This kind of misunderstandings over their ecology and functioning leads to the notion that wetlands are hazardous wastelands. But the local inhabitants who live in the vicinity of wetlands often support and understand wetlands as a resource and depends on them in various ways. Moreover now a days wetlands are attractive centre for many tourists (Wade and Lopez-Gunn, 1999). Floodplains of rivers and vicinities of wetlands are considered as the cradle of human civilisation. However we treat them with indifference rather than with care.

In the last few decades the role and values of the wetlands are recognized as they support a wide range of functions that are essential for plant, animal and human life and also for maintaining the quality of the environment. Rich resources of fauna and flora, and its genetic diversity constitute an important genepool for potential exploitation and management (Pani and Mishra, 2000). In ecological sense, values of a wetland are mainly related to primary production in providing food energy that drives the ecosystem (Mitsch and Wilson, 1996). The direct and indirect benefits from a wetland are high productivity; reservoirs for water coloumn, controls flood; prevent soil erosion; water purification and nutrient recycling; aquifer recharge; aesthetic, cultural and recreational value, protects shore line (Vymazal,1995) besides providing high biological diversity especially waterfowl habitat (Sherman et al., 1996). In a long term scale, wetlands, the swampy environment of the carboniferous period produced and preserved many of the fossil fuels, which we depend on now. Considering the ecological values and benefits of wetlands, international scientific review boards and political leaders have promoted these benefits and called for their protection. 'Ramsar convention in 1971 and Rio summit in 1992 were the milestones in the history of conservation of the wetlands (Denny, 1994). This has resulted in re-designating some of the wetlands as 'Wetlands of International Importance', 'hemispheric reserves for shore birds' or 'conservation wetlands' (Wigham, 1999). According to Ramsar Convention, (1971) wetlands are defined as "Areas of marshes, pens, peat lands of water whether natural or artificial, permanent or temporary with water which is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed six meteres" (Matthews, 1993). Cowardin et al. (1979) modified the definition and according to him "wetlands are lands of transition between terrestrial and aquatic system where the water table is usually at or near the surface of the land or the land is covered by shallow water. Wetlands must have one or more attributes i) the land supports predominantly macrophytes periodically; ii) the subsurface is predominantly undrained hydric soil; and iii) the substrate is non soil and saturated with water at some time during the growing season of each year''. Realising the international importance of wetlands and need for conservation, a significant step was taken towards this by India through ratification of Ramsar Convention. Ministry of Environment and Forests, Government of India initiated the following conservation measures, management action plan, research, public awareness, policy formulation and legal implementation. A national committee was constituted in the 7th five year plan and the first meeting was held on 2nd April 1987. The expert committee recognized ten wetlands as areas of conservation and for the preparation of management action plan. In this category wetlands are broadly divided into inland wetlands and coastal wetlands and each class is further divided into several other classes. The National Wetland Inventory and Assessment published recently by the Ministry of Environment, Forest and Climate Change (MoEFCC), Govt. of India (www. envfor.nic.in/essential-links/national-wetlands-inventory-assessment) estimates that 10.56 million hectares of inland wetlands and 7.6 million hectares of coastal wetlands exist in India, further inland wetlands comprising of 6.62 million hectares of natural wetlands and 3.94 million hectares of manmade wetlands. The total area of Indian wetlands is only 0.03% of the geographical extent of the country (Chandra et al., 2017). The topography, climate and rainfall pattern of Kerala is very conducive for the development of natural wetlands. The 43 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 (Joseph, 2016). Ramsar convention on 19th of August, 2002, classified wetlands of Kerala into major three wetland ecosystems the Vembanad–Kole, Ashtamudi and Sasthamkotta wetlands (Nair and Sankar, 2002).

In Kerala, wetland area estimated is 1,60,590 ha and mainly divided into five major systems, the marine, estuarine, riverine, lecustrine and palustrine which include marshy and water logged areas and vast paddy cultivating areas (*Padasekharam*) associated with backwaters and lakes and swamps in the Western Ghat forests (Center for Environment and

Development, 2003; Abraham, 2015). The Vembanad wetland system lie in the humid tropical region between 09°00’ -10°40’N and 76°00’-77°30’E. It is unique in terms of physiography, geology, climate, hydrology, land use and flora and fauna (Bijoy Nandan, 2008). The rivers are generally short, steep, fast flowing and monsoon fed. The Vembanad wetland system includes the Vembanad backwater, the deltaic lower reaches of the rivers draining into it and the adjoining Kole lands (National wetland conservation and management programme, MoEF, 2008) (Bassi et al., 2014).

The Kole land, is a unique wetland ecosystem having multiple uses down south of India and they are often located between dry terrestrial systems and permanent deep water systems like rivers and deep lakes. It is a part of Vembanad-Kole wetland system spread across 151250 ha, which is the major fresh water wetland system in India and included as Ramsar site in 2002. It is believed that Kole lands along with the Vembanad estuarine areas have been formed by an upheaval of the shoreline subsequent to the regression and transgression of the coastal waters in the past (Anonymous, 1997). The Kole land area is a submerged plain land having rich alluvium deposits. Kole rice fields are low lying tracts located at 0.5 to 1 m below mean sea level extending to an area of 13632 ha, spread over Thrissur and Malappuram districts of Kerala (Srinivasan, 2012). The name “Kole” is a Malayalam word referring to bumper yield (a typical high yielding type of paddy farming carried out in the flooded wetland for about six months in a year). In the remaining six months Kole lands remain submerged under flooded condition. Due to the prominent seasonal variations it has both terrestrial and water related properties which determine the structure and functions of ecosystem which in turn give rise to various provisioning services. The traditional rice cultivation is practiced in these low lying wetlands by erecting earthen bunds (levees) and pumping out the water (Jyothi and Suresh Kumar, 2014). Average productivity of rice in the State was less compared to Kole lands, which gives four to five tonnes of rice per hectare. Kole wetlands have been recognized worldwide as important biographic zones and the Vembanad-Kole complex is the second largest wetlands in the country after Chilka lake in Orissa in terms of the number of birds depend on it (Sivaperuman, 2004).

Kole lands show hydrological fluxes (< 1 year hydroperiod) seasonally and it is considered as natural grouping of water. There is a fluctuation in animal population due to differences in seasons and fluctuation in the height of water. Beetles, bugs, spiders, frogs and other small animals are found on the surface of floating vegetation in the water. Emergent vegetation shows mainly water birds using it as launch pad. Bottom animals are few at the time of flooded condition but in paddy cultivation period so many insects, snails and other invertebrates are present. Kole wetland contains low oxygen concentration and large amount of organic matter (Vineetha et al., 2015). There is lack of water circulation in summer period. During summer period decay is inhibited by accumulation of decomposed vegetation which can sometimes cause acidity and partial carbonization. These could influence the metamorphosis of some kind of insects, or migration to other ecosystems. Therefore, change in community structure and variations in trophic level are more common in these kinds of wetlands.

In a Kole wetland ecosystem, paddy fields are important as they act as a paradigm shift of biodiversity. Paddy fields are exsisting since the beginning of an organized agriculture. A rich biodiversity is associated with all paddy fields. These are generally known as man made ecosystems or artificial ecosystems. Paddy fields are vast extend of land in the humid areas, also an array of ecological habitat which encompasses different phases during a single cultivation period. Hence they became unique ecosystems. An agro ecosystem that sustains not only the people whose staple diet is rice but also a diverse assemblage of plants and animals they have made the paddy fields their niche. These agricultural fields are dynamic and rapidly changing ecosystems. Various agricultural practices on rice fields and the series of growth stages of the crop during a short time, have made the paddy fields, a heaven for vast array of plants, invertebrates and vertebrates communities. To these life forms, the paddy fields offer food, shelter, breeding and nesting grounds. The rice fields also offer temporary refuge to those animals that are not permanent inhabitants but visit this ecosystem for variety of purposes (Edirisinghe and Bambaradeniya, 2010).

Wetlands predominantly support macrophytes community which grows either submerged or floating on the surface, continuously or periodically depending on the availability of water column (Environmental Protection Agency, 2005). These plants contribute to biomass and nutrients to various trophic levels in the ecosystem by providing habitat and refuge to the aquatic communities or alteration in the abundance of individual species provide valuable information on how and why an ecosystem might be changing (Scott et al., 2002). Over exploitation and eutrophication can result in a progressive change in species composition and community change which lead to ultimate loss of species diversity (Kelly and Whitton, 1998). Macrophyte beds are favorable for the increase in plankton development and also for zooplankton abundance, they provide refuge from against fish predation. They also act as a substrate for periphytic growth, providing shelter to various aquatic fauna and serving as a breeding ground for associated fauna (Petr, 2000).

Macroinvertebrates are important members in food webs. Invertebrates that are large enough to be seen by the unaided eyes and live at least part of their life cycles within or upon available substrates in a body of water or water transport system are defined as macroinvertebrates (Benke et al., 1984). Macroinvertebrates are one of the most employed groups of organisms; they have a series of advantages as bioindicators (Platts et al., 1983). Most have limited mobility hence reflect the local characteristics of the sampled area. They generally have long life cycles and therefore their characteristics are unpredictable (Metcalfe-Smith, 1994). Many forms are important for digesting organic material and recycling nutrients. The major taxonomic groups of freshwater macroinvertebrates include insects, annelids, molluscs, flatworms and crustaceans (Wiggins et al., 1980). Among these, dominance of insects amongst all living organisms on earth, is a fundamental scientific fact and is important for the existence of human beings (Philips, 2003). Insects are integral and complex part of the terrestrial and freshwater ecosystems with which the future of humans are inextricably linked. Insects have ultimately achieved a formidable diversity. Generally, insects are beneficial organisms, however, many of them are important pests and/or vectors to a large number of parasites and other microbial pathogens to human beings and the associated plants. The presence or absence of certain families of aquatic insects indicate whether the particular water body is healthy or polluted (Foil, 1998). All over the world, due to human exploitation large areas of wetlands are being subjected to pollution problems. Concequently, changes in physico-chemical properties of water adversely affect the diversity, distribution and composition of aquatic fauna. India is one of the highest mega biodiversity countries (Mittermieier et al., 1998). Water pollution, salinity intrusion and over harvesting are threats to the wetland biodiversity of Asian countries (Dudgeon, 2000). Therefore, knowledge about biodiversity and ecological relationships of these animals is a practical necessity.

1.3 Significance of the study

The Vembanad-Kole wetland is a complex and valuable ecosystem from ecological, environmental, biodiversity and socio-economic point of view and despite the international recognition, this complex ecosystem is getting endangered in the State (Jayson and Sivaperuman, 2005). The Kole lands exhibit a distinct hydro period, which alter the biotic as well as abiotic factors of the ecosystem. It is generally known that, aquatic plants provide a physically and chemically complex habitat in aquatic ecosystems, and architectural features of this habitat can affect the species diversity, density and distribution of invertebrates (Carpenter and Lodge, 1986). Structure and abundance of macrophytes depend on different factors, of which the trophic state of the water body, the depth, light penetration and water movement are most important (Cenzato and Ganf, 2001). Aquatic insects are extremely important in ecological systems for many reasons and they are the primary bio-indicators of freshwater bodies. Considering other ecosystems, Kole lands are offering the richest vegetation during full inundation. In another six months period, the entire field was diverged to an agro ecosystem. Most studies did not explain macroinvertebrate diversity and their influence in interannual cycles and variations, complex abiotic and biotic interactions as well as biocenosis with macrophytes, and their natural and anthropogenic disturbance and recovery. Without these studies, we could know much less about the magnitude of natural temporal variations, the importance of physical and biological disturbance and interactions, the role of organisms and introduced species, the overall impact of pollution and the effectiveness of protection and remediation efforts (Jackson and Fureder, 2006). Therefore, this study is mandatory in the point of biocenosis of macrophytes and associated macroinvertebrates.

Paddy fields are classified as temporary wetlands (Lupi et al., 2010) these habitats are among the most threatened and valuable ecosystems that our earth harbours. Paddy fields are fragile ecosystems susceptible to damage, even due to a little change in the composition of biotic and abiotic factors. The paddy fields are threatened due to inadequate water management, modernization of farming activities, tillage, discharge of raw sewage and industrial effluents, dumping of solid waste, eutrophication, leached fertilizers and application of insecticides (Ramachandran et al., 2005). Macroinvertebrates play a key role in paddy field through organic matter decomposition and nutrient translocation (Daufresne et al., 2004). In paddy fields, habitat fragmentation is considered, macroinvertebrates with different migration abilities will be differentially affected by habitat isolation (Bowman et al., 2002).

The significance of the study on biodiversity of Kole lands associated with agro-ecosystems is two-fold as the maintenance of biological diversity is essential for productive agriculture, is in turn essential for maintaining biological diversity (Pimental et al., 1992). The increasing importance as well as alarming threats in wetlands also demands similar studies. Vijayan (2004) studied that in India more than 38% of wetlands were lost in last few decades. In Kerala different development activities were carried out alarmingly and reclamation of wetlands for residential plots are common scenario now a days. At many places the wetland has been converted to brick-kilns. Moreover, the indiscriminate use of pesticides has been found to affect the migrant bird population, which visits the wetlands from September to April every year (Nameer, 2003). Tomita et al. (2003) suggests that harmonizing agricultural productivity with biological diversity should be the ultimate goal of the analysis of paddy wetlands. Bambaradeniya and Amerasinghe (2004) had a documentation of the overall biodiversity associated with a wetland paddy ecosystem in Sri Lanka.

The water column variation in Kole lands leads to habitat destruction into flora and aquatic infauna or reducing the habitat. In the case of macroinvertebrates that have greater adult migration abilities can disperse more easily between habitats (Smith and Brumsickle, 1989) and are less likely to be effected by habitat isolation. The impacts of changes in hydrological regimes on each invertebrate taxa is different based on its different habitat requirements, physiological traits and life history characteristics. There were studies on macrophytes and macroinvertebrates from wetlands, paddy fields/ paddy wetlands and isolated water patches separately, but the seasonal transformations in Maranchery Kole wetland facilitated the study of the same area as different systems during different seasons, which is novel. Realising the importance of paddy wetlands and its sustainable development of the ecosystems, the Kerala State Biodiversity Board initiated a research and development programme from August 2009 to July 2011 in order to study the ecology and production potential (plankton and invertebrates) of the Maranchery Kole wetlands in Ponnani, Northern Kerala was implemented at the Department of Marine Biology, Microbiology and Biochemistry, under the Principal Investigatorship of Prof. (Dr.) S. Bijoy Nandan.

It was in this context, the pioneering work which critically examined the community structure and biocenosis, population studies, and its abundance pattern of macrophytes and its associated macro invertebrates from Maranchery Kole wetland ecosystem in relation to environmental variables.

1.4 Objectives of the study

i) Characterise the environmental and productivity status of the Kole wetland.

ii) Explore and document the composition, abundance and diversity of macrophytes.

iii) Study the distribution and abundance pattern of macro invertebrates *vis a vis* biocenosis with macrophytes

iv) Analyse the species composition and community structure of insect fauna.

v) Propose measures for rejuvenation and improving the ecology of the Kole wetland.

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Chapter - 2

REVIEW OF LITERATURE

2.1 Introduction

Several years back the term “wetland” brought to mind the common images of cattail marshes or peat bogs. Later the importance of wetlands was recognized by people and extensive studies were conducted worldwide that include general nature of wetlands, trophic status, bio-ecological features, diversity and distribution of various aquatic organisms, etc. Here an attempt is made to discuss the work on various aspects of wetlands included in the context of the present study. Maltby and Turner (1983) has documented the status of wetlands of the world and reported about 6.4% of the total land area in the world is estimated as wetland area. Smith, (1995) described that wetlands are fragile ecosystems and the water body connects half way world between terrestrial and aquatic eco systems. Wetlands provide a major role in the landscape providing unique habitats for a wide variety of flora and fauna (Bambaradeniya et al., 1998) and are essentially for hydrological and ecological processing. Cowardin et al. in (1979), describes wetlands as lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. This definition is widely used all over the world (Mitsch and Gosselink, 1993). The Asian wetland bureau (1991) re describes the wetlands as areas where a water table is at, near, or just above the surface and where soils are water-Saturated for a sufficient length of time. Another simple definition is given that the wetlands are areas where for part of the year atleast, water stands naturally from 2.5cm to around 300 cm. Wetland are all submerged or water saturated lands, natural or man-made, inland or coastal, permanent or temporary, static or dynamic, vegetated or non-vegetated, which necessary have a land-water interface by Anon, (1994). Cowardin et al., (1979) and Keddy (2000) gave classifications of wetlands. Biotic control and their significance in hydrology, especially by wetland vegetation was studied by Gosselink and James (1984). Xie et al. (2010) analysed qualitative and quantitative changes in coastal wetland associated to the effects of natural and anthropogenic factors in a part of Tianjin, China. Meng et al. (2017) reviewed status of wetlands in China, further documented degradation of wetlands.

2.2 Ecology of major wetlands

Anon (1990), Jhingran (1991) and Garg (1998) gave the status of wetlands of India. Space Applications Centre (2011) prepared the total areas of Indian wetlands based on Geographic Information System (GIS) techniques, India has about 757.06 ha wetlands with a total wetland area of 15.3 million hectares, accounting for nearly 4.7% of the total geographical area of the country, consisting 69% of inland wetlands, 27% of coastal wetlands and 4% of other wetlands (smaller than 2.25 ha.). Unfortunately wetlands are fast disappearing all over the world, and time has come to make a coordinated effort to halt this trend and to optimize the use of wetlands. The third meeting of the conference of the contracting parties of the Ramsar Convention (World Wildlife Fund, 1987) defined the wise use of wetlands and as their sustainable utilization for the benefit of human kind. Salari et al. (2014) quantified tropical wetlands using field surveys, spatial statistics and remote sensing. Similarity analysis and ecosystem services and values from a tropical coastal wetland in India was studied by Ghermandi et al. (2016). Ramesh et al. (2017) documented status, issues, challenges and involvement of community in managing coastal wetlands in South Asia.

The wetlands of Kerala has been studied by Abdul Azis (1990) who made a detailed study on certain wetland ecosystems in Kerala. The environmental degradation of Vellayani fresh water wetland in Neyyatinkara taluk, the Shasthamkotta freshwater wetland in the Kunnathur taluk and Ashtamudi estuarine wetland in the Karunagappally-Kunnathur taluks of Kerala were discussed in detail. Kurup (1996) made a survey of coastal wetlands of Kerala. Ahmed Ali (1985) examined dynamics of Chettuva - Kottapuram sound and Kuttiyadi estuary of Malabar coast. The distribution of mangroves, a complex wetland ecosystem, in Kerala had been worked out by Basha (1991). In Kerala 25.72% area of inland wetlands are man-made wetlands as reported by Nair et al. (2001). Ecology and bioresources of the wetland ecosystems on the south west coast of India was documented by Bijoy Nandan, (2008, 2008a). Sreelakshmi et al. (2016) carried out distribution of mangroves in Kerala Coast.

Water quality study forms a very significant area of environmental studies, and the physico-chemical characters of water bodies have gained worldwide acceptance. The importance of the study of ecology of water resources in our country has been realized from the early years of previous century. The various physico-chemical characteristics, the dynamics of plankton population, macrophyte diversity and relation to water quality, fishery potential and methods of improvement of wetlands formed a subject of detailed discussion by various scientists. In the early half of last century various workers studied the different aspects of wetlands (Weibe, 1930; Rice, 1938; Campbell, 1941 and Chandler, 1944). During the second half of the 20th century lot of researchers contributed valuable information about various aspects of lentic and lotic systems of different countries (Welch, 1952 (New York lake, U.S); Pennak, 1955 (Colorado mountain lakes in North America); Odum, 1957 (Silver Springs, Florida, U.S); Geldermalsen, 1985 (Oosterschelde estuary, Netherlands); Tafas and Amiliy, 1997(lake Trichonis in Central Western Greece); Kassas, 1998 (wetlands of East Countries); Olguin et al., 2000 (Reconquista river, Argentina). Sahu et al. (2014) evaluated environmental conditions of Chilika lagoon during pre and post hydrological intervention. Similarly application of multivariate analysis to determine spatial and temporal changes in water quality after a new channel construction in the Chilika lagoon was discussed by Kim et al. (2016). Bhanja et al. (2016) analysed the variation in water column in different wetland regions using data from GRACE satellite mission. Camacho et al. (2016) discussed the effects of land use changes on ecosystem services and values provided by coastal wetlands. Reddy et al. (2016) assessed the spatio-temporal changes associated with natural and anthropogenic factors in wetlands of Great Rann of Kutch, India. Chaturvedi (2017) reviewed the diversity of Indian wetlands.

Paddy fields are one of the wetland types recognized by Ramsar Convention. These are anthropogenic wetland managed for rice cultivation and experience both dry and wet conditions depending on water availability. According to Subramanya and Veeresh (1998) rice fields are not mere monoculture habitats but are in effect dynamic and heterogenous man made habitats created by varying microhabitat conditions and their succession. Flood, drought and the inter-annual variation to the number and size of ponds and small wetlands in an English lowland landscape a three years of study was conducted by Jeffries et al. (2016). There are some specific reports from the Kole wetlands/paddy fields of northern regions of Kerala (Ahmed Ali et al. 1987; Johnkutty and Venugopal, 1993 and Sujana and Sivaperuman, 2008).

The researchers have mainly focused on the two backwater systems of Kerala, one is Vembanad and other one is Cochin backwater. Most of the research on the ecology and fisheries aspects of Vembanad backwater in Kuttanad was conducted during the pre-impoundment phase before the commissioning of the Thanneermukkom barrage. Elaborate information has been generated as the physico-chemical parameters and its relation to biota of Vembanad Kole wetland as well as Cochin estuary (Devassey and Gopinathan, 1970; Wellershaus, 1971; Haridas et al., 1973; Abdul Aziz, 1974; Manikoth and Salih, 1974; Silas and Pillai, 1975; Rasalam and Sebastian 1976; Madhuprathap and Haridas, 1978; Antony and Kuttiyamma, 1983; Gopalan et al., 1983; Joseph, 1987; Thampatti and Jose, 2000; Asha et al., 2014, 2015, 2016). An account of the history of the Cochin estuary has been presented by different researchers (Qasim and Reddy, 1967; Rama Raj et al., 1979; Nixon, 1988; Sarala Devi, et al., 1991; Bijoy Nandan and Abdul

Azis, 1994; Menon et al., 2000; Renjith, 2006; John, 2009; Martin et al., 2010; Bijoy Nandan et al., 2014; Dipson et al., 2014; Thasneem, 2016).

Similarly under the Indo-Dutch collaborative research project on the water balance study of the Kuttanad Region, various aspects of the ecology and fisheries of Vembanad lake were investigated and reported (Anon., 2001). Sarala Devi et al., (1991) elaborated the coexistence of different benthic communities in the northern limb of Cochin backwaters. Devassy and Gopinathan (1970) studied the hydrobiological features of Kerala backwaters in premonsoon and monsoon months and recorded the salinity range of Vembanad wetland was ranging from 6.13 to 31.9 ppt. Some preliminary information is also available on the decline in fishery of Vembanad wetland based on the study by Padmakumar et al., (2002). Recently the biodiversity of the estuarine systems of the south west coast of India has been studied (Bijoy Nandan and Unnithan, 2003, 2004; Bijoy Nandan, 2004, 2004a, 2007, 2008, 2011; Bijoy Nandan et al., 2014, 2015).

Studies conducted at the centre for water resource development and management (CWRDM), Kozhikode (1990), was mainly on the hydrology, salinity intrusion and core water quality parameters. Abundance of zooplankton from Pookot backwaters of Kozhikode was reported by James, (2007). The Central Inland Fisheries Research Institute (CIFRI) has undertaken some preliminary seasonal studies on the water and sediment quality, distribution of plankton, benthos and fishery of selected backwaters of Kerala (Anon, 2005). The Cochin University of Science & Technology and the Department of Aquatic Biology & Fisheries, University of Kerala have also done substantial work in these lines but most of the contributions are from the Cochin backwater, Vembanad, Ponnani estuary, Sasthamkotta lake, Veli, and Kadinamkulam backwaters (Jayachandran et al; 2013; Retina et al; 2015; Bijukumar and Sushama, 2000; Bijukumar and Raghavan, 2015; Girijakumari et al., 2011).

Several research works in different lakes and wetlands were also noted. Usha Kumari et al., (1991) reporting the ecological parameters of Basman Lake, Bihar recorded the absence of any direct relation between temperature and plankton production. Kaur et al., (1997) studied the inter relation between physico- chemical parameters at Harike wetland in Punjab and pointed out that water temperature showed negative correlation with pH. Arnulf (1999) used macrophyte as tool of lake management. Among the study, nine different groups of macrophytes were recognised, including, in total, 45 different species of macrophytes. Sharma (2000) studied the tropical flood plain lake of upper Assam, and rotifers showed a qualitative dominance. Some of the recent reports in Indian water bodies are that of Goswami and Goswami (2001) studied the productivity indicators of Mori beel of Assam and reported 9 species of rotifers from one beel. Malu (2001) studied the phytoplankton diversity in Lonar lake, Maharashtra and opined that they are the bioindicators of water quality. While studying Hussain Sagar Lake in Hyderabad, Reddy et al. (2002) reported that human activities can heavily pollute a lake. Further reported phosphate rate was found high and showed inverse relation with growth of Pistia plants. Patil and Sigh (2002) conducted a complete limnological investigation of abiotic factors of Ujani wetlands of Maharashtra. Mukhopadhyay and Dewanji (2005) reported the presence of tropical hydrophytes in relation to limnological parameters and a study of two freshwater ponds in Kolkata, India. The presence of different species of hydrophytes was investigated in relation to Secchi disc visibility, pH, dissolved oxygen, electrical conductivity, total Kjeldahl nitrogen, total phosphorus and chlorophyll-*a* concentration in two tropical ponds, Kolkata. The impacts of climate change on biodiversity and ecosystems in India were studied by Sukumar et al. (2016). Goswamy et al. (2017) noticed the variation of major nutrients in the aquatic phase of East Kolkata wetlands. Namgail et al. (2017) noted the migratory ducks in protected wetlands in India. Singh et al. (2017) reported the limnological status and productivity pattern of wetlands in West Bengal.

2.3 Primary production

Primary productivity of wetlands have been estimated through different studies. Moyle, (1949) evaluated the production pattern of lake Minnesota, U.S; Rohde et al. (1966) reported productivity of pelagic ponds in Sweden; Williams and Murdoch, (1966) examined phytoplankton production and chlorophyll concentration in the Beaufort Channel, North Carolina, U.S; Qasim and Madhupratap, (1979) noticed productivity pattern of Cochin estuary, Kerala; Zutsh et al., (1980) observed primary productivity of lakes in Jammu and Kashmir, Himalayas; Girijakumari, (2007) studied production potential of Sasthamkotta lake, Kerala; Meera and Bijoy Nandan, (2010) reported primary productivity of Valanthakkad backwater, Kerala; Radhika, (2013) examined productivity and trophic structure interactions in Cochin backwaters, Kerala; Bijoy Nandan, (2016) conducted detailed investigation on production pattern of coastal wetland ecosystems of Kerala. Cloern et al. (2014) gave a detailed examination on the phytoplankton primary production in the world's estuarine-coastal ecosystems. In India, studies were reported by Sreenivasan (1963) and Hussainy (1967) in certain reservoirs and Karunakaran et al. (1971) in shallow ponds studied the primary production. Qasim, (1970) reported that, in aquatic food chains or tropho dynamics, estimation of the standing crop of plankton becomes mandatory and chlorophyll indicates the total plant material available in the water at the primary stages of the food chain. Nair et al., (1975) and Pillai et al., (1975) examined water quality and variation in productivity in Vembanad lake. Gopinathan et al., (1984) studied productivity pattern in Cochin estuary. In Ashtamudi estuary high productivity was reported by Nair et al. (1984). Vass and Langer (1990) observed the dynamics in primary production and its effects in trophic status of Oxbow lake, Kashmir. Phytoplankton productivity of few tropical ponds are investigated by Bhaskaran et al. (1991). Gupta et al. (1992) studied primary productivity and zooplankton of a shallow pond in Rajasthan. Seasonal variation of gross and net productivity in Pampa river was studied by Thomas et al. (1976) and Koshy and Nayar (2001). Selvaraj (2000) and Selvaraj et al. (2003) inferred the gross primary production and net primary production and validated the light and dark bottle oxygen technique in tropical inshore waters.

Gowda et al. (2002) measured spatial and temporal variations of primary productivity in relation to chlorophyll *a* and phytoplankton have been studied in Gurupur estuary, Mangalore. Krishnakumari and John (2003) reported the primary productivity of Mandovi-Zuari estuaries of Goa. Sobha et al. (2003) made a detailed investigation of productivity and chlorophyll pigments in Azhikode estuary. Bijoy Nandan (2004) examined primary and secondary production in Kayal ecosystems of Kerala. Prema et al. (2004) estimated the primary productivity of Rajakkamangalam Estuary of Kanyakumari district. Lakshmi Ganeshan and Ghan (2008) studied the plankton ecology and productivity of floodplain wetlands of W. Bengal. A case study of Mansi Ganga lake, UP and its trophic states was conducted by Sharma et al. (2010). Chaudhuri et al. (2012) explored the estuarine metabolism in the Sundarbans of West Bengal. Sooria et al. (2015)

described the planktonic communities and food web in the Cochin estuary. Sahoo et al. (2017) discussed the effect of physico-chemical regimes and tropical cyclones on seasonal distribution of chlorophyll-*a* in the Chilika lagoon ecosystems. Extensive reports were made based on productivity and water quality of Sasthamkotta lake by Thomas et al. (1980) and Prakasarn and Joseph (1989). Sareena (1998) observed the primary production and its seasonal variations in Vellayani lake and Mathew Koshy (2001) reported production potential in Pampa river. Productivity pattern of Paravur canal and Azhikode estuary was studied by Sobha et al. (2003). Jayachandran et al. (2012) conducted a detailed investigation on production pattern of Kodungallur-Azhikode estuary. Thasneem (2016) reported the trophic status and production potential of Cochin estuary.

2.4 Aquatic macrophytes

According to Wiegleb (1988) the wetland flora are vitally important for many reasons: Wetland plants are at the base of the food chain and as such, are a major conduit for energy flow in the system. Through the photosynthetic process, wetland plants link the inorganic environment with the biotic one. Cronk and Mitsch (1994) examined periphyton productivity in constructed freshwater wetlands under different hydrologic regimes. The primary productivity of wetland plant communities varies, but some herbaceous wetlands have extremely high levels of productivity (Grace, 1999). The composition of the plant community has highly influenced the diversity of macroinvertebrates. Different studies correlated with the above aspects Wetzel, (1983) and Wiely et al. (1984) observed macrophytes and its relation with pisces. Wetzel, (1985) correlated periphyton and macroinvertebrates. Carpenter and Lodge (1986) and Van der velde, (1987) they examined macrophyte and its relationship with minor crustaceans. The changes in the community composition or alterations in the abundance of individual species of macrophytes provide valuable information on the causes and direction of ecosystem transformation. Macrophytes strongly influence water chemistry, acting as both nutrient sinks through uptake, and as nutrient pumps, moving compounds from the sediment to the water column. Their ability to improve water quality through the uptake of nutrients, metals, and other contaminants is well documented by Gersberg et al. (1986); Reddy et al. (1989); Peverly et al. (1995); Rai et al. (1995); Tanner et al. (1995, 1995a). Submerged plants also release oxygen to the water that is then available for respiration by other organisms and this kind of plants give shelter to different epiphytes (Cattaneo and Kalff, 1980 and Wetzel, 1990).

Wetland communities are highly productive, as they enjoy favourable conditions of both aquatic (abundant water) and terrestrial (light and nutrients) habitats. A wide variety of macrophytes occur naturally in wetland environments. Brylinsky and Mann (1973) analysed the factors governing macrophyte based productivity in lakes and reservoirs. Litter and Murray, (1977) studied the seasonal aspects of macrophyte productivity. Godfrey and Woolen (1981) listed the wetland macrophytes in their taxonomy of the South Eastern United States. Schubauer and Hopkinson (1984) studied seasonal patterns of above ground plant biomass and the depth distribution of live roots, rhizomes, and dead belowground organic matter were measured for *Spartina alterniflora* and *Spartina cynosuroides* in Georgia tidal marshes. Litter et al. (1987) studied the dominant macrophyte standing crop, productivity and community structure on a Beliz barrier reaf, Australia, that describes the productivity of dominant plants and zonation pattern. Canfield and Hoyer, (1992) reported emergent and floating macrophytes seldom grow in depth exceeding 3 m. Distribution and dynamics of submerged vegetation in a shallow eutrophic lake was done by Scheffer et al. (1992). The nature of hydrophytes and their different uses was described by Kadlec and Knight (1996). They tried to classify hydrophytes into various types like floating, submerged, suspended, amphibious, emergent etc. According to Scheffer et al. (1992) hydrophytes provides refuge for filter-feeding zooplankton. Effects of emergent macrophytes on dissolved oxygen dynamics in a prairie pothole wetland in central Iowa, Midwestern United States was studied by Charles and Crumpton, (1996). Villar et al. (1996) studied the macrophyte primary production and nutrient concentration in floodplain marsh of lower Parana river, Central South America, and opined that flood plain marshes are nitrate sinks due to denitrification losses and macrophyte uptake. Virginie and Mitsch (1999) study represents the net productivity of macrophytes in different seasons and determined the limited harvesting of plants to estimate the productivity of the system was possible without affecting the general succession and productivity of the overall system. Penha et al. (1999) assessed productivity of the aquatic macrophyte *Pontederia lanceolata* on floodplains of the Pantanal Mato-grossense, Brazil. Effects of macrophyte species richness on wetland ecosystem was monitored by Katharena et al. (2001). Reuben and Mwende, (2001) study was carried out to determine the distribution, zonation and succession patterns of macrophytes in lake Victoria, Africa.

Growth of macrophytes is affected by a variety of biotic and abiotic factors including light availability, water depth, nutrient availability and sediment composition (Spence 1967; Canfield et al. 1983; Kalff, 2002). Random above ground biomass samples of submerged vascular macrophytes were collected from lake Okeechobee, Florida, U.S, and documented the relative effects of selected biotic and abiotic factors on temporal variation in abundance and community composition in three macrophyte communities (Margaret et al., 2003). Schallenberg and Waite (2004) survey of aquatic macrophytes in lake Waihola, New Zealand, reported higher percentage of macrophytes that contributed to the clear water and decreasing macrophyte percentage by both wave action and re-suspension of sediments, and by increasing both competition with algae for nutrients and habitat complexity. Rodrigo (2006) analysed the structure of the microbial plankton community and opined that light deficiency influenced the floating macrophytes community. Thenya, (2006) analysed macrophyte biomass, productivity, utilization and its impact on various eco-types of Yala Swamp, lake Victoria basin, Kenya. Rejmankova and Sirova (2007) explained how changes in nutrient content along a salinity gradient affect activities of extracellular enzymes involved in macrophyte decomposition. The experiment was set up in long-term control and nutrient addition plots (P, N, and NP) established in herbaceous wetlands of Northern Belize, Central America. Deegan et al. (2007) examined the influence of the amplitude of water level fluctuations and elevation on the gas space anatomy and potential for convective flow in the emergent macrophytes. Pott et al. (2011) studied the *Typha domingensis* and *Phragmites australis* diversity of the Pantanal wetland of Brazil and commented on problems of conservation and observed that *Panicum elephantipes* is one of the few natives to compete with the invasive species *Urochloa arrecta*. Three habitat zones could be identified based on patterns in vegetation and dissolved oxygen: a zone of dense emergent macrophytes providing significant submerged structure but with nearly or completely anoxic water, a transition zone of sparse emergent macrophytes providing less structure but with more aerobic water, and an open water zone with consistently aerobic water but with little submerged structure. Ghosh (2010) studied the metal accumulation capacity of macrophytes. Rolon et al. (2010) in their study gathers the dynamic of aquatic macrophyte community in natural and managed wetlands of Southern Brazil. Approximately 250 species of aquatic macrophytes in the wetlands were identified and also encountered the habitat diversity, altitude and hydroperiod that were determinant for macrophyte richness. Atkinson, (2010), studied the primary productivity of wetlands in Southwestern Virginia. Peak above-ground biomass noticed in facultative wetland community compared to obligate wetland community. Identification of aquatic macrophytes and determination of water quality parameters of the river Benue, South Africa, and its floodplain in Makurdi, Nigeria was carried by Okayi et al. (2011). Feldmann (2012) gives the details of aquatic macrophytes and their structuring role of lake. Further explained, various passive aspects of macrophytes in lakes, and how they are related to the plant architecture, species composition and distribution in lakes are shaped by environmental conditions. Three main aquatic macrophytes were also identified namely *Eichhornia crassipes, Ipomoea aquatica* and *Nymphaea lotus,* and were analyzed to determine their levels of minerals and metal concentration. Cronk and Fennessy (2016) and Okello et al. (2017) conducted detailed studies on aquatic vegetations and their importance in wetland ecosystem. Overbeek et al. (2017) reported decomposition of aquatic pioneer vegetation in constructed wetlands of Netherlands.

Previous work on Indian aquatic macrophytes and their water quality aspects had been very scanty and scattered. Earlier major contributions were made by Hooker (1872-1897). Different studies of aquatic floral composition was contributed by Biswas and Calder (1936, revised in 1954), Bhadri et al. (1961), Subramanyam (1962), Chauhan (1971), Thomas (1976), Gupta (1979) and Kachroo (1983), Islam (1988) and Nayana and Pajevar (2003). Trisal (1990) had done a comprehensive work on the distribution and production of macrophytes in different wetlands of 13 states including Kerala. The potential use of wetland vegetation and conservation had been discussed by Banerjee (1990). The total macrophytes exceeded 1200 species and a partial list of aquatic and wetland system was provided by Gopal (1995). General article on plant taxonomy was given by Nair (2004). He observed flower as the fundamental base for all systems of plant classification. The Indo - Dutch Mission study (1989) in Kuttanad, listed the aquatic plants of the area. The major aquatic plants of the area are: *Eichhornia crassipes, Salvinia molesta, Nymphaea stellata, N. Nouchali, Nymphoides cristatum, Nymphoides indicum, Hydrilla verticellata, Najas minor, Limnophila heterophylla, Aponogeton crispium, Potamogeton pectinatus, Scripus validus, Cyperus corymbosus* and *Ischaemum barbatum.* The study conducted by *Centre for Water Resources Development and Management*, (CWRDM) (1990) recorded 8 Pteridophytes and 202 Angiosperms of which 68 are trees from watersheds of Kerala.

Research contributions towards macrophytes and their distribution in Indian wetlands were enumerated by different researchers. Niche response surfaces and productivity estimates of macrophytes in lake Nainital, Central Himalaya, India was reported by Regha and Singh, (1987). Prasad (1988) made a detailed study of macrophytes in Keoladeo National Park, Rajasthan. Seshavatharam (1990) studied aquatic macrophytes and their standing biomass in Kolleru lake, Andhra Pradesh. Baruah and Baruah (2000) evaluated hydrophytes of Kaziranga National Park, Assam. Verma

(2001) conducted economic valuation of Bhoj wetland and floral patterns, Mumbai. Nandan and Mahajan (2002) examined periphyton in Hartala lake system of Jalgaon District, Maharashtra. Pattern of floral distribution of the wetlands of Kerala was documented by Joseph (2002). Sanil Kumar and Thomas (2002) studied the aquatic macrophytes of Muriyad wetlands, Thrissur to assess the ecological effects and role of macrophytes in relation to rice cultivation and fishing. *Ipomoea carnea* , *Salvinia* sp. and *Limnocharis flava* are some of the major weeds seen in this wetland. Variations in the net primary production of the macrophytes in the Sanapat Lake, Manipur were reported by Bebika and Sharma, (2003). Nayana et al. (2003) studied the biodiversity of some macrophyte infested lakes from Thane City, Maharashtra. Assessment of diversity of aquatic and wetland vascular plants of Koch Bihar District, West Bengal was investigated by Bandopadhyay and Mukherjee (2005). The lake exhibited the occurrence of 34 different macrophyte species during the study period. Sylas et al. (2006, 2008, 2009) assessed the primary production of dominant macrophytes of Kuttanad wetland ecosystem and the peak biomass of most macrophyte species exceeds the reported values. Sharma and Aggarwal (2007) enumerated aquatic vegetation of Nagaur District, Rajasthan. Vaheeda (2007) identified macrophytes of *Kodungallur* estuary, Kerala with special reference to mangroves and mangrove associates. Sujana and Sivaperuman (2008) conducted preliminary studies on flora of Kole wetlands, Thrissur, Kerala. Suman (2008) studied diversity of aquatic macrophytes, with respect to distribution in three lakes of Jammu. Sabu and Babu Ambat (2007) examined floristic analysis of wetlands of Kerala. Manilal and Sivarajan (2009) examined floral pattern and their medicinal properties in ponds of Calicut region, Kerala. An attempt has been made to enumerate the macrophytes and their distributional pattern in a polluted pond of

Shahjahanpur, U.P (Saltanat and Namdeo, 2010). Goswami et al. (2010) presents the investigation on concerning the seasonal change of macrophyte diversity and physico-chemical characteristic of water and soil in Rajmata wetland, West Bengal. It also encompass with the economic prospect of wetland associated macrophytes. Distribution of emergent macrophytes in three eutrophic lakes from Jhansi, Bundelkhand region, U.P, was studied by Javid et al. (2011). Physicochemical status and primary productivity of Ana Sagar Lake, Ajmer (Rajasthan), was analyzed by Vijay Kumar and Ranga (2011). Jaikumar et al. (2011) conducted studies on distribution and succession of aquatic macrophytes in Chilika Lake, Odisha. Khelchandra and Sharma (2012) studied productivity studies of the macrophytes in Kharungpat lake, Manipur. Bhagyaleena and Gopalan (2012) studied aquatic medicinal plants in Palakkad, Kerala. Sanchita et al. (2012) studied the utilization of some aquatic macrophytes in Borobandh-a lentic water body in Durgapur, West Bengal. As many as 52 species of macrophytes belonging to 26 families have been enumerated and their potential utilization has been evaluated. The present investigation revealed the multifarious uses of macrophytes viz., as a source of medicines (*Alternanthera sessilis, Bacopa monnieri, Centella asiatica* etc.*)*, foods (*Commelina paludosa, Enhydra fluctuans, Hygrophila difformis* etc.), fodder (*Brachiaria ramosa, Echinochloa colona* etc.), compost or green manure, bioferilizer, soil binder, etc.

Distribution pattern of macrophytes in different regions of West Bengal were done by Mandal and Mukherjee (2007, 2010); Bala and Mukherjee (2007); Mitra et al. (2009); Chowdhary and Das (2010); Mandal (2012). Sajith Babu et al. (2012) examined floral diversity in wetland rice ecosystem of Thiruvananthapuram, Kerala. Distribution pattern of aquatic vegetation and their biomass in Asan wetlands, Himalaya was evaluated by Malik and Nidhi Joshi (2013). Ranjit Saikia (2013) assessed macrophytic diversity of Poba reserve forest, Assam and Arunachal Pradesh. Singh et al. (2012) assessed diversity and biomass of macrophytes of Bahiara wetland, Saran, Bihar. Sanjeeb Kumar (2012) reported a detailed study of macrophytic diversity of the wetlands of Laokhowa wildlife sanctuary, Assam and recorded along with seasonal variation. Altogether 373 plants belonging to 258 genera and 93 families were recorded from the study site. Vipin Vyas et al. (2012) study was carried out on the distribution of macrophytes near water intake point in river Narmada and study depicted about the loss of macrophytic distribution in lower reaches of water intake point in river Narmada in conjunction with some physico-chemical parameters of water quality. Palit and Mukherjee (2012) documented the physico-chemical characteristics of water and aquatic macrophyte from 12 wetlands of Bankura district, West Bengal, for two year period. Jyothi and Sureshkumar (2012, 2013, 2014) conducted continuous evaluation of medicinal macrophytes of Ponnani Kole wetlands in Kerala. Diversity of herbaceous riparian flora in the lower stretch of Bharathappuzha river, Kerala was done by Liji Balan and Paul (2016).

2.5 Biocenosis of macrophytes and its associated fauna

The shallow depth of fresh water wetland supports suitable growth of macrophytes and offers ample micro- niches to diverse organisms. From the economic point of view macrophyte associated macroinvertebrates of freshwater wetlands are important for their significant role in aquaculture (Jingran, 1997) and serve as reliable indicator of water quality. The macrophyte associated insects are also important component of food web in the wetland ecosystem. Aquatic insects include mayflies, stoneflies, dragonflies, bugs, midges, caddis flies, mosquitoes etc. are aquatic only as larvae or as pupae, but terrestrial as adults, while others are aquatic both as larvae and as adults. Macan (1963) noted the scarcity of aquatic beetles in big lakes and concluded that factors like wave motion and macrophyte distribution affects the habitat of beetles. Wind velocity and scarcity of emergent vegetation paved way for the scarcity of beetles. Studies on aquatic vegetation and macroinvertebrate association were conducted by Krull (1970). He reported that the aquatic macroinvertebrates were more abundant in vegetated area than non-vegetated area. Aquatic insects feed on water plants and decaying organic matter having biocenotic relationship can be seen in water plants (Mani, 1971). Soszka, (1975) studied ecological relations between invertebrates and submerged macrophytes in the littoral region of lake. Sublittoral zoobenthos have been studied by Nocentini, (1973) with reference to some zoological groups (mainly Oligochaeta, Chironomidae and Gastropoda) and considering as a whole fauna was found having associated with bottom and submerged vegetations. Mclachlan (1975) studied the role of aquatic macrophytes in the recovery of the benthic fauna of a tropical lake after a dry phase. Lodge et al. (1988) conducted spatial heterogeneity study and habitat interactions in lake communities. Mastrantuono (1991) determined zoobenthos associated with submerged macrophytes in littoral areas of lake Vico (Italy), and detailed about some relations between fauna structure and water quality. A total of 110 taxa were identified, crustaceans, nematods and chironomids were widely distributed in this lake, and secondarily by several other groups such as oligochaetes and ostracods accounting for quite high percentages. The study on macroinvertebrates living in *Eichhornia* sp. in the Paraguay river, Brazil, was conducted by De Neiff (1995). The study envisages chironomids and crustaceans are highly associated with *Eichhornia* sp.. In small lakes and wetlands, where the littoral region with aquatic macrophytes occupies relatively a large portion, there is relatively a high intensity of competitive interaction or biocenosis among consumers that move from the pelagic zone to use littoral resources was reported by Gasith and Hoyer, (1998). Olson et al. (1999) studied the abundance and distribution of macroinvertebrates in relation to macrophyte communities in Swan lake, Nicollet County, Minnesota, U.S.A. In his study three major macrophyte communities were selected, the *Typha*, *Potomogeton*, and *Scirpus* species and concluded that vegetation supported the greatest numbers and most diverse invertebrate fauna and also recorded *Typha* sites produced the largest total biomass of invertebrates.

Margaret and Carolyn, (2000) observed water depth is crucial for macrophyte establishment and survival. Water depth and the extent of flooding and drying determine the macrophyte types and wetland zones as well as invertebrate communities. Casatti, et al. (2003) in the present investigation studied the feeding habits of the fishes associated with aquatic macrophytes in the Rosana Reservoir, Southeastern Brazil. Smiljkov et al. (2005) studied biocenotic composition of the macrozoobenthos on different habitats from the littoral region of lake Ohrid, South Eastern Europe. The maximum number of species was recorded between depth points from 3 to 11m. Thomas et al. (2005) assessed the macrophyte diversity and association with chironomid larvae and explained in terms of physical and chemical habitat variables. He concluded that, competitive dominance of a few taxa was responsible for lower richness in low pH wetlands. Momo et al. (2006) studied the relationship between micro-invertebrates and macrophytes in a wetland, Laguna Ibera (Argentina) and its implications for water quality monitoring. Species composition, distribution and percentage cover of aquatic macrophytes which will determine the associated invertebrate biodiversity and their biocenosis was reported by Jerry et al. (2006). David and Papas (2007) had reported the macroinvertebrate communities in artificial wetlands and their influence on aquatic vegetations. Macroinvertebrate richness was higher in habitats consisting of native macrophytes than for exotic macrophytes within the artificial wetlands. Alves and Gorni (2007) studies examined the occurrence of Naididae species of oligochaetes on the submerged macrophytes in two reservoirs of the state of Sao Paulo (Brazil). Greatest average abundance of Naididae was found in the macrophytes- *Cabomba, Ipomoea,* and *Najas* species. Aquatic macrophytes are virtually present in all freshwater bodies. Influence of aquatic macrophyte habitat complexity on invertebrate abundance and richness in tropical lagoons was studied by Sidinei et al. (2008). Survey of herbivores insect associated with aquatic and wetland plants in the United States carried out by Nathan and Grodwitz, (2010). Marcin and Sender, (2011) conducted comparative analysis that was focused on evaluation physical and chemical factors of water, as well as selected biocenotic elements in those reservoirs (macrophyte, bottom fauna, and zooplankton structure). In their study meager collections of hydrophytes were carried out from 1.5 to 2m depth and observed seven classes of invertebrates. Capello et al. (2012) studied feeding habits and trophic niche overlap of aquatic Orthoptera associated with macrophytes. This is the first experiment of the diet composition of species *Centella aquaticum*, and it is important information to explain orthopteran assemblages associated with macrophytes in rivers in Argentina. The diversity of Chironomidae (Diptera) associated with *Hydrilla verticillata* and other aquatic macrophytes in lake Tanganyika, Burundi, Africa, was studied by Copeland et al. (2012). Hill et al. (2016) examined the biodiversity and conservation value of macroinvertebrates from 91 lowland ponds across 3 land use types (35 floodplain meadow, 15 arable and 41 urban ponds). A total of 224 macroinvertebrate taxa were recorded from different macrophyte communities. Jeffries et al. (2016) studied the invertebrates and its association with wetland vegetation in temporary wetlands of the temperate biomes. Che Salmah et al. (2017) studied the dynamics, abundance and predator-prey interactions of aquatic organisms in a rice field ecosystem and its effects of seasons and cultivation phases. Bonari et al. (2017) assessed the hydrophytes and insect diversity from semi natural grass lands of White Carpathians protected landscape area, Slovakia, Central Europe.

Literature shows that, in international scenario extensive studies were carried out on macrophytes and its relation with environment and biota. In wetlands they occupy predominantly the shallow littoral regions, and their importance in a wetland ecosystem generally declines with increasing wetland size. The portion of the wetland occupied by the littoral zone is inversely related to basin slope and to the degree of shoreline regularity, and macrophyte associated macroinvertebrates community being smallest in large deep lakes with low shoreline wetlands (Center for Environment and Development, 2003). Aquatic macrophytes can also be efficient indicators of water quality, and their presence may enhance water quality due to their ability to absorb excessive load of nutrients, that will provide a habitat for variety of macroinvertebrates. Kulstreshtra, (2005) reported that aquatic macrophyte refers to macroscopic vegetation including macroalgae, mosses, ferns and angiosperms that grow in aquatic and wetland habitats. The littoral region is often the most diverse part of the lake community, supporting variety of macrophytes, their associated micro flora and large number of animal species. Most ecological researches have been focused on open water habitats rather than in the littoral zone of the lake. Littoral studies have been hampered by difficulties with quantitative sampling of the vegetation and sediment substrata (Lodge et al., 1988). According to Pennek (1966) diversity is often high in the vegetative habitats compared with pelagic regions. Masataka (2002) analysed the community structure and vegetation that is indispensable for studies on the biodiversity of limnetic ecosystem. This group is a good biological indicator of water quality due to rapid responses for both exposure and recovery. Wetland plants have major effects in terms of the physical (temperature, light penetration, soil characteristics) and chemical environment of wetlands (dissolved oxygen, nutrient availability), and support nearly all wetland biota. They are drivers of ecosystem productivity and biogeochemical cycles, because they occupy a critical interface between the sediments and the overlying water column (Carpenter and Lodge, 1986). The back scattering characteristics of wetland vegetation and water level changes were studied by Zhang et al. (2017).

Information regarding wetland macroinvertebrates with reference to their association with macrophytes is limited in India. Major studies were reported by Srivastava, (1959); Tonapi and by Ozakar (1969); Roy and Munshi, (1978); Mitra and Kumar, (1988); Roy, (1982); Bhattacharya and Gupta, (1991); Rai and Sharma, (1991); Mishra et al., (1992); De and Sengupta, (1993). Similar association was also reported by Vijayan (l991). Harkal et al. (2011) present study deals with micro-invertebrates associated with littoral macrophytes of Kagzipura reservoir, Maharashtra. Species of Protozoa, Rotifera, Copepoda, Cladocera and Ostracoda along with Sponges, Bryozoa, Nematodes and Insect larvae were recorded. Sobhana and Nair (1983) examined the biocenosis of *Salvini molesta* in the Veli lake, and its associated oligochaetes. Nagare and Dummalod (2012) investigated aquatic flora and fauna associated with the freshwater snail *Lymnaea acuminata* in Kham river at Aurangabad. The different microhabitat exploitation plus diet composition suggests partitioning of resources and absence of food competition among the most representative fish species in the studied community, and indicating the importance of the naturalistic approach to fish ecology studies. Macrophyte preference and insect diversity of freshwater wetlands in south eastern Bengal was studied by (Sujith et al., 1998). Seventy three species of insect belonging to 5 genera associated with 39 species of macrophyte were reported. The composition and distribution of the invertebrate fauna associated with submerged macrophytes was analysed by Pathak et al. (2004) in wetlands of Uttar Pradesh. Sugunan et al. (2000) studied ecology and fisheries of Beels in West Bengal and also investigated the relation with macrophytes and fishes. Srivasthava, et al. (2000) examined the ecology and fisheries of Tawa reservoir, Madhya Pradesh and observed reservoir having wide variety of aquatic plants and associated insects, which can act as a food for fishery resources. Latha and Thanga (2010) studied bioindicator species for estuaries of south Kerala, with special reference to macro invertebrates. Choudhury and Gupta (2017) conducted a rapid assessment of water quality and insect fauna of deeper beels, Northeast India. Brraich and Kaur (2017) examined insects and its association with macrophytes in Nangal wetland, Punjab.

Aquatic insects are very integral part of any biotic component of any water bodies or wetlands. They are indicators of ecological diversity and habitat characteristics (Eyre and Foster, 1989; Brown and Gange, 1990; Foster, 1991; Riberia, 2000; Polhemus, 1993; Sanchez –Fernandez et al., 2006). Martinoy et al. (2006) studied the Mediterranean coastal which presents a vivid description of the crustacean and aquatic insect composition of Emporda wetlands, Spain. There is a great paper discussing how to use several methods for estimating the species richness and habitat fragmentation of insects for a wide range of taxonomic groups (Gonzales et al., 2009). Payakka and Prommi (2014) studied aquatic insects in Kasetsart University, Kamphaeng Saen Campus, Central Thailand. The aim of this study was to investigate the diversity of aquatic insects in relation to water quality variables in order to explore the bioindication potential of aquatic insects for assessing water quality. Wide studies have been carried out on the ecological aspects of aquatic entomofauna. Some recent works are those by Rosenberg (1992); Whiles and Wallace (1997); Merrit et al. (1996); Buss et al. (2004); Yule (2004); Bonada et al., (2006). Diversity of aquatic insects in irrigated rice fields of South India with reference to mosquitoes of Order Diptera was investigated by Ponraman et al. (2016). Swarup et al. (2016) discussed the benthic diversity and its distribution in a typical tropical Ramsar wetland. Macedo et al. (2016) developed a benthic macroinvertebrate multi metric index (MMI) for neotropical Savanna streams, Zambia, Africa. Gu et al. (2016) assessed species diversity and functional diversity of insects in Wuxijiang national wetland park, East China. Jiani et al. (2017) conducted advanced research on the structure, diversity and variation of insect communities in wetland ecosystems.

Chadd, (2010) opined that, invertebrates represent a useful ‘indicator community’ for assessing the condition of aquatic habitats, both in freshwaters and in transitional coastal zones. Girotti et al. (1997) authors have elaborated molluscs, fresh-water and brackish ostracods faunas, for the selected Plio-Pleistocene fossiliferous localities of the Italy. Mustow (2002) conducted biological monitoring of aquatic insects of rivers in Thailand.

Ramírez and Fonseca (2014) carried out studies on functional feeding groups (FFGs) of aquatic insect families in Latin America and provided general guidelines on how to assign organisms to their FFGs. Taxonomic diversity of aquatic insect assemblages and functional feeding groups in neotropical Savanna streams was studied by Ferreira et al. (2017).

Aquatic Hemiptera holds an important place in the ecology of freshwater ecosystem. They are important food for many organisms, including fish, amphibians, waterfowl and other animals (Clark, 1992). They generally have an intermediate place in the food chain, for apart from being eaten, are often important predators too (Runck and Blinn, 1994). Hemipterans are exceedingly important in relation to fish production. They are the primary food for many wild and cultivable fishes, which make them valuable for sport fisheries (Ohba and Nakasuji, 2006). Certain families of the bugs may be utilized in the biological control of mosquito larvae (Saha et al., 2007).

The chironomid family (Insecta: Diptera: Chironomidae) commonly referred to as non-biting midges, are frequently the most abundant insect found in freshwater ecosystems. It includes the most diverse group of aquatic insects, including many different feeding groups, habitat references, tolerance levels to different environmental conditions and often makes up about one third of the micro-invertebrate fauna of freshwater stream and rivers (Epler, 2001). Chironomids have long been used by limnologists and aquatic ecologists as biotic indicators to classify lakes in terms of trophic status and hypolimnetic oxygen concentration. These are now increasingly being used by paleolimnologists to reconstruct past lake conditions and to access the impact of environmental change and pollution on the structure and function of aquatic communities (Heiri et al., 2003; Rossaro et al., 2006; Maskey, 2007; Nazarova et al., 2008). Fonseca and Rocha (2004) evaluated the distribution of chironomid larvae during four periods of the flood plains, and the possibility of using them as bioindicators of ecological conditions in Amazonian Lake. Cranston (2007) studied the chironomid larvae of tsunami impacted waterbodies of the coastal plain of South Western Thailand. Özkan et al. (2010) conducted ecological analysis of chironomid larvae in Ergene river basin, Turki. Sensolo et al. (2012) conducted studies on influence of landscape on assemblages of Chironomidae in neotropical streams, southern Brazil. Several studies reveal that chironomids can live in wide range of environmental conditions, qualify larval chironomid as suitable organism that can indicate the various dimensions of the ecological conditions of the habitats by Rossaro, (1991); Mousavi, et al., (2003); Luoto, (2011); Nicacio and Juen, (2015); Raposeiro et al., (2017).

Studies regarding aquatic insects and their relevance were reported by several researchers in India. Outstanding studies on aquatic insects in Indian wetlands were contributed by Corbet (1962); Baid (1968); Tonapi and Ozakar (1969) and Alfred (1974). Corbet (1962) made a comprehensive study on the biology of odonates. Baid (1968) deliberated the insect life in Sambhar lake, Rajasthan while Tonapi and Ozarkar (1969) studied the aquatic Coleoptera of Pune, Maharashtra. Alfred (1974) enumerated in dipterans of different freshwater bodies. Limited research also been carried out on general entomofauna of some specific wetlands, with taxonomic viewpoints which includes the woks of Roy and Munshi (1978); Roy (1982); Roy et al., (1988); De and Sengupta (1993), Bhattacharya (2000) and Pal et al. (2000). Water bugs of freshwater bodies in Kangra, Himachal Pradesh, were recorded by Prasad (1975). A study on the odonates of

Renuka lake, Himachal Pradesh was conducted by Kumar and Juneja (1976). Kumar (1978) prepared field notes on the odonates around a freshwater lentic system of Himalayas and noted the behaviour of dragonflies present around those habitats. Information on freshwater molluscs of Pune, Maharashtra was given by Tonapi and Mulherkar (1963). A brief account of various freshwater snails of Gwalior, Madhya Pradesh, was made by Goel and Srivasthava (1980). Sharma (1997) reported on freshwater snails of southern Rajasthan. Aquatic molluscs of Keoladeo National Park, Rajasthan were reported by Ali and Vijayan (1987). Freshwater oligochaeta from Bombay city and environs were studied by Naidu and Naidu (1981). A number of works were carried out on the aquatic insects of Keoladeo National Park, Rajasthan, in three decades back (Saxena, 1975; Mahajan et al., 1981; Ali and Vijayan, 1986; Vijayan, 1991; John, 1999; MoEF, 2012). Investigations on the biomass fluctuations of aquatic macroinvertebrates in a pond at Bhagalpur, Bihar were carried out by Sharma et al. (1986). Bal and Basu (1994) listed out Hemiptera of West Bengal. Subramanian (2005) prepared a field guide of odonates of penisular India and reported Odonata was numerically the most abundant group constituting of 54% of the total aquatic insects. Dev Roy et al. (2009) accounted invertebrate diversity of Vembanad lake, Kerala. Microhabitat distribution of stream insect communities of the Western Ghats was given by Subramanian and Sivaramakrishnan (2007). Sarmistha et al., (2009) assessed diversity and community structure of aquatic insects in a pond in Midnapore town, West Bengal, India. Diversity and community structure of aquatic insects in a pond in Midnapore town, West Bengal was documented by Sarmistha Jana et al. (2009). Guptha and Paliwal (2010) gave special attention to aquatic insects and water quality of river Yamuna, India. Deepa Jaiswal (2010); Deepa Jaiswal and Rao, (2007, 2010, 2011) documented

Hemiptera and Coleoptera of different fresh water bodies of India. Sharma and Agarwal (2012) reported the diversity of aquatic insect fauna of Surha Tal, District Ballia, U.P. Twenty nine species of aquatic insect were collected in their study. The aquatic coleopterans are highly diverse and widely distributed, only four families namely Dytiscidae, Gyrinidae and Hydrophilidae and Haliplidae are chiefly represented in the present preliminary report of Ameenpur lake, Hyderabad (Deepa Jaiswal, 2012). Joshi (2012) examined diversity of Hemiptera and its variation with environmental parameters of Nilona dam, Yavatmal, Maharashtra. Balachandran et al. (2012) discussed the diversity and distribution of aquatic insects in Aghanashini river of Central Western Ghats, Kerala. Takhelmayum and Gupta (2013) in a study was made on the temporal fluctuations of distribution of aquatic insects around Phumdi Live (PL), Phumdi Mixed (PM) and Phumdi Dry (PD) areas of Loktak lake, Manipur. The study revealed the presence of predators, and the absence of herbivores and detritivores in both PL and PM, the PD area was totally devoid of insects. Abhijna et al. (2013) reported the diversity and distribution of aquatic insects of Vellayani lake, Kerala. Habib and Yousuf (2017) studied the phytophilous macroinvertebrate community of Dal lake in Kashmir, Himalayas.

The freshwater biodiversity of Kerala State is not well documented and the rate of possible biodiversity loss is not yet quantified in Kerala. The compilation of the bibliography on the wetlands of Ramsar sites of Kerala shows that the knowledge of aquatic vegetation and associated macroinvertebrates was meagre. A perusal of the existing literature reveals that very few limnological investigations related to biocenosis of community ecology had been done in Kole wetlands. There was lack of comprehensive data on the biodiversity of the Kole wetlands, especially with regard to the data on the lower plant groups and aquatic macro invertebrates. In fact, there was no clear information available on the macrophytes of the Kole wetlands of Kerala, as the areas was not fully or partly studied and remains under explored for community study.

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Chapter - 3

MATERIALS AND METHODS

3.1 Study Area

Maranchery Kole lands are part of Vembanad Kole ecosystems covering an area of 13,632 ha spread over Thrissur and Malappuram Districts of Kerala, which extend to northern bank of Chalalakudy river in the south and to the southern bank of Bharathapuzha river in the north. The area lies between 10° 20´ and 10° 40´ N and 75° 58´ and 76° 11´ E. The southern part of the Kole land covering Thrissur and Ponnani Kole includes Velukkara in Chalakkudy river bank in Mukundapuran Taluk and Tholur-Kaiparampa areas of Thrissur Taluk form the Thrissur Kole (Taluk is an administrative division in India). Coming to the down south of this ecosystem, Chavakkadu and Choondal to Thavannur, covering Chavakkad and Thalappally Taluks of Thrissur district and Ponnani Taluk of Malappuram district form the Ponnani Kole. The estimated Ponnani Kole is 3,445 ha. geographical area, out of this 1,487 ha. are located in Thrissur district and 1,958 ha. is in Malappuram district, which includes Veliamcode and Maranchery Panchayath. Ponnani Kole, mainly discharges to

Kanjiramuku river basin and average depth of water body varied between 1 to 2m. The Viyyam dam is situated at the southern part of the Kole which prevents the saline water intrusion from the Arabian Sea, whereas river Bharathapuzha opens at the northern part in the downstream region. Adjoining canals and small rivers have been supporting a lucrative fishery in Kole lands.

Kole lands were developed from sea lagoons and these are gradually developed to shallow lands which can be bunded and dewatered by farmers and turn as a rice granary of Kerala (Vineetha, 2015). Rice cultivation in Kole lands is said to have started way back in the eighteenth century. However, earliest record on rice cultivation in Trichur Kole lands dates back to 1916 (Kokkal et al., 2008). During rainy seasons the area gets completely submerged in water for about six month period from June to November. The floodwater from the rivers used to bring enormous quantities of nutrient rich alluvium, which gets deposited in the Kole lands. The cyclical nutrient recharging of the wetland during the flood season rendered the area as one of the most fertile soils of Kerala. This is indicated by the fact that while the average productivity of rice in the state is less than two tonnes per hectare, Kole lands yielded 4-5 tonnes of rice per hectare (John Thomas et al., 2003). The Kole lands are dewatered after protecting the rice fields (*Padavu* or *Padashekharam**) with permanent or temporary earthen bunds (*Mattoms**). These temporary earthen bunds are not always trustworthy and breaches occur during high floods. In December, the farmers start dewatering the Kole lands using traditional methods by an indigenous axial flow centrifugal pumping device (*Petti* and *Para**) and started Ist step for cropping *Punja Krishi** (summer crop). The IInd step is tillage (*Nilamorukkal**) by

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[*] The terms are of regional language Malayalam

traditional methods (using plough) and using machine (tractor) and all the macrophytes were removed which gets gradually decomposed is a natural compost and manure in paddy fields. In addition to this they added some weedicides and wood ashes (for maintaining pH and to avoid clams) into the mainland before planting. The next step is planting rice saplings and the commonly used varieties are *Uma* or *Jyothi*[†]. Drainage channels were kept between the rice fields. Growth stage of paddy plants, takes four months, from January to April, whereas rice harvesting initiates by end of April and or by the first week of May. At the end of cropping usually south west monsoon get started in this area. This Kole land is well known for migratory birds, coots, terns, egrets and herons which enjoy greater part of year in this wetland.

An area of 100 acres of the study area Maranchery Kole, is a part of the Ponnani Kole lands. The study was conducted for a period of two years from October 2010 to September 2012. Eight stations were selected for monthly sampling (Fig. 3.1 to 3.9). The stations were visited once in every month as far as possible on the same date. For collection of samples for analysis of various parameters the area was visited in the early morning and proceeded to the collection sites in a small country craft.

3.2 Study stations and hydrological regimes (phases)

Phase wise variation was more prominent because of continuous variation of hydrological regimes in this Kole lands. The wetland transformed into four different phases which include, wet phase (normal water bodies), paddy phase, stable phase (fully inundated during the study period) and channel phase (channels connecting to paddy fields) (Fig 3.10).

[†] The terms are of regional language Malayalam

When sampling started during October 2010, the area was covered with water, during December 2010 the water got reduced due to dewatering for paddy cultivation. Stations 1, 2, 3, were under seasonal paddy cultivation. From January 2011 to May 2011 in the 3 stations, water was drained and paddy was cultivated. This period was taken as paddy phase. Diversity of aquatic macrophytes were comparatively less in these stations. Station 2 was situated very near to the residential area. Station 4 was deep in nature characterized by the presence of more aquatic macrophytes. Large channels were present in this station connecting station 5 and station 7. Station 5 was also similar to station 4, characterized by existing channels which connect different paddy fields, slightly shallow nature having more aquatic macrophytes. Station 4 and 5, were in complete inundation from the beginning of sampling from October 2010 and November 2010. During December 2010 to May 2011 stations 4 and 5 act as channels therefore it was considered as channel phase in this period. Seasonal fishing activities were carried out during summer months (March to May) in the channels. Again stations 1,2,3,4 and 5 were inundated by June 2011 with the advent of south west monsoon. These stations were completely inundated from June 2011 to November 2011. The period from June 2011 to November 2011 was considered as wet phase. Station 6, 7, and 8 were not under seasonal paddy cultivation that was kept fallow from several years back, and was inundated throughout the year supporting a variety of aquatic macrophytes and hydrological regime slightly fluctuated during summer months. Therefore, from June 2011 to November 2011 period 3 stations (Station 6, 7 and 8) taken as stable phase. During second year sampling period similar spatial pattern was seen in all eight stations. In June 2012 period bund breaching was noticed and the water was covered across the bund. Station wise comparison and phase wise variations were noticed during the study period.

Table 3.1 represents the seasonal transformation in Maranchery Kole wetland during the study period.

Table 3.1. The seasonal transformations in Maranchery Kole wetland during the study period (October 2010 to September 2012).

	Station 1	Station 2	Station 3	Station 4	Station 5		Station 6	Station 7	Station 8
Oct-10									
Nov-10		**inundated**							
Dec-10									
Jan- 11									
F									
M		**paddy cultivation**		**channels**					
A		**paddy phase**		**channel phase**					
M									
J									
J									
A		**wet phase**							
Sep-11		**(inundated)**				**Earthen bund**		**Stable phase**	
Oct-11								**(inundated)**	
N									
D									
J									
F									
M		**paddy cultivation**		**channels**					
A		**paddy phase**		**channel phase**					
M									
J				**Inundated**	**Bund breach**				
J									
A		**wet phase**							
S'12		**(inundated)**							

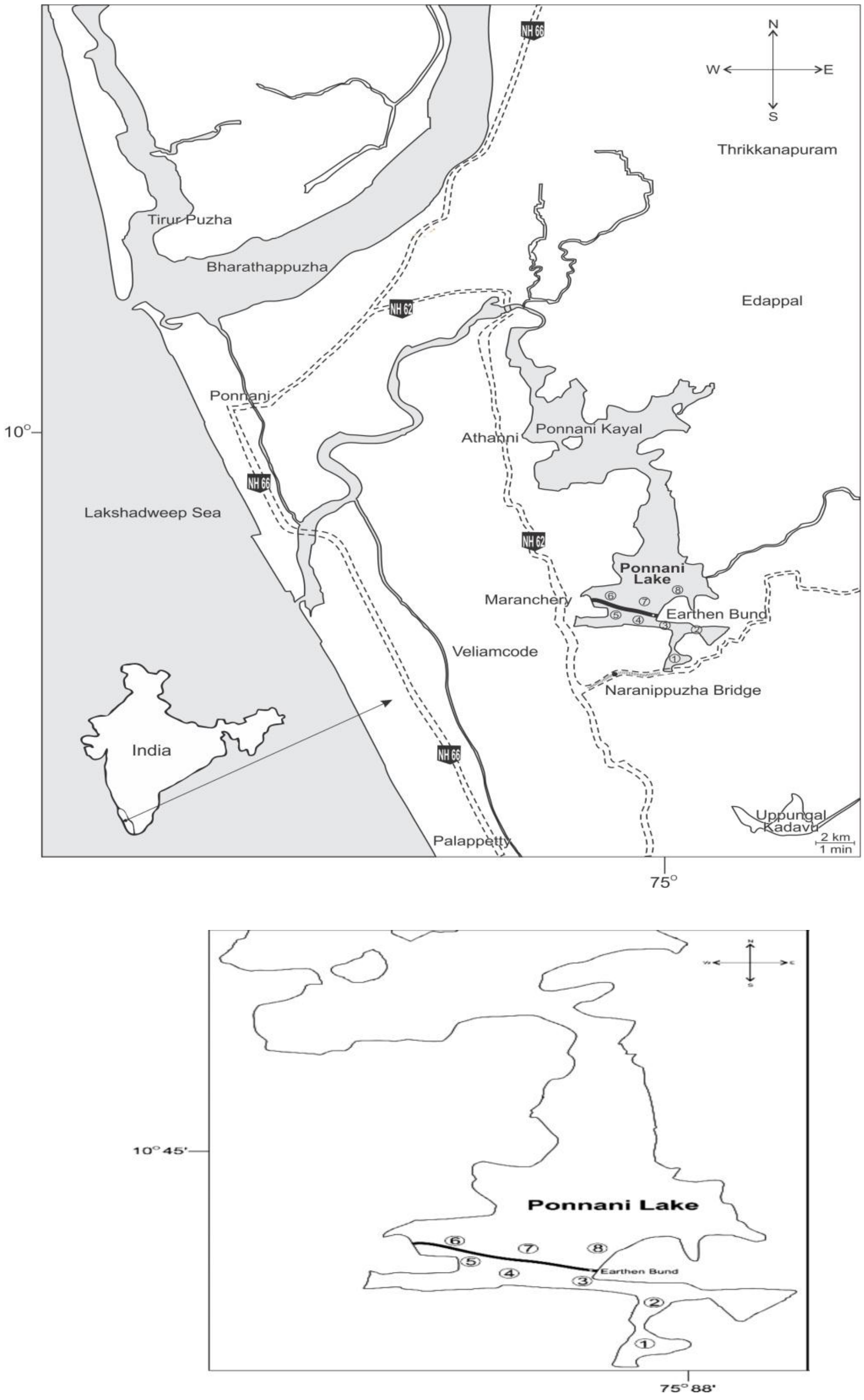


Fig.3.1. Map showing Stations 1 to 8 in Maranchery Kole wetland.

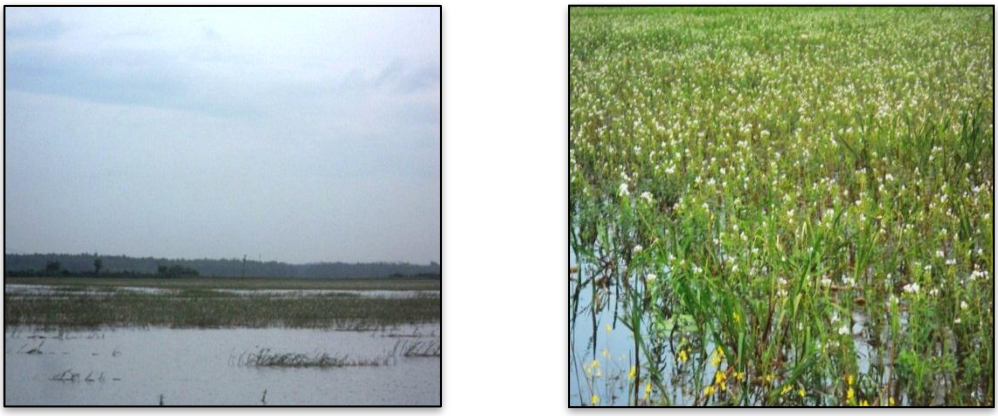
Station 1. Full inundation from June to November period

Station 1. Tillage of paddy filed near the habitat of different flocks of herons (December)

Station 1. Extensive paddy cultivation from January to May period

Station 1. Flocks of herons searching for food in paddy fields

Fig. 3.2. Field photograph of Station 1 (10 ^{0} 726'N 75 ^{0} 988'E)



Station 2. Full inundation from June to November period.

Station 2. Under inundation surface of water covered with growth of *Limnophila heterophylla* plant

Station 2. In paddy cultivation period (January to early weeks of May).

Station 2. After paddy harvesting (May).

Fig.3. 3. Field photographs of Station 2 (10 ^{0} 725'N 75^0 986'E)

Station 3. In full inundation period (June to November)

Station 3. Preparation stage for paddy cultivation, in between paddy fields shows removed macrophyte heap during December month.

Station 3. Extensive paddy cultivation from January to April period

Station 3.Growth of aquatic weed *Salvinia molesta* in between paddy plants

Fig. 3.4. Field photographs of Station 3 (10^0 723'N 75^0 986'E)

Station 4. Full inndation (from June to November)

Station 4. Existing Channels connecting to Station 7 (from December to May)

Station 4. Lecturious growth of macrophytes

Station 4. Herons sitting in macrophyte bed

Fig. 3.5. Field photographs of Station 4 (10^0 723'N 75^0 983'E)

Station 5. Full inundation with different macrophytes (from June to November)

Station 5. Channel connecting to paddy fields (from Decmber to May)

Fig. 3. 6. Field photographs of Station 5 (10^0 722'N 75^0 982'E)

Full inundation throughout the study period (October 2010 to September 2012)

Station 6. Lexturous growth of macrophyte *Nymphaea pubescens*

Fig. 3.7. Field photographs of Station 6 (10^0 727'N 75^0 985'E)

Fig. 3. 8. Field photographs of Station 7 (10^0 727’N 75^0 986’E)

Fig. 3. 9. Field photographs of Station 8 (10^0 728’N 75^0 989’E)

Station 7 and 8 full inundation throughout the study period (October 2010 to September 2012)

Paddy phase

Wet phase

Channel phase

Stable phase

Fig. 3. 10. Different phases in Maranchery wetland during the study period

3.3 Field Sampling and Analytical Methods

During wet periods, samples were collected on a country boat (*Vallam*)[*]. The water column was generally shallow, surface and bottom water was not taken separately. In wet periods the water samples was collected using a Niskin water sampler (Hydrobios 5 L). In paddy and channel phases, the water samples were collected using a locally fabricated shallow water sampler of 1 L capacity. All the water samples for different laboratory analysis were stored appropriately in well-insulated pre-labeled bottles and kept in boxes filled with ice cubes. For estimation of dissolved oxygen, samples were collected in 125 ml stoppered glass bottles and was fixed in the sampling site in accordance with modified Winkler method. While sampling precautions were taken that no air bubbles were trapped in

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[*] The terms are of regional language Malayalam

the samples. The samples for BOD analysis were collected from surface of the wetland in separate 125 ml BOD bottles (APHA, 2005; Goltermann and Clymo, 1969).

For productivity analysis, water samples were collected from the surface and at a predetermined depth (on the basis of light availability), each in three bottles (initial, light and dark bottles). The light and dark bottles are normally incubated for 3 hours (between dawn and midday) at the respective depths where the water samples were taken for the experiment (APHA, 2005). The control bottle containing water samples were immediately fixed with 1 ml of manganese sulphate and 1 ml of alkaline iodide (fixatives normally used in the determination of oxygen by Winkler's method). After the incubation period, the bottles were taken out and fixed similar to control bottles. All the bottles were brought to the laboratory in cold condition for analysis. The oxygen content in the different bottles was determined by Winkler's method with manganous sulphate ($MnSO_4$), alkaline iodide and sulphuric acid (H_2SO_4). For the estimation of chlorophyll pigments samples were taken in dark bottles from the selected eight stations.

The aquatic vascular plants present in the eight selected study stations were enumerated. The frequency of the plants in all these stations was determined. A 1 x 1m x 65cm quadrate was laid along the shore line of wetland ecosystems to study the macrophyte community (Vollenveider, 1974; Misra, 1968; APHA, 2005). Triplicate samples were collected from each station. The collected specimens were brought to laboratory for further identification. The taxonomic characteristics of the plants were noted along with their local names, abundance, distribution, growth form and uses along with the frequency of plants recorded according to standard classification manuals (Bentham and Hooker, 1862-1883). Biomass of macrophytes was estimated every month during the study period using quadrate of 50 x 50 x 60 cm size from the selected eight stations (Osborne, 1984; Downing and Anderson, 1985 and Madsen, 1993). Monocular patches were selected for biomass estimations. Above ground plant biomass were harvested in each stations and triplicate measurements were taken in each sampling. The obtained plant biomass was washed and the harvest was spread on news papers in cool shady places to drain off excess moisture. The surface of the plants was apparently dry it kept in oven with a temperature 70^0C until getting a constant weight. The dry weight data represents biomass in gms./square metre.

Macroinvertebrates associated with each macrophyte species were sampled using a 500 µm mesh net, attached with a 25cm x 25 cm diameter quadrate. The mesh net was placed carefully over the macrophytes and plant was cut gently approximately 5 cm above the substratum with scissors. The mouth of the net was then turned upward, and lifted out of the water. Then the contents washed into a plastic bag. Plant samples were screened, sorted and identified for invertebrates to the lowest possible taxa according to standard literature. To avoid or to minimise error, samples were collected nearly one meter depth from shore during inundated period. Replicate samples were taken randomly from monospecific patches of macrophyte species (Downing and Cyr, 1985). The collected samples were stored in 70% ethanol.

3.4 Meteorological characters

The rainfall data of Malappuram District was collected from the Indian Meteorological Department, Thiruvananthapuram, website (imd.gov.in), and is expressed in millimeter.

3.5 Hydrological parameters

Standard methods were employed to estimate the hydrological parameters. Estimations were carried out as soon as possible to minimise errors due to chemical and microbial action. Air and water temperature was recorded at all the eight study stations by a standard degree centigrade alcohol thermometer with an accuracy of ±0.01^{0}C. Depth of the wetland was measured in meters (m) by lowering a graduated weighted rope until it reaches the bottom. The hydrogen ion concentration of water was determined by using a digital pH meter (Model 371 Systronics). The pH meter was standardized with the help of standard solution having pH 4.0 and 9.2 before taking the reading of the samples. Conductivity and Total Dissolved Solids (TDS) of water samples was measured using Systronics water analyser (Model No. 371; accuracy ± 0.01) calibrated with standard KCl solution. The results were expressed in parts per million (mg/L) for TDS and micro siemens per centemeter (µS/cm) for conductivity. Turbidity was measured by using Nephelo–Turbidity meter (Systronics model no: 13) by Nephelo-metric method. Formazin polymer is used as the primary standard reference and it is prepared by mixing hydrazine sulphate and hexamethylenetetramine and it expressed in NTU (Nephelometric Turbidity Unit) (American Public Health Association (APHA), 2005 and Goltermann and Clymo, 1969). Salinity was determined by Mohr-Knudsen method (Strickland and Parsons, 1972). The chloride ion concentration present in the water sample was measured by titrating with silver nitrate solution and potassium chromate as the indicator. The values were represented as parts per thousand (ppt).

Alkalinity of the water sample was estimated according to the method suggested by APHA (2005) and Larson and Henley, (1955) by titration. Bicarbonates, carbonates and hydroxides are considered as chief bases in natural waters. Methyl orange indicator solutions are added to a 25mL sample which is titrated with concentrated sulfuric acid solution until the colour of the solution changes from yellow to faint orange. The results were expressed in mg/L. Chloride can be titrated with mercuric nitrate because of the formation of soluble, slightly dissociated mercuric chloride when the pH range of water was 2.3 to 2.8 (APHA, 2005 and Goltermann and Clymo, 1969). Two ml of 5% potassium chromate as an indicator used for the estimation until a persistent reddish-brown tinge appears. Values were represented in mg/L.

Hardness of the water sample was estimated by EDTA method (APHA, 2005). To 25ml of water sample, l ml of NH_4C1 and NH_4OH buffer solution were added. Erichrome Black T indicator (EBT) were added as indicator and then titrated against 0.01 Molar EDTA solution till wine red colour changes to blue. The calcium and magnesium dissociate form their complexes and with EBT to form more stable complexes with EDTA. The results were expressed in mg/L. Calcium in water was determined by titrimetric method (APHA 2005). To 25ml of water sample, 100mgs. of murexide indicator were added. It was titrated with 0.01 molar EDTA till pink colour changes to dark purple. Calcium was represented in mg/L. Magnesium content of the water was determined by titrimetric method as follows (Goltermann and Clymo, 1969; APHA, 2005). Magnesium was expressed as a difference between Ca + Mg titration (total hardness) and the titration alone for calcium used, it is expressed in mg/L.

Dissolved free CO_2 was estimated immediately after sample collection by titration method (Trivedi and Goel, 1986; Boyd, 1982; Goltermann and Clymo, 1969). The water is titrated with NaOH (0.02N) solution to the phenolphthalein used as indicator. The free CO_2 in the water sample react with sodium hydroxide to form sodium bicarbonate that indicated by the appearance of the pink colour. The results were represented in mg/L.

The dissolved oxygen content of each water sample was fixed *in situ* using Winkler's reagents and analysed by the modified Winkler's titration method (APHA, 2005; Goltermann and Clymo, 1969). The fixed samples were brought to laboratory. A brown precipitate appeared indicating the presence of oxygen. The contents were well shaken by frequently inverting the bottle and the precipitate was allowed to settle. A 2 ml of Conc. H_2SO_4 was added and shaken well to dissolve the complete precipitate. About 25 ml of the contents was transferred to a conical flask and titrated against 0.025 N sodium thiosulphate solution using starch (1 gm of starch in 100ml of distilled water) as an indicator. The initial point was dark blue-black colour changes to colourless. The results were presented in mg /L. Biological oxygen demand (BOD_3) was determined by a three day incubation method (Kale and Mehotra, 2009; APHA, 2005). Molecular oxygen utilized during a specified incubation period for the biochemical degradation of organic matter. The difference in the initial and final molecular oxygen was calculated using modified Winkler method and the BOD was expressed in mg/L.

The concentrations of five nutrients were determined during the present investigation. They were inorganic nitrite-nitrogen, nitrate-nitrogen, ammonia-nitrogen, phosphate-phosphorus and silicate-silica. The water samples collected for the estimation of nutrients were preserved by adding a few drops of chloroform. Particulate matter in the water sample was separated by filtration through a uniform millipore Whatman GF/C filter paper (0.5 pm porosity) in the laboratory. The concentration of nutrients was recorded by spectrophotometer. Nitrite-nitrogen was measured by diazotised method (APHA, 2005; Goltermann and Clymo, 1969). Reagents used for analysis was sulphanilamide which is coupled with N-(1-Naphthyl) ethylene diamine di hydrochloride and formed azo dye complex. The amount of dye formation is proportionate to the concentration of nitrite in sample. The absorbance of the resultant azo dye was measured at 543 nm and expressed in µmol/L. Nitrate-nitrogen was analysed using the resorcinol method (Goltermann and Clymo, 1969 and Zhang and Fischer, 2006). This method is based resorcinol (Benzene-1,3-diol) in acidified water, after on nitration of water resulting in a colour product, nitrosophenol. Absorption was measured at 505nm and expressed in µmol/L. Ammonia-nitrogen was measured by the phenate method (APHA, 2005; Goltermann and Clymo, 1969) and recorded the absorbance on spectrophotometer by 635nm. Ammonia react with phenol and hypochlorite under alkaline condition. For colour development sodium nitropruside reagent is used as a catalyzer and developed a indophenols blue. The intensity of colour is directly related to the concentration of ammonia in the sample. The results are expressed in µmol/L.

Dissolved inorganic phosphate-phosphorus was measured by ammonium molybdate- ascorbic acid method (APHA, 2005). Phosphate of samples is allowed to react first with a mixed reagent of molybdate, ascorbic acid and trivalent antimony. The phosphomolybdic acid reduces to molybdenum blue by ascorbic acid. The absorbance was measured at 882nm and expressed in µmol/L. The dissolved silicate-silica in water was analysed by molybdosilicate method (APHA, 2005; Goltermann and Clymo, 1969). The samples were acidified with concentrated sulfuric acid and precipitated silicate reacted with acidic ammonium molybdate to form a yellow precipitate (silicomolybdate complex). This complex further reduced by sodium sulphate to form molybdate blue colour. The absorbance was measured in 810 nm and expressed in µmol/L.

3.6 Gross and Net primary productivity

In an aquatic ecosystem the process of productivity is accomplished by two main type of primary producers, phytoplankton and macrophytes. It is estimated by Light and Dark bottle method (Strickland and Parsons, 1972; Brinson et al., 1981; and Loeb, 1981). Productivity is the rate at which organic matter is added to the exisisting phytoplankton standing crop. The amount of oxygen liberated is taken as a measure of primary production. These rates were converted to carbon units, assuming a photosynthetic quotient (PQ) of 1.3 based on the C:N:P molar elemental composition of phytoplankton (Redfield et al., 1963). The productivity is calculated based on the assumption that one atom of carbon is assimilated for each molecule of oxygen released. The advantage of this method is that it estimates gross (GPP) and net (NPP) productivity. The productivity was expressed in the unit g C /m^3/day.

3.7 Chlorophyll measurements

The chlorophyll a, b, c were estimated by the vacuum filtration – acetone extraction method, using the membrane filter assembly (Santhanam et al., 1976; APHA, 2005). For the estimation of these pigments, a known volume of water samples were filtered through 47 mm GF/C filters (pore size 0.7 µm). Before filtration, 1 ml of 1% $MgCO_3$ solution was added to the water samples, which $MgCO_3$ prevent the development of any acidity and subsequent degradation of pigments in the extract. The filtrate was extracted with 90% acetone for 20-24 hours in the dark in refrigerator. After the incubation the extract was stirred and centrifuged for about twenty minutes at 5000 rpm. The supernatant was decanted and made up to 10 ml. The extinction was measured at 750 nm, 665 nm, 664 nm, 647 nm, 630 nm, 510 nm and 480 nm in a spectrophotometer before and after acidification, using a 1 cm cuvette with 90% acetone in the reference path. Algal biomass was estimated by multiplying the chlorophyll 'a'content by a factor of 67 (APHA, 2005). The wet weight of algal biomass was expressed in mg/m^3.

3.8 Identification of macrophytes

Identification of macrophytes was done using standard literature (Cook, 1996; Gamble and Fischer, 1921-1935; Subramanyan, 1962; Sreekumar and Nair, 1991; Manickam and Irudayaraj, 1992; Mohanan and Henry, 1994; Sunil, 2000; Sasidharan, 2004 and Ghosh, 2005;). The macrophytes were photographed in field using a Samsung 12 pixel camera with zoom.

3.9 Identification of macroinvertebrates

Collected macroinvertebrates was examined under stereo microscope (Olympus SZX10) and compound microscope (Leica DM 500) depending upon the sample size. For identifications manuals used for crustaceans like, Nematoda, Oligochaeta, Euhirudinea, Mollusca, Ostracoda, Branchiopoda, Isopoda, Decapoda, Arachnida and Pisces (Yule and Sen, 2004), whereas insect and insect larvae of different orders of Ephemeroptera (Dudgeon, 1999); Odonata, Hemiptera, Coleoptera, Diptera and Lepidoptera by

Edmonson, (1992); Fraser, (1933-36); Morse et al., (1994); Dudgeon, (1999); Patil and Singh, (2002); Epler, (2001); Hemiptera by Thirumalai, (1989, 1999) and Morse et al., (1994), Trichoptera by Wiggins, (1975, 1996). Various internet search engines were also used for identification purpose like, http://www.esb.enr.state.nc.us/ and www. water bugkey. vcsu.edu.net. The photos of the insect fauna were taken on Cat Cam.

Macrophyte associated macroinvertebrate assemblage and its environmental relationship also account on the ecological quality status of the Maranchery wetland using biomonitoring index of aquatic insects. The indices such as Taxa richness (total number of taxa obtained), percentage of intolerant taxa (percentage of Odonata and Hemiptera) and percentage of tolerant taxa (percentage of Diptera), percentage of EPT (Ehemeroptera, Plecoptera and Trichoptera ratio), percentage of predators, functional feeding groups (FFG,%), biomonitoring working party score (BMWP) and average score per taxon (ASPT) have been used to measure the ecological quality status of aquatic insects fauna of this Kole land, impacted with various types of stress changing like land use pattern, organic enrichment, eutrophication, agriculture runoff and pollution problems (Morse et al., 1994; Sivaramakrishnan et al., 1996; Subramanian and Sivaramakrishnan, 2007; Namwong et al., 2013; Ramírez and Gutiérrez-Fonseca, 2014).

The biomonitoring working party scores (BMWP) can be obtained by summing the individual scores of all families present (Annexure 2). Score values for individual families reflect their pollution tolerance (Armitage et al., 1983). The average score per taxon (ASPT) was calculated by dividing the score by the total number of scoring taxa (Sivaramakrishnan et al., 1996).

3.10 Data analysis

Variety of statistical tools, diversity measures, species abundance models and graphical tools are available to assess the biodiversity of all the habitats. In this thesis arrays of statistical analysis were done for the better explanation of sample data including univariate and multivariate analysis. For this, software programmes SPSS version 16.0 (Statistical Programme for Social Sciences, version 16.0) and PRIMER version 6.1.8 (Plymouth Routines in Multivariate Ecological Research, version 6.1.8) were used for statistical analyses and representation of data. Excel 2010 and Origin pro 8.5 were used to plot spatial and temporal variations of various environmental and biological parameters. SPSS version 16.0 statistical software used to calculate two way ANOVA, mean, standard deviation and correlation analysis for testing the presence of significant differences among the environmental parameters between stations and between phases. Pearson correlation, linear correlations between two variables was used to correlate the hydrographic parameters with biological parameters. Statistical significances for Pearson correlation and ANOVA was determined at the 1% ($p < 0.01$) and 5% ($p<0.05$) probability level. Univariate and multivariate analysis were employed in this thesis to evaluate the community structure of Maranchery Kole wetland.

3.10.1 Univariate Analysis

The indices of species diversity such as Shannon-Weaver’s index of general diversity, Margalef index of species richness and index of evenness (Pielou’s index) was widely accepted in community studies.

Species richness: Margalef index (d) (Margalef, 1968)**:** This index is weighted towards species richness between different samples collected from various habitats.

Margalef's index (d) = (S-1) / log N

Where, d = Species richness

S = Total number of species in the community

N = Total number of individuals in the community

Species diversity: Shannon index (H') **(**Shannon and Weaver, 1963)**:** It measures of evenness in a community. Maximum Shannon index shows in a community means possibly occur in a situations where all species were equally abundant. It is calculated as,

$$H' = \Sigma i \; pi \ln (pi)$$

Where, pi is the proportion of the individuals in the total sample belonging to the species i and ln is the natural logarithm ($\log_2$).

Species evenness: Pielou's index (J') (Pielou, 1966)**:** It expresses how evenly the individuals are distributed among the different species.

It is calculated as

$$J' = H'/\ln S, \text{ Where } \ln S = H' \max$$

Where, J' is the evenness, H' max (the maximum value of Shannon diversity) is what H' would be if all the species in the community had an equal number of individuals; S is the number of species.

Species dominance: Simpson index (Lambda' or 1-λ) (Simpson, 1949)

It help to find out the most abundant species in a community. It is helpful for assess the pollution of a habitat.

$$\lambda = \Sigma \, Pi^2$$

where, D is a measure of dominance, so the D increases, diversity decreases.

Pi^2 = Proportion of (ni/N)

ni, is the individuals of one particular species found divided by the total number of individuals found (N).

3.10.2 Multivariate Analysis

It is a powerful tool for analyzing large set of data. In order to assess the consistent changes in the abundance and distribution of macrophytes and macroinvertebrates in various stations and in various phases, multivariate analyses were conducted. It is often a satisfactory coefficient for biological data on community structure (Clarke and Warwick, 2001).

Principal component analysis (PCA)

PCA is a statistical technique used to examine the interrelations among a set of variables in order to identify the underlying structure of those variables. It is also called as factor analysis. The problems of data reduction and interpretation, characteristic change in environmental parameters and indicator parameter identification can be approached through the use of this tool. It is a non-parametric analysis and the answer is unique and independent of any hypothesis about data distribution. PCA technique extracts the eigen values and eigen vectors from the covariance matrix of original variables. PCA is designed to transform the original variables into new, uncorrelated variables (axes), called the principal components, which are linear combinations of the original variables. The new axis lie along the directions of maximum variance (Shrestha and Kazama, 2007). It reduces the dimensionality of the data set by explaining the correlation amongst a large number of variables in terms of a smaller number of underlying factors, without losing much information (Vega et al., 1998; Alberto et al., 2001). Different applications were noticed from different authors (Voutsa et al., 2001; Gangopadhyay et al., 2001; Bengraine and Marhaba, 2003; Ouyang, 2005; Singh and Tripathi, 2016) they examined the spatio-temporal variations of environmental characteristics, identification of invertebrates related to hydrological changes, etc. In this study this parameter is applied to find out the inter relationship of environmental variables and its biocenosis to macroinvertebrates as well as aquatic insects.

BEST analysis (BIO - ENV + BV - STEP)

BIO-ENV and BVSTEP procedure of PRIMER v 6 combined together to get BEST. In this study, BIO-ENV procedure is used to link biological community analyses to environmental variables or to examine the degree of variations, such as environmental data, is related to the observed biological pattern or community. According to Clarke et al. (2008) a weighted spearman rank correlation coefficient was used to determine the harmonic rank correlation between the biological matrix and all possible combinations of the ecological variables. Spearman rank correlation done in between the variables, which ranks the subsets of variables that best 'matches' the biological patterns.

Hierarchical cluster analysis

Meng and Maynard, (2001) explains that hierarchical cluster analysis is a powerful device for analyzing water chemistry data as well as ecological data. In this study, the hierarchical cluster analysis (HCA) was applied to find out the stations wise and phase wise similarities (Bray and Curtis, 1957). Pooled data were selected for cluster analysis. In PRIMER, abundance and distribution of fauna and flora in each stations and phases was standardized and square root transformed prior to the calculations of similarity matrices using the Bray-Curtis similarity coefficient.

MDS (Non Metric Multi Dimensional Scaling)

Sheppard (1962) and Kruskal (1964) was proposed this metrics. The tool was used to find out the similarities between each pair of entities to produce a ‘map’, which would preferably show the interrelationships of communities. This explains the matrix with the greatest ‘goodness of fit’ or lowest stress and gave different dimensions visually displays the ranking of the similarity. The data from the Bray-Curtis similarity coefficient matrix were used to construct the ‘map’. Here stations and phases were plotted on a two dimensional non metric multi dimensional scaling (MDS) based on the similarity matrix.

Bubble plot

Field et al., (1982) explained the role of bubble plot express in a community study The bubbles will be superimposed and the relative size of the bubbles is related to find out the abundance of species in the different ecosystems like paddy fields, channels and stable and wet phases or environments. This data is also merged with PCA plots and explains the relation with different environmental parameters to major species. In this thesis bubble plots were used to plot the abundance of a single species represented over an area.

Funnel plot

It is stated as the average taxonomic distance between any two individuals or communities. It denotes taxonomic path length and the average phylogenetic index are obtained by dividing the total phylogenetic diversity index by the number of species. The taxonomic tree was drawn using the Linnaean classification. The variations in taxonomic distinctness index were used to assess biodiversity between healthy, moderately degraded and heavily degraded habitats could be compared using the 95% funnel plots. In this study, stations and phase wise variations of macroinvertebrates plotted with average taxonomic distinctness.

K-dominance curves

K-dominance curves is that the distribution of species abundances in a community or ecosystem with its ranks in that particular community. According to Clarke and Warwick, (2001) *K*- dominance curve used to compute for abundance, biomass, % cover or other biotic measure representing quantity of each taxon. Relative abundance is expressed as a percentage of the total abundance in the sample, and this is plotted across the species, against the increasing rank as the x axis, the latter on a log scale and the y axis either the relative abundance itself or the cumulative relative abundance were given. *K*-dominance curve is used here for comparing the biodiversity between different habitats of Maranchery Kole wetland.

Species accumulation plot

In this study species accumulation plot was used to describe the species composition of the area, which plots the cumulative number of species against the cumulative number of samples (grabs). Various species estimators such as CHAO1, CHAO2, Jacknife, UGE, SOBS etc., were used to predict the true number of species that would be observed as the number of samples.

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Chapter - 4

PHYSICO-CHEMICAL CHARACTERISTICS OF THE KOLE WETLAND

4.1. Introduction

Wetlands are most precious to earth and the basic ingredient to life. Increased demands on the resources have impacted heavily on wetland ecosystems. The major value of the wetlands includes, groundwater recharge, receptacle for flood waters, sink for pollutants that attributes as an ideal habitat for freshwater flora and fauna (Bijoy Nandan, 2007). Due to the multiple role they play in improving water quality, they are referred to as *nature's kidney.* Keddy (2000) referred that wetlands are *nature's supermarket* for the role they play in supporting food chains, both aquatic and terrestrial ecosystems.Coastal wetlands protect coastlines from hurricanes and tsunamis. The environmental characteristics of an aquatic system are very important in determining the biological productivity of the aquatic ecosystem. The physico - chemical features prevalent in an aquatic system govern the diversity, abundance and behaviour of organisms in that aquatic system (Adesina et al., 2010). In a wetland ecosystem, by their very nature, experience dynamic hydrofluxes (Hayworth 2000). Hydrology is a major environmental determinate of ecosystem character, influencing floral and faunal community structure by the frequency and duration of hydrological alterations. Sometimes, due to extreme hydrological fluctuations, the aquatic phase in aquatic ecosystems is shrunk spatially and temporally.

Different wetlands at different stages exhibit various degrees of trophic status under accepted conditions and equilibrium. A satisfactory understanding of aquatic life requires knowledge about the organisms as well as the external influences, which directly or indirectly affect them. A thorough knowledge of the physico-chemical parameters is essential to our understanding of the trophic status of an aquatic system during different seasons of the year because wetlands experience extensive variations from drying to flooding. Quantification, evaluation and study of interrelations between various physico-chemical aspects are prerequisites for understanding the health status of wetlands (Agoramoorthy and Hsu, 2002).

According to Tilton and Kadlec, (1979); Mitsch and Gosselink, (1986); and Hammer, (1992) natural wetlands have several attributes that enhance their capacity for improving water quality including the following.

a) High capacity for reducing the velocity of water flow which results in suspended particles being more readily deposited.

b) Generally high capacity for filtering out suspended solids from the water owing to characteristically dense plant growth and abundant litter surface.

c) Shallow nature of the water column is a general characteristics of a wetland and this leads to high levels of sediment -water exchanges. However, some wetlands may have considerably less favourable hydraulic conditions than others, where most of the water flow is being concentrated within a channel.

d) A variety of anaerobic and aerobic processes that remove pollutants from the water, like chemical precipitation, adsorption, ion exchange, nitrification and denitrification.

e) Microbial activity in the wetland is particularly is important for promoting nitrification and denitrification.

f) Aquatic vegetations of many wetlands, leads to high rates of mineral uptake and microbial decomposition of certain organic substances. Wetland plants provide substantial surface area for the attachment of microbes, both above and below the ground, due to its aerobic rhizosphere roots.

Wetlands are highly productive due to the accumulation of nutrients as well as high water table, the two limiting factors in terrestrial systems. The hydrographic conditions in paddy wetlands are also determined by the factors such as precipitation and the temperature resulting in surface cooling and heating. Over the years, the ecobiological status of the wetlands has under gone severe modifications mainly due to anthropogenic interventions; notably pollution from various point and non-point sources, reduction and shrinkage of the water body due to various agricultural activities, habitat change, depletion, extinction of bio resources affecting the livelihood condition (Anon, 2005). The distribution of environmental parameters in the wetlands depends upon the morphology, circulation and mixing, sources of dissolved and suspended materials, anthropogenic pressures, etc.

The hydrographical features of the extensive wetlands of the world have been investigated by many investigators (Reid and Wood, 1976; Curnmins, 1979; Carter et al., 1979; Holdon, 1979; Werner et al., 1978; Kadlec and Kadlec, 1979; Mathew et al., 1980; Dharmaraj and Nair, 1981; Anonymous, 1983; Tiner, 1984; Whigham et al., 1988; Ahmad and Singh, 1990; Berg, 1993; Novotny, 1994; Smith, 1997; Greenway and Woolley, 1999; Holis and Thomson, 1998; Mitsch et al., 2000; Chen et al., 2002; Beklioglu et al., 2007; Joseph and Jacob, 2010; Duan Pei et al., 2015; Handler et al., 2016; Choudhury and Gupta., 2017.

The limnological studies regarding seasonal fluctuation of water characteristics and biological conditions of Kole wetlands are comparatively scantywith that of lakes and estuaries of Kerala (Gopalan et al., 2014). Therefore, this chapter, presents the phsico-chemical characteristics of the Maranchery wetland on a spatio-temporal scale. The different phase changes in wetland habitat is also discussed in the context of the prevailing environmental quality of the region.

4.2. Results

4.2.1. Rainfall

Based on the pattern of rainfall in Kerala, three seasons are recognized, Monsoon (June-September) when thesouth-west monsoon is active, Post monsoon (October-January) when the north-east monsoon become active and Pre monsoon (Feb-May). The data on the mean variations in rainfall in Kole lands are given in Figure 4.1. During the monsoon season the highest rainfall was recorded in June 2012 (495.3mm). Rainfall was lowest in December 2011(4mm) and January 2012 (0.0mm). An average year wise variation of rainfall of 220.5 mm (± 217.5) in 2011 and 203mm (±187) in 2012 period was recorded.

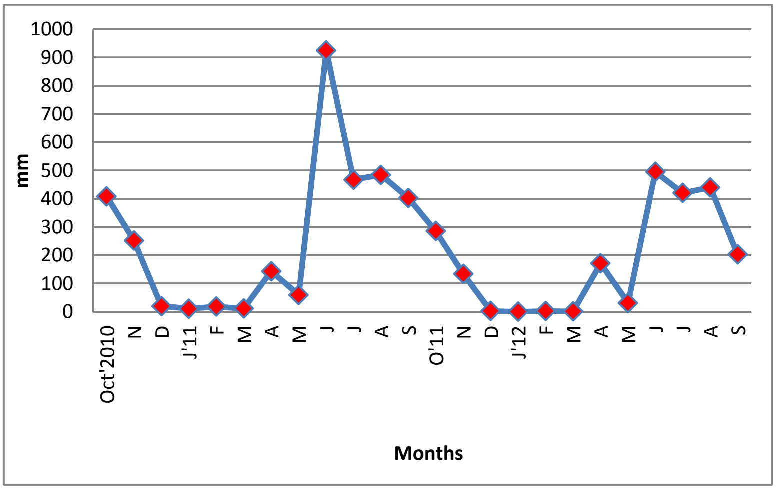


Fig.4.1 Monthly variation in rainfall in Maranchery Kole wetland during the study period.

4.2.2. Depth

Depth shows wide variation during the study period, the mean variation of depth is given in Table 4.1. The water depth ranged from 0.2 to 3.2 m in the Maranchery wetland (Fig.4.2; 4.3). The minimum water depth recorded was 0.2m during May 2010in station 1, 2 and 3and maximum water depth recorded was 3.2 m at station 7 during June 2012. In station1, it varied from a minimum of 0.2m in the months of March 2011 and April 2011, 2012 to a maximum of 3.0 m in the month of July and August 2011 (1.4± 1.0). Station 2, showed a range of 0.2 m to 3 m with minimum values recorded in the month of and March, 2011, 2012and April 2012 and maximum in the month of August 2011 (1.4± 0.9). In Station 3, the depth fluctuated from a minimum of 0.2m in the month of February 2011 and April, 2011, 2012 to a maximum of 3.0 m in the month of July, 2011 (1.5 ± 1). The mean depth was 1.8 m (±0.6m) in station 4, the water column varied from 1 m in April 2011 to 2.7 m in August 2011. In station 5, April 2012 month showed the lowest depth of 1 m whereas the highest depth was in

July 2011 (2.8 m) with a mean value of 1.9m (±0.6m). Station 6 showed the lowest depth of 1.2 m in May 2011 period and highest depth of 2.9 m in July 2011 with a mean of 2.2 m (±0.5). In station 7, the minimum depth was recorded in April 2011 and May 2011 (1.3 m) and maximum in June 2012 (3.2 m) the mean depth being 2.4m (±0.7). In station 8 depth varied between 1.3 m in March and April 2011 to 3.0 m in July 2011, 2012 and August 2011 showing a mean depth of 2.3m (±0.6). The comparison between the wet, paddy, channel and the stable phase showed that the lowest depth was in the paddy phase showing 0.3m and highest in the wet phase of 2.3m (Fig. 4.4) ANOVA result of depth of the water body showed that it was significant at 1% level between phases (P<0.01).

Table 4.1. Mean variation of depth in Maranchery Kole wetland during the study period.

Stations	**Min (m)**	**Max (m)**	**Mean ± SD**
Station 1	0.2	3.0	1.2± 1.0
Station 2	0.2	3.0	1.3±1.0
Station 3	0.2	3.0	1.3±1.0
Station 4	0.3	2.7	1.7±0.07
Station 5	0.4	2.8	1.7±0.7
Station 6	1.2	2.9	2.2±0.5
Station 7	1.3	3.2	2.4±0.6
Station 8	1.3	3.0	2.3±0.6

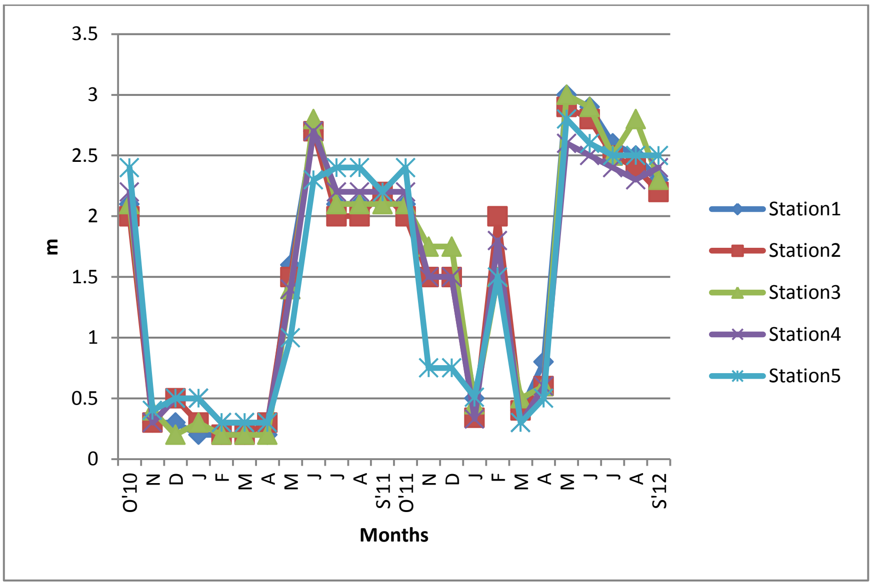


Fig.4.2. Monthly variation in depth in stations 1 to 5 in Maranchery Kole wetland during the study period.

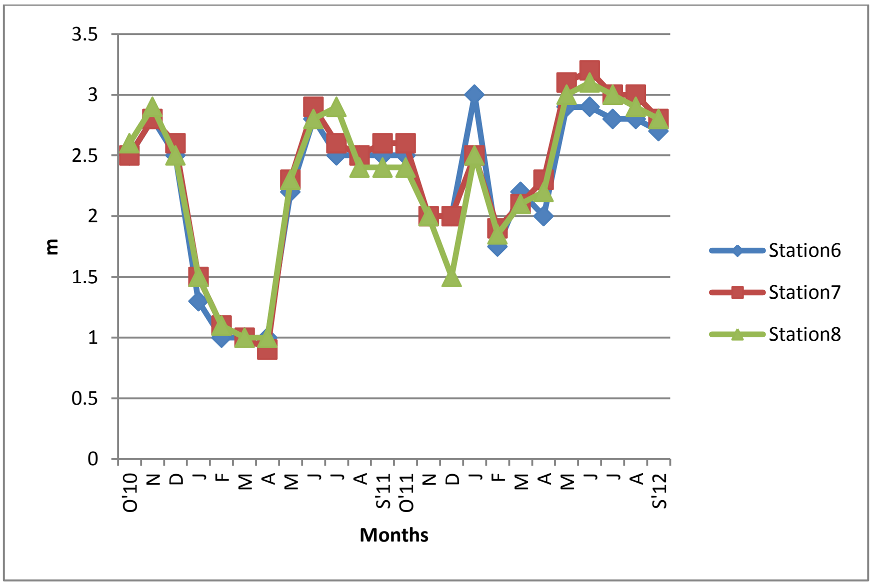


Fig. 4.3. Monthly variation in depth in stations 6 to 8 in Maranchery Kole wetland during the study period.

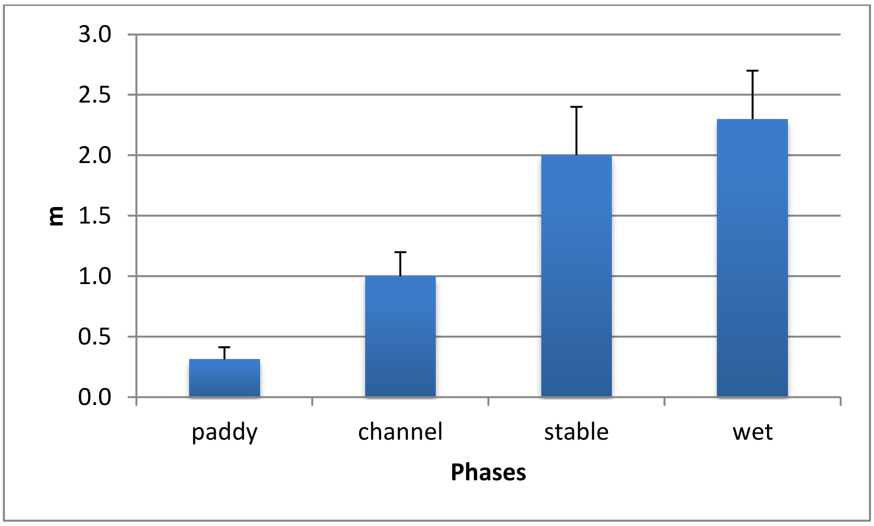


Fig.4.4. Mean variation in depth in various phases in Maranchery Kole wetland.

4.2.3. Atmospheric temperature

The results of the monthly variations in atmospheric temperature at the eight stations were given in Figures 4.5, and 4.6. Temperature ranged from 27.0°C (during June) to 33.5^{0}C (during March) with a difference of 6.5^{0}C. The mean atmospheric temperature registered the maximum during May and June(31.3^{0}C) followed by September (29^{0}C). A significant difference in the atmospheric temperature was noted in various stations (Table 4.2). Comparatively in other months, January 2012 month showed lowest temperature in all stations. The lowest temperature recorded in station 1 was 20.5^{0}C in January 2012 and highest was 32.5^{0}C in June 2012 with a mean value of 28.1^{0}C (±2.6). The atmospheric temperature ranged from 22^{0}C in January 2012 to 32^{0}C in June 2012 in station 2 showing a mean value of 28.3^{0}C (±2.31). The lowest atmospheric temperature recorded in station 3 was 25^{0}C in January 2012 and highest was 32^{0}C in April and June 2012 showing a mean value of 2.4 (±2.1). In station 4, the atmospheric temperature observed was 25^{0}C in November and December 2012 and the maximum was 32^{0}C in February 2012 with a mean value of 28.1 (±2.0). In

Station 5, it ranged from a minimum of 24.5^{0}C in the month of December 2011 to a maximum of 34^{0}C in the month of February 2009 (28.1 ± 2.5). Station 6, atmospheric temperature varied from a minimum of 24^{0}C in the month of January, 2012 to a maximum of 34^{0}C in the month of April 2012 (28.3 ± 2.2). While in station 7, the range was between 25.5^{0}C in January 2012 to 34^{0}C in April 2012, the mean value was 28.6 (±1.5). The lowest atmospheric temperature recorded in station 8 was 26^{0}C in January 2012 and highest was 35^{0}C in April 2012 showing a mean value of 29 (±2.2). The variation in atmospheric temperature in the wet, paddy, channel and stable phase was studied. The wet phase showed the maximum value of (28.7^{0}C) followed by stable phase (28.4^{0}C) channel phase (27.7^{0}C) and paddy phase (27.3^{0}C) respectively (Fig.4.7). The results of ANOVA showed that the observed difference in atmospheric temperature between phases was 5% significant ($P<0.05$).

Table.4.2. Mean variation of air temperature in Maranchery Kole wetland during the study period.

Stations	**Min (^{0}C)**	**Max (^{0}C)**	**Mean± SD**
Station 1	20.5	32.5	28.2±2.6
Station 2	22	32	28.3±2.4
Station 3	25	32	28.4±2.2
Station 4	25	32	28.1±2.1
Station 5	24.5	34	28.1±2.5
Station 6	24	34	28.3±2.2
Station 7	25.5	34	28.6±2.0
Station 8	26	35	29.1±2.2

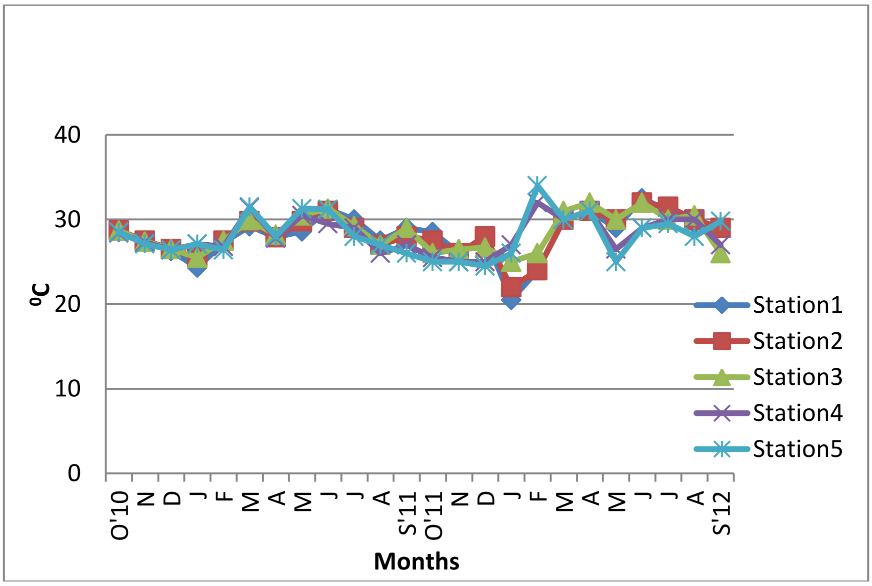


Fig.4.5. Monthly variation in air temperature in stations 1 to 5 in Maranchery Kole wetland during the study period.

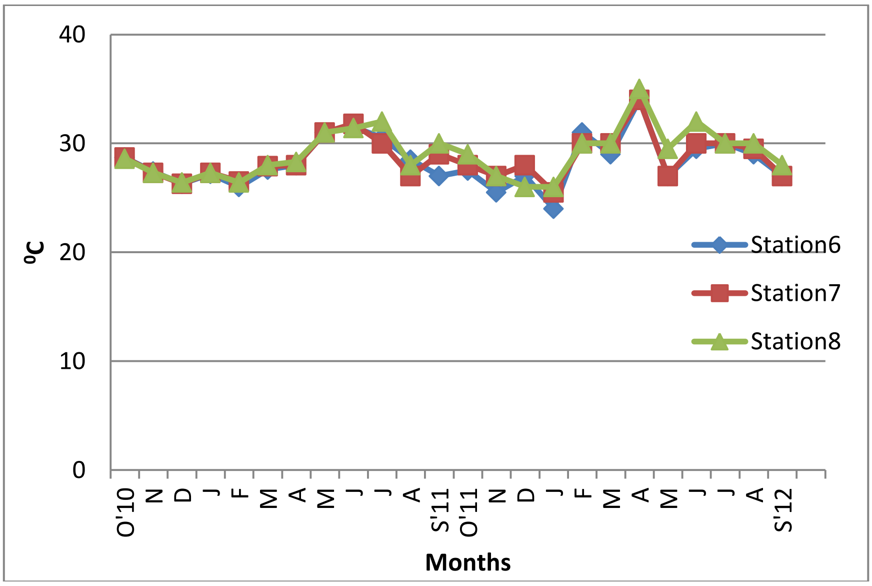


Fig.4.6. Monthly variation in air temperature in stations 6 to 8 in Maranchery Kole wetland during the study period.

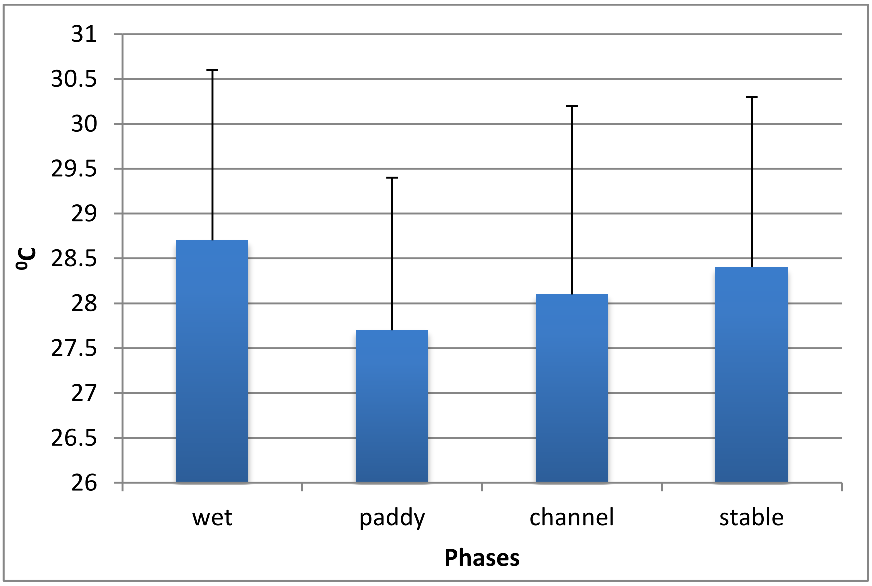


Fig.4.7. Mean variation in air temperature in various phases in Maranchery Kole wetland.

4.2.4. Water temperature

Surface water temperature measured in Maranchery Kole wetland during the period of study is given in Figs. 4.8 and 4.9. The average fluctuations in stations are given in Table 4.3. The highest water temperature was observed in month of February (35.0^{0}C) at station 5, while the lowest temperature was in January (21.0^{0}C)at Station 1 with a difference of 14^{0}C. The water temperature fluctuated from a minimum of 21°C in the month of January, 2012 to a maximum of 32^{0}C in the months of June, July, 2012 in station1(28.4± 2.6). In station 2, it varied from minimum of 22.5°C in January 2012 to a maximum of 32.5^{0}C in June, 2012 (28.3± 2.5). In station 3, it ranged from a minimum of 23.5°C in January 2011 to a maximum of32.5^{0}C in April 2011 (28.7 ± 2.3). The minimum water temperature was recorded in February 2011 (25.4) and maximum in March 2011 (33) from station 4 having a mean of 28.9 (±2.3). The mean temperature in station 5 was 28.6^{0}C (±2.7), ranging from 24^{0}C in December

2011 and January 2012 to 35^{0}C in February 2012. Station 6 showed the lowest value of 23^{0}C in January 2012 and highest value of 34.5^{0}C in April 2012 with a mean of 28.8^{0}C (±2.3). In station 7, it varied from a minimum of 26^{0}C in the month of January, 2012 a maximum of 34^{0}C in the month of April 2012 (29.3±1.9) whereas it fluctuated from a minimum of 26^{0}C in January, 2012 to a maximum of 34.5^{0}C in April 2012 in station 8 (29.5 ± 2.1). The comparison between phases showed that temperature was maximum in the stable phase showing a mean value of 29.0 ºC and minimum in the paddy phase 27.2 ºC (Fig.4.10).The observed difference in water temperature between phases was statistically significant at 1% level (P<0.01).

Table.4.3. Mean variation of water temperature in Maranchery Kole wetland during the study period.

Stations	**Min (^{0}C)**	**Max (^{0}C)**	**Mean± SD**
Station 1	21	32	28.4± 2.6
Station 2	22.5	32.5	28.3±2.5
Station 3	23.5	32.5	28.8±2.4
Station 4	25.4	33	28.9±2.3
Station 5	24	35	28.6±2.8
Station 6	23	34.5	28.9±2.4
Station 7	26	34	29.4±2.0
Station 8	26	34.5	29.6±2.1

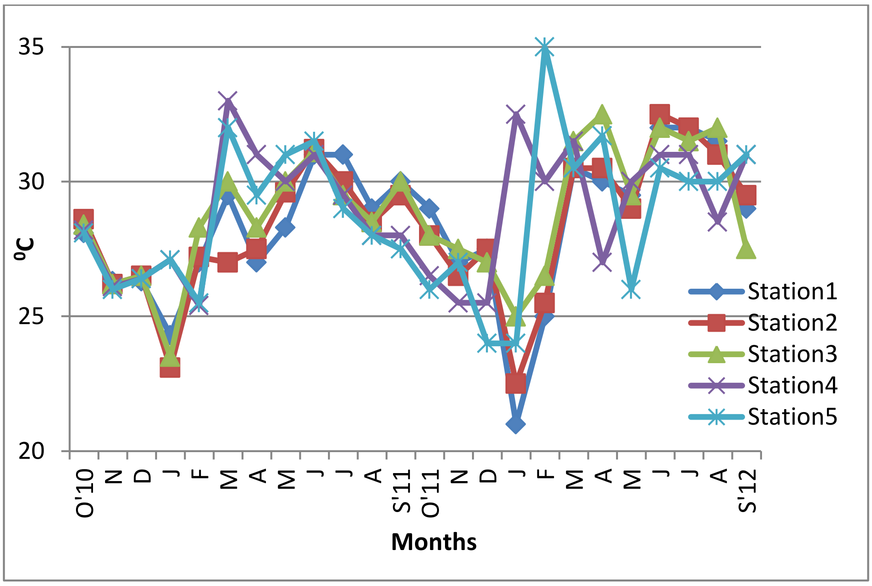


Fig.4.8. Monthly variation in water temperature in stations 1 to 5 in Maranchery Kole wetland during the study period.

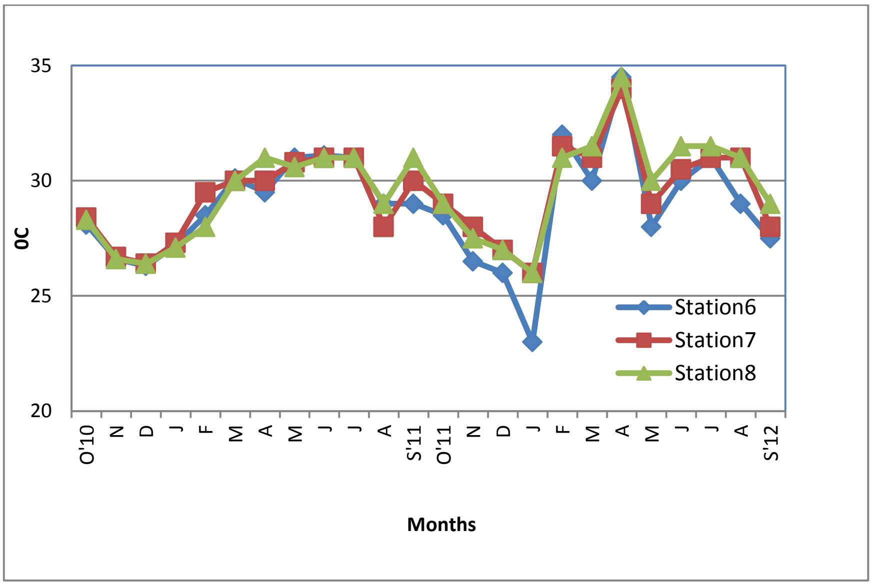


Fig.4.9. Monthly variation in water temperature in stations 6 to 8 in Maranchery Kole wetland during the study period.

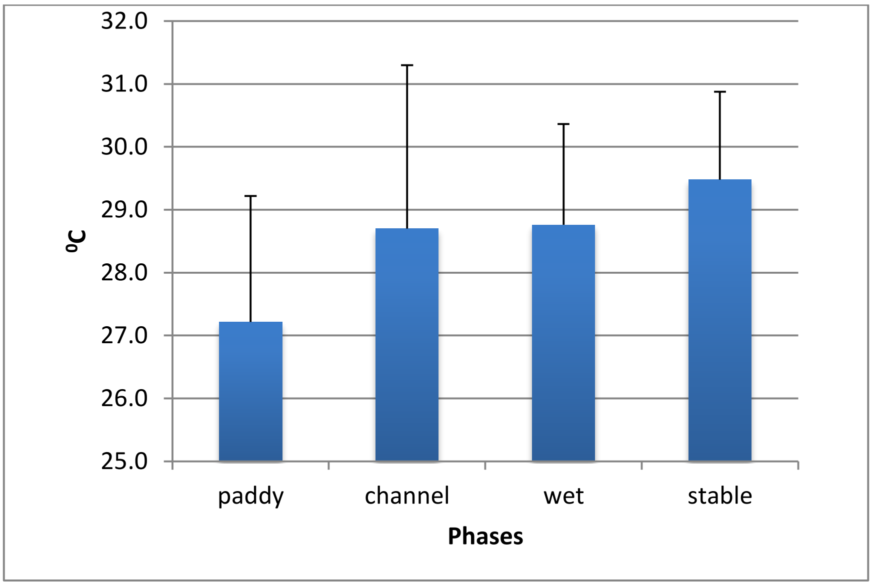


Fig.4.10. Mean variation in water temperature in various phases in Maranchery Kole wetland.

4.2.5. Hydrogen ion concentration (pH)

The mean variations in pH of Maranchery Kole is represented in Table 4.4. The results of the monthly variations in water pH at the eight stations are presented in Figs. 4.11 and 4.12. The pH values ranged from 3.1 to 8.9. The lowest pH value recorded was 3.1 in station 6 during May 2011 and the highest value was recorded (8.9) at station 4 during January 2011. The average pH remained neutral in study period (mean 6.78±0.43) except for few instances where a slightly acidic pH was noticed. In station1, it varied from a minimum of 3.6 in April, 2011 to a maximum of 7.7 in November 2011 (6.4 ± 0.92). In station 2, the mean pH was 6.6 (±0.49) that ranged from 5.1 in April 2011 to 7.4 in August 2012. Station 3 showed the lowest value of 5.8 in July 2011and highest value of 7.3 in August 2012 with a mean of 6.6 (±0.40). In station 4, January 2011 showed the lowest pH value of 4.3 whereas the highest value was in December 2010 (8.9) showing a mean of 6.3 (±0.91). In station 5, it fluctuated from a minimum of 4.1 in

May 2012 to a maximum of 7.1 in February 2012 (6.2±0.75). The mean pH was 6.3 (±0.84) in station 6, varying from 3.2 in April 2011 to 7.2 in March 2012. In station 7, it varied from a minimum of 3.7 in April 2011 to a maximum of 7.3 in March 2012 (9.0 ± 0.31) whereas in station 8, pH ranged from a minimum of 3.9 in April 2011 to a maximum of 7.5 in March, 2012 (6.5 ± 0.84). Phase wise trend in pH is given in Fig. 4.13. There was no wide variation seen in four phases in overall study period. The difference in water pH between phases wise was significant at 5% level ($P>0.05$).

Table.4.4. Mean variation of pH in Maranchery Kole wetland during the study period.

Stations	**Min (pH)**	**Max (pH)**	**Mean±SD**
Station 1	3.6	7.7	6.5±0.9
Station 2	5.1	7.5	6.6±0.5
Station 3	5.9	7.3	6.6±0.4
Station 4	4.2	9.0	6.4±0.9
Station 5	4.1	7.1	6.2±0.7
Station 6	3.2	7.2	6.4±0.8
Station 7	3.7	7.4	6.5±0.8
Station 8	4.0	7.5	6.6±0.8

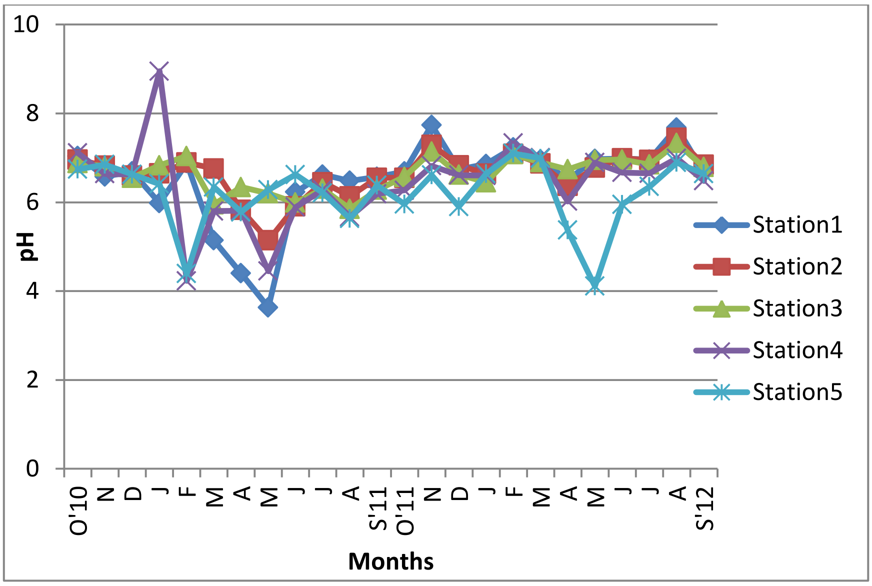


Fig.4.11. Monthly variation in pH in stations 1 to 5 in Maranchery Kole wetland during the study period.

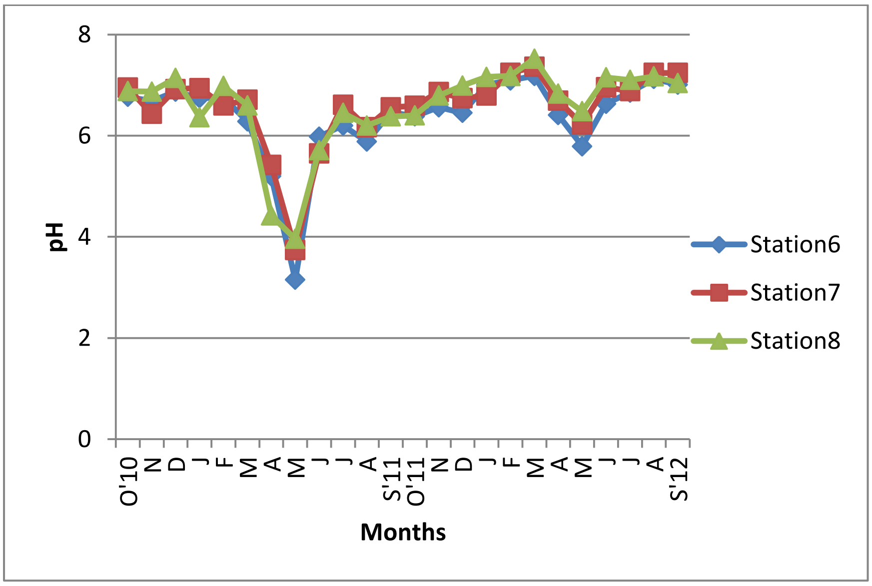


Fig.4.12. Monthly variation in pH in stations 6 to 8 in Maranchery Kole wetland during the study period.

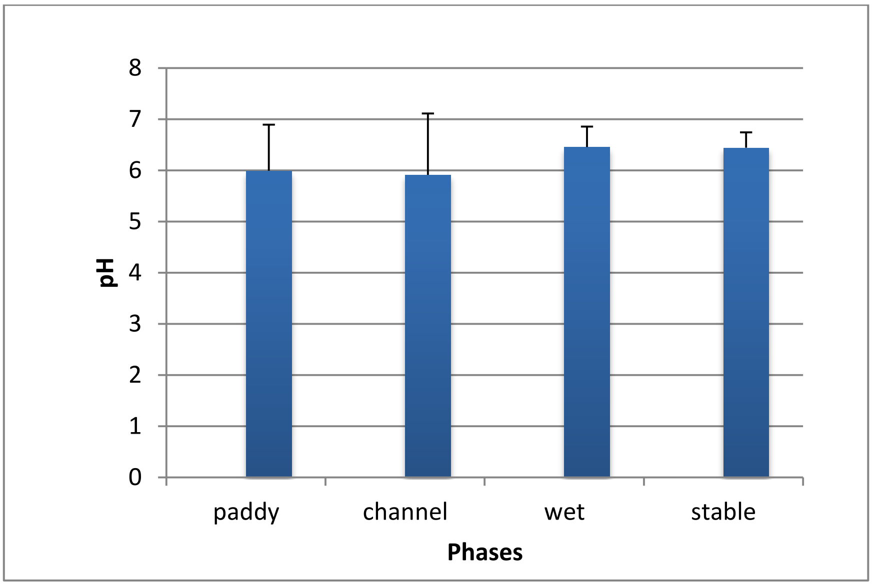


Fig.4.13. Mean variation in pH in various phases in Maranchery Kole wetland.

4.2.6. Conductivity

Figure 4.14 and 4.15 gives the conductivity values of water in different stations of Kole wetland during the period of study. The mean variation in conductivity is given in Table 4.5. Conductivity fluctuated between a minimum of 41.0 µScm^{-1} at station 1 in February 2010 to a maximum of 3589.0 µScm^{-1} in September 2011 at station 6. In February 2011 lowest conductivity was recorded in 8 study stations. In station 1, it varied from a minimum of 43.4 µScm^{-1} February 2011 to a maximum of 1270 µScm^{-1} in April 2012 (400µScm^{-1} ± 318.4). The minimum conductivity was recorded in February 2011 (60.3 µScm^{-1}) and maximum in April 2012 (1280 µScm^{-1}) from station 2 showing a mean value of 416.7 µScm^{-1} (±314.0). The mean conductivity in station 3 was 364.5 (±242.6), ranging from 53.5 in October 2010 to 928.0 in April 2012. In station 4, May 2011 showed the lowest conductivity value of 62.3 µScm^{-1} whereas the highest value was in April 2012 (1170 µScm^{-1}) showing a mean of 352.3

µScm^{-1} (±277.5). The mean conductivity was 504.1 µScm^{-1}(±724.0) in station 5, the range varied from 54.3 µScm^{-1} in October 2010 to 3540 µScm^{-1} in September 2012. In station 6, the mean conductivity was 498.0 µScm^{-1} (±714.7) varying from 48.2 µScm^{-1}in October 2010 to 3580 µScm^{-1}in September 2012. The conductivity ranged from 60.9 µScm^{-1} in February 2011 to 1150 µScm^{-1} in April 2012 in station 7 with a mean of 354.5 µScm^{-1} (±275.3). In station 8, the mean conductivity observed was 361.9 µScm^{-1} (±285.8) with a minimum value in October 2010 (58.3 µScm^{-1}) and maximum in April 2012 (1160 µScm^{-1}). Phase wise variation in conductivity values is given in Fig. 4.16. Compared to other phases average variation were higher in channel phases during the study period (1379.7 µScm^{-1}) followed by paddy phase (1247.7 µScm^{-1}) wet phase (326.3.0 µScm^{-1}) and stable phase (286.6 µScm^{-1}). Significant variation (5% level) in conductivity values was observed between phases (P>0.05).

Table.4.5. Mean variation of conductivity in Maranchery Kole wetland during the study period.

Stations	Min (µS/cm)	Max (µS/cm)	Mean±SD
Station 1	43.4	1270	400.93±18.5
Station 2	60.3	1280	416.8±314.0
Station 3	53.5	928	364.5±242.7
Station 4	62.3	1170	352.4±277.5
Station 5	54.3	3540	504.1±724.2
Station 6	48.2	3580	498.0±714.8
Station 7	60.9	1150	354.5±275.3
Station 8	58.3	1160	361.9±285.8

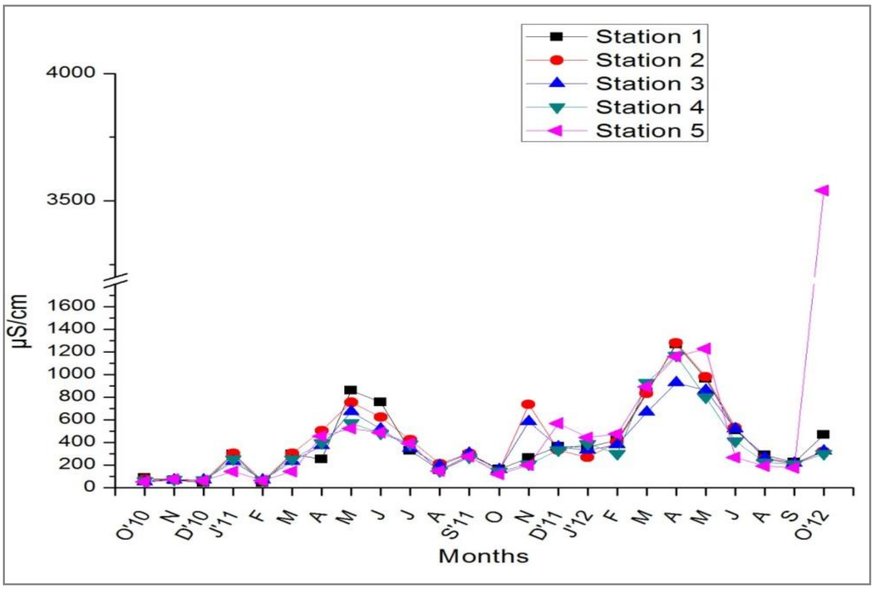


Fig.4.14. Monthly variation in conductivity in stations 1 to 5 in Maranchery Kole wetland during the study period.

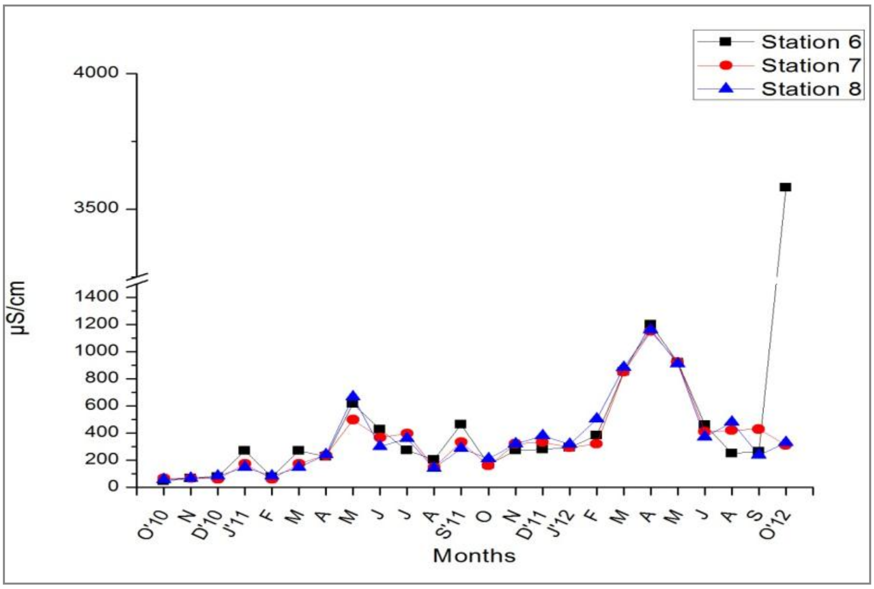


Fig.4.15. Monthly variation in conductivity in stations 6 to 8 in Maranchery Kole wetland during the study period.

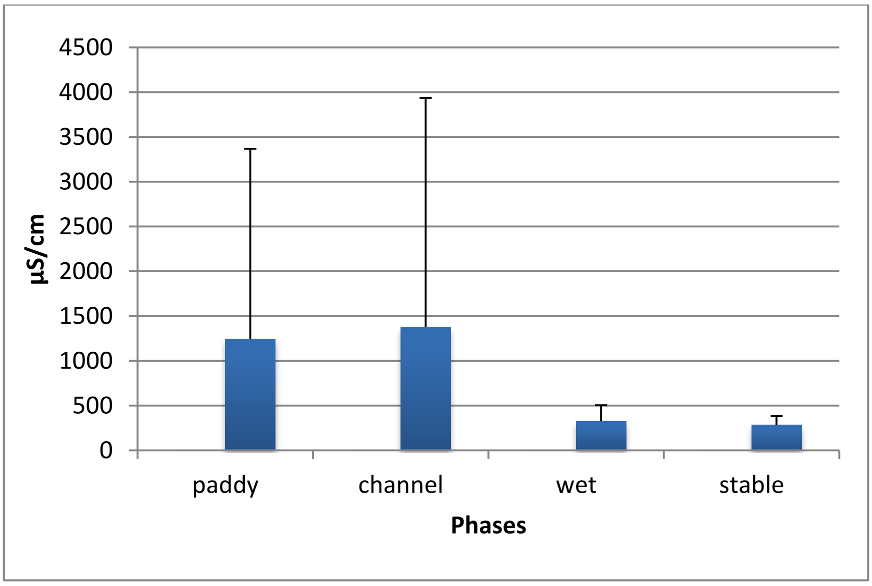


Fig.4.16. Mean variation in conductivity in various phases in Maranchery Kole wetland.

4.2.7. Total dissolved solids (TDS)

The total dissolved solids (TDS) ranged from 0.91 ppm to 670 ppm (Figs. 4.17 and 4.18). The average values of TDS in eight stations is given in Table 4.6. The least TDS recorded was 0.91 ppm at station 8 during February 2010 and the highest TDS of 670 ppm was recorded at station 1 during March 2011. In station1, it varied from a minimum of 24.6ppm in December 2010 to a maximum of 670ppm in March, 2011 (232.9 ± 182.5). In station 2, it fluctuated from a minimum of 33.7 ppm in December, 2010 to a maximum of 670 ppm in April, 2012 (242.9±176.5). In station 3, October 2010 showed the lowest TDS value of 28.1 ppm whereas the highest value was in May 2011 (490 ppm) showing a mean of 214.4 ppm (±135.0). The TDS was 202.1 ppm (±146.1) in station 4, the range varied from 33.3ppm in October 2010 to 600 ppm in April 2012. It ranged from

29.8 ppm in October 2010 to 1870 ppm in September 2012 in station 5 having a mean of 282.4 ppm (±378.6). In station 6, it varied from a minimum of 26.4 ppm in October, 2010 to a maximum of 1990 ppm in September, 2012 (283.4 ± 392.2) whereas in station7, it ranged from a minimum of 33.8 ppm in December 2010 to a maximum of 670 ppm in April 2012 (205.2 ±153.8). In station 8 the range of TDS varied 31.7 ppm in October 2010 to 574 ppm in April 2012 showing a mean of 224.1 ppm (±163). The paddy phase showed the maximum value of 820 ppm and the wet phase showed the minimum value of 125.8 ppm (Fig. 4.19). The results of ANOVA showed that there existed a significant variation in TDS at 1% level between phases (P<0.01).

Table4.6. Mean variation of in total dissolved solids in Maranchery Kole wetland during the study period.

Stations	**Min (ppm)**	**Max (ppm)**	**Mean±SD**
Station 1	24.6	670	233.0±182.6
Station 2	33.7	670	243.0±176.6
Station 3	28.1	490	214.4±135.1
Station 4	33.3	600	202.2±146.1
Station 5	29.8	1870	282.5±378.7
Station 6	26.4	1990	283.5±392.2
Station 7	33.8	670	205.3±153.8
Station 8	31.7	574	224.1±163.1

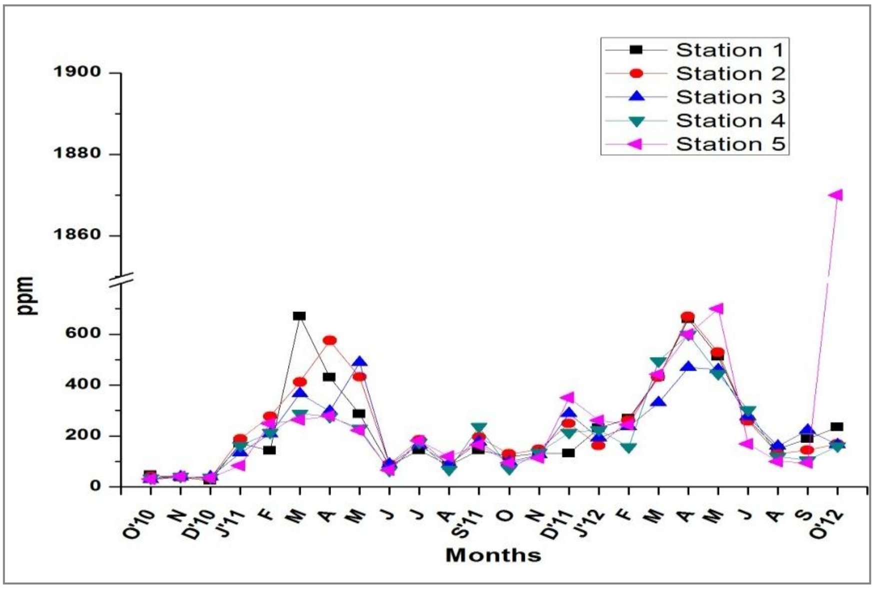


Fig.4.17. Monthly variation in total dissolved solids in stations 1 to 5 in Maranchery Kole wetland during the study period.

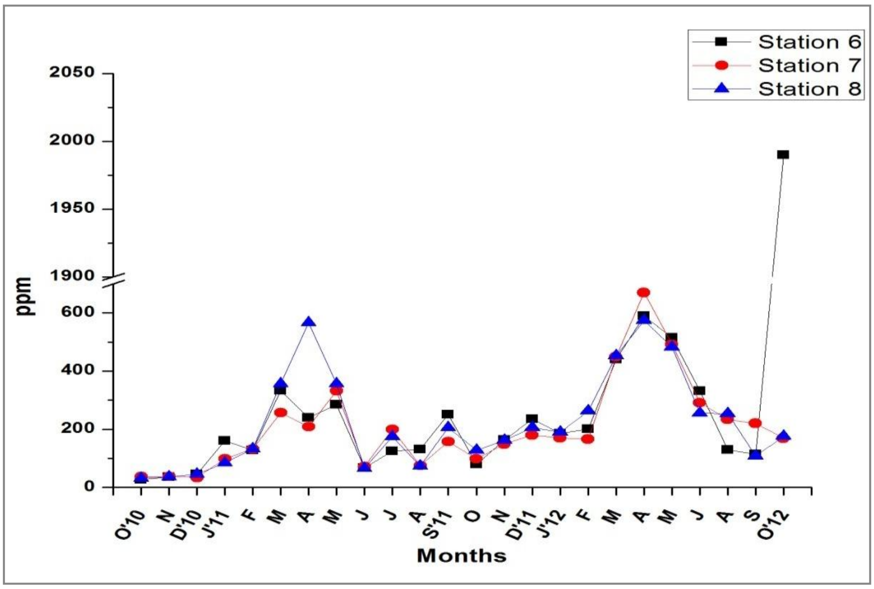


Fig.4.18. Monthly variation in total dissolved solids in stations 6 to 8 in Maranchery Kole wetland during the study period.

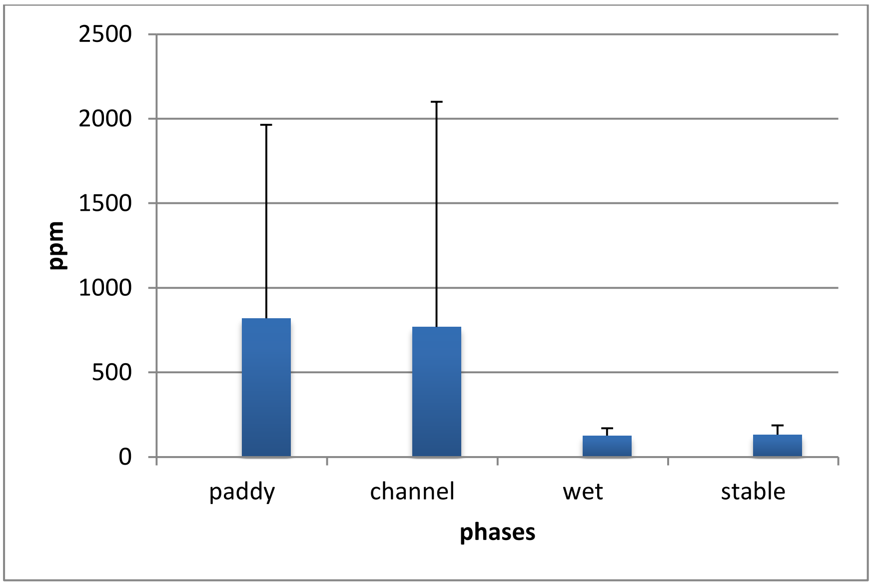


Fig.4.19. Mean variation in total dissolved solids in various phases in Maranchery Kole wetland.

4.2.8. Turbidity

The observed variations in turbidity values were illustrated in Figs. 4.20 and 4.21. The turbidity values ranged between 0.67 NTU to 50 NTU. Mean variations of turbidity in eight stations are given in Table 4.7. When the monthly variation of turbidity during the study period considered, the maximum value of 50 NTU was observed in January 2011 at Station 4 and the minimum of 0.67 NTU in October 2010 at Station 6. In station 1, the mean turbidity was 8 NTU (±8.6) with a minimum of 2.1 NTU in November 2010 and maximum turbidity of 40 NTU in January 2011 while in station 2, the minimum turbidity recorded was 1.6 NTU in November 2010 and the maximum of 22 NTU in April 2011. The mean turbidity was 6.9 NTU (±4.9). In station 3, it fluctuated from a minimum of 1.8 NTU in November 2010 to a maximum of 20 NTU in June and February 2011 (7.0 ± 4.3). In station 4, it ranged from a minimum of 1.1 NTU in October 2010 to a maximum of 50 NTU in January 2011 (9.45 ± 9.7). In station 5, turbidity ranged from 2.5 NTU in October 2010 to 44 NTU in January 2011, 11(±9.7) being the mean value. Station 6 showed a mean turbidity of 6.7 NTU (±4.3). The lowest turbidity recorded was 0.67 NTU in October 2010 and highest was 20 NTU in November 2011. In station 7, it varied from a minimum of 1.5 NTU in October 2010 to a maximum of 15 NTU in March 2011 (5.5 ± 3.0) whereas in station 8, it ranged from a minimum of 1.8 NTU in October 2010 to a maximum of 21 NTU in March 2011 (5.7±4.0). The phase wise mean values (Fig. 4.22) of turbidity showed that minimum was observed during stable phase and maximum in channel phase. The lowest turbidity values was obtained during stable phase with 5.6 NTU and the maximum value was 17.1 NTU in the channel phase. Paddy phase registered the mean turbidity value 12 NTU and average variation of showed that wet phase was 6.5 NTU. The ANOVA of turbidity between phases was found to be significant at 1% level (P<0.01) (Table 4.14).

Table 4.7. Mean variation of turbidity in Maranchery Kole wetland during the study period.

Stations	Min (NTU)	Max (NTU)	Mean±SD
Station 1	2.1	40	8.08±8.6
Station 2	1.6	22	6.94±4.9
Station 3	1.8	20	7.06±4.4
Station 4	1.1	50	9.45±9.7
Station 5	2.5	44	11.0±9.9
Station 6	0.67	20	6.71±4.4
Station 7	1.5	15	5.59±3.0
Station 8	1.8	21	5.70±4.0

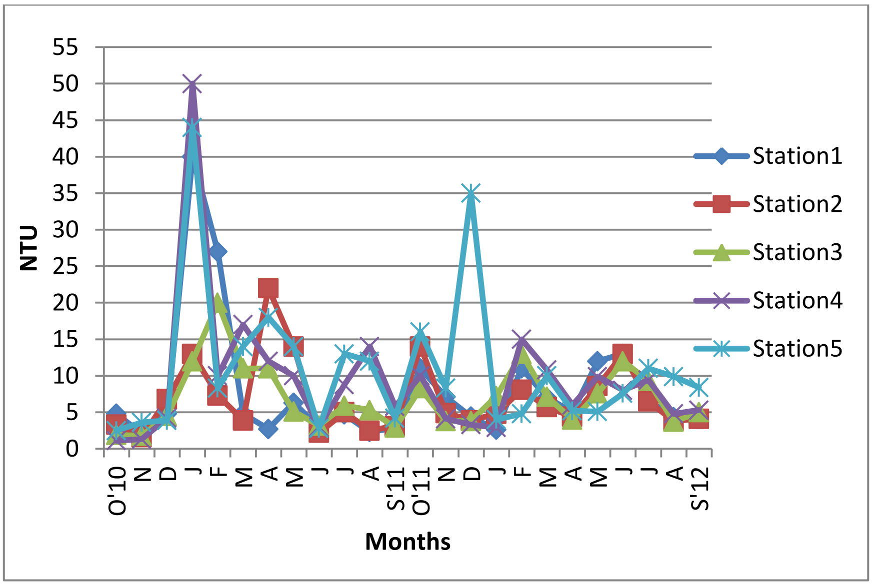


Fig.4.20. Monthly variation in turbidity in stations 1 to 5 in Maranchery Kole wetland during the study period.

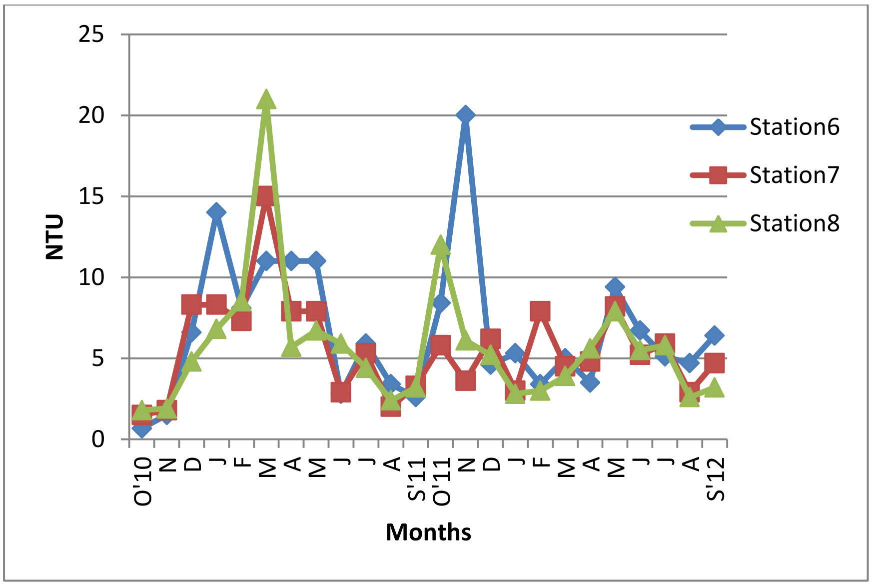


Fig.4.21. Monthly variation in turbidity in stations 6 to 8 in Maranchery Kole wetland during the study period.

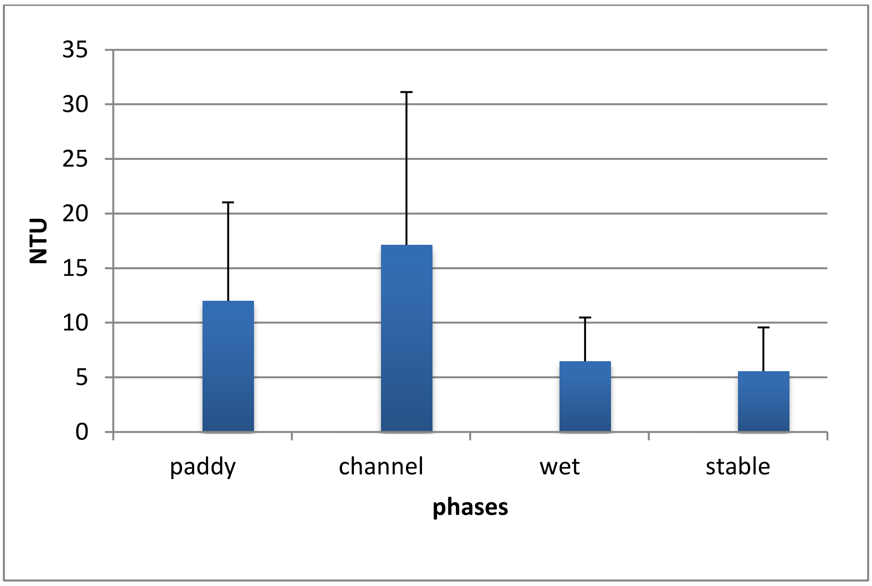


Fig.4.22. Mean variation in turbidity in various phases in Maranchery Kole wetland.

4.2.9. Dissolved Oxygen (DO)

The dissolved oxygen ranged from 2.4 mg/L to 10.2 mg/L (Figs. 4.23 and 4.24). The minimum mean value of DO was 6.9(± 1.2)mg/L . The lowest dissolved oxygenvalue2.4 mg/L was noted at station 3 and 5 during various months, August 2011, October 2012 and November 2012 and the highest values of 12 mg/L was observed in station 3 during March 2012. The mean station wise values are given in Table 4.8. In station 1 the range of dissolved oxygen varied 3.2 mg/L in April 2011, 2012 and May 2012 to 9.2 mg/L in July 2011 showing a mean of 6.2 mg/L(±1.8). In station 2, it varied from a minimum of 3.2 mg/L in the months of April 2012 and May 2012 to a maximum of 9.6 mg/L in August 2011(6.4 ± 1.8), whereas in station 3, it ranged from a minimum of 4 mg/L in August 2011 to a maximum of 12 mg/L in March 2012 with a mean value of 6.8 ±1.4. In station 4, it fluctuated from a minimum of 2.4 mg/L in the months of August 2011and July 2012 to a maximum of 8.0 mg/L in the months of October, November 2010 and February, March 2012 (5.4 ± 1.8). In station 5, it varied from a minimum of 2.4 mg/L in the months of October, November 2010 and July 2012 to a maximum of 8.2 mg/L in the month of February 2012 (5.0 ± 1.9). In station 6, December 2010 and January 2011 showed the lowest value of 4.8 mg/L whereas the highest value was in February 2011 (10mg/L) showing a mean of 6.8 mg/L (±1.3). The average value of dissolved oxygen was 7.3mg/L (±1.3) in station 7, the range varied from 4.8 mg/L in May 2012 and 10.2 mg/L in February 2011. The lowest dissolved oxygenvalue(4.8 mg /L) was noted at station 8 during September 2012 and the highest value (9.6 mg/L) in February 2012 with an average value of 7.2mg/L±1.2. Phase wise variation noticed during the study period (Fig.4.25) In this study period maximum value (7.7mg/L) were observed during stable phase followed by paddy phase and channel phase (6.2mg/L) and wet phase (5.7mg/L) respectively. The ANOVA of dissolved oxygen showed an overall significance at 1% level in phase wise(P<0.01), station wise (P<0.01) and between phase*station interaction (P<0.01).

Table 4.8. Mean variation of dissolved oxygen in Maranchery Kole wetland during the study period.

Stations	Min(mg/L)	Max(mg/L)	Mean±SD
Station 1	3.2	9.2	6.2±1.9
Station 2	3.2	9.6	6.5±1.8
Station 3	4	12	6.9±1.6
Station 4	2.4	8	5.5±1.9
Station 5	2.4	8.2	5.0±2.0
Station 6	4.8	10	6.8±1.4
Station 7	4.8	10.2	7.4±1.3
Station 8	4.8	9.6	7.3±1.2

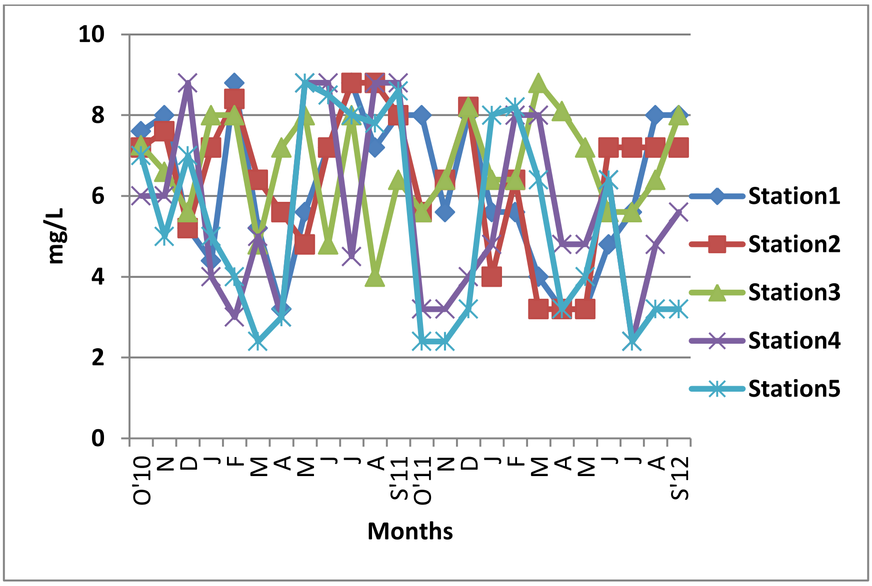


Fig.4.23. Monthly variation in dissolved oxygen in stations 1 to 5 in Maranchery Kole wetland during the study period.

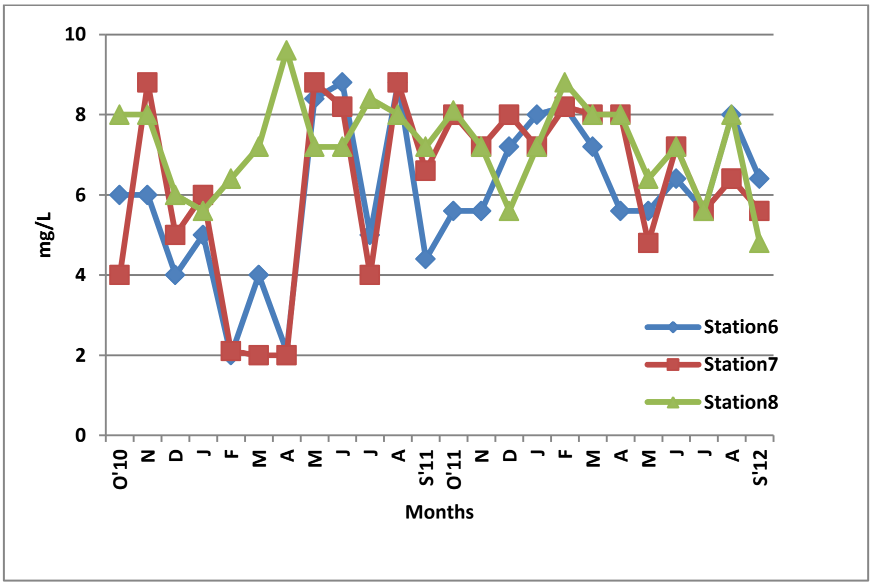


Fig.4.24. Monthly variation in dissolved oxygen in stations 6 to 8 in Maranchery Kole wetland during the study period.

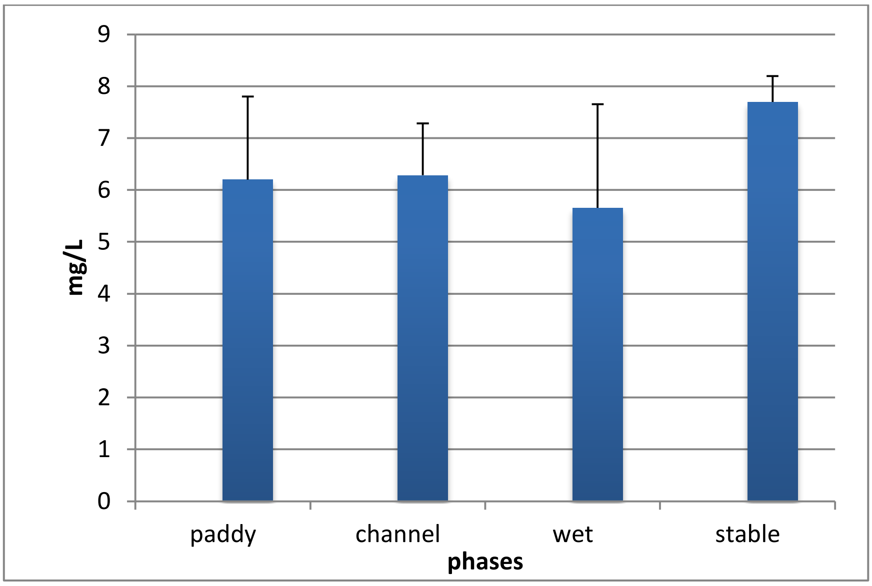


Fig.4.25. Mean variation in dissolved oxygen in various phases in Maranchery Kole wetland.

4.2.10. Alkalinity

Details of total alkalinity of water at different stations in the Kole land are given in Figs. 4.26 and 4.27. Station wise average variations are given in Table 4.9. The highest reported value was 160 mg/L at station 1 during January 2011 and lowest recorded value was 8 mg/L at station 7 during May 2011. In present investigation peak values of alkalinity was recorded during January 2011 in all eight stations. The alkalinity fluctuated from a minimum of 12 mg/L in May, 2011 to a maximum of 160 mg/L was in January 2011 in station with an average of 32.0 ± 29.4 mg/L. In station 2, it varied from minimum of 12 mg/L in June 2011 to a maximum of 88 mg/L in January 2011 (30.6 ± 17.3). In station 3, it ranged from a minimum of 16 mg/L in September 2011 to a maximum of 152 mg/L in January, 2011 (32.6 ± 26.9). The mean alkalinity in station 4 was 29.1 mg/L±20.6 with the minimum and maximum being 12 mg/L in June 2011 and 112 mg/L in

January 2011 respectively. In station 5 the range was 12 mg/L in May 2012 to 108 mg/L in January 2011 with an average alkalinity of 27.5 mg/L±18.9. In station 6, a mean alkalinity of 28.5 mg/L(±19.3) was recorded with the lowest value in May, 2012 (12 mg/L) and highest in January 2011 (112mg/L). Station 7 showed the minimum value of 8.0 mg/L in May 2011 and the maximum value of 116mg/L in January 2011 with a mean of 29.3 mg/L(±20.5). It ranged from 12 mg/L in May 2011 to 100 mg/L in January 2011 in station 8(28.6 ±17.4). The lowest mean value of alkalinity was recorded at 22 mg/L in stable phase and highest at 47.2 mg/L during paddy phase. Average value of wet phase was 30.0 mg/L and channel phase was 41.0 mg/L (Fig. 4.28). ANOVA of alkalinity was significant at 5% level between phases (P<0.05), stations (P>0.05) and phase *stations (P>0.05) during the study period.

Table 4.9. Mean variation of alkalinity in Maranchery Kole wetland during the study period.

Stations	**Min(mg/L)**	**Max (mg/L)**	**Mean±SD**
Station 1	12	160	32.08±29.47
Station 2	12	88	30.67±17.32
Station 3	16	152	32.67±26.91
Station 4	12	112	29.17±20.68
Station 5	12	108	27.50±18.99
Station 6	12	112	28.50±19.36
Station 7	8	116	29.33±20.59
Station 8	12	100	28.67±17.40

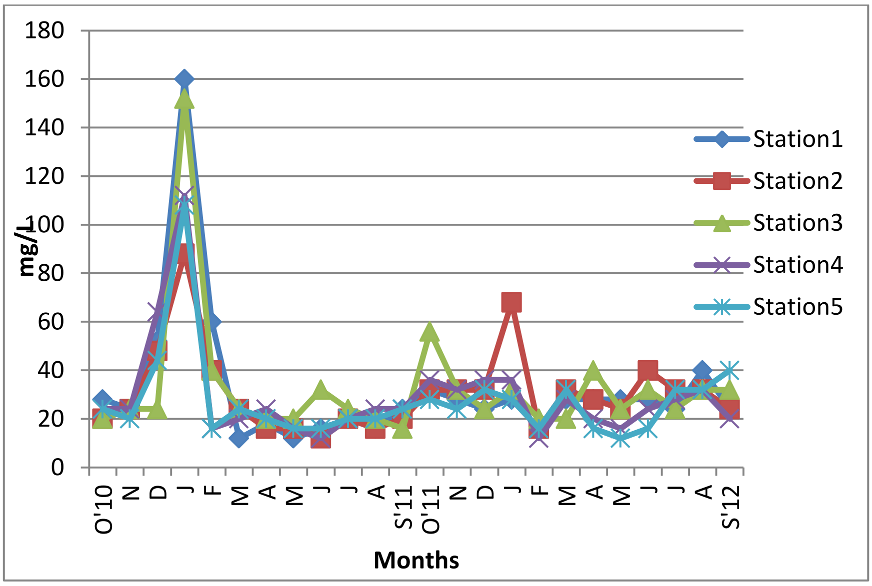


Fig.4.26. Monthly variation in alkalinity in stations 1 to 5 in Maranchery Kole wetland during the study period.

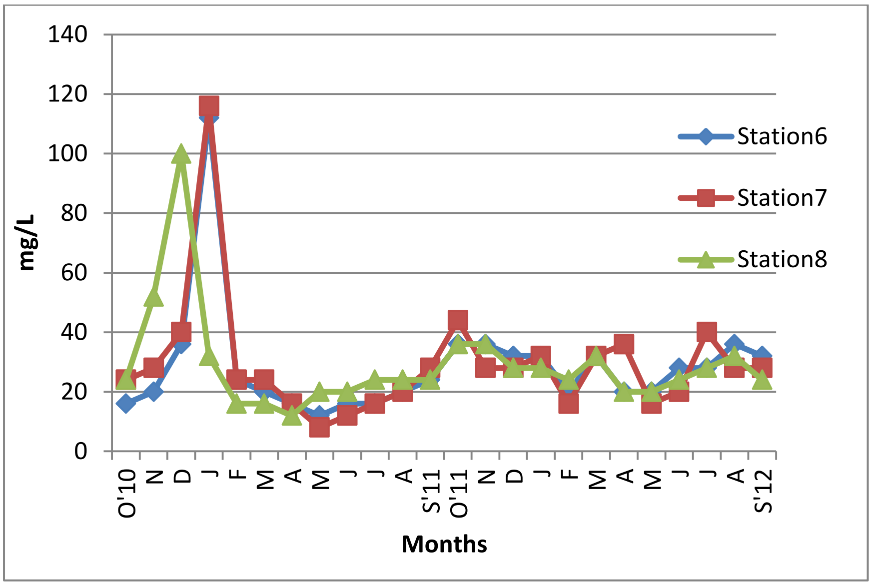


Fig.4.27. Monthly variation in alkalinity in stations 6 to 8 in Maranchery Kole wetland during the study period.

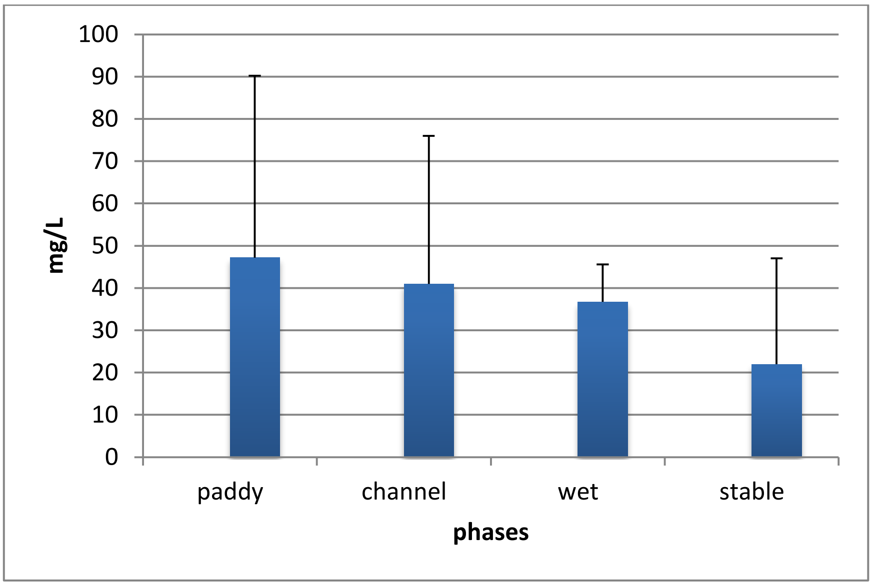


Fig.4.28. Mean variation in alkalinity in various phases in Maranchery Kole wetland.

4.2.11. Salinity

Monthly fluctuation in salinity of water in the different stations at Maranchery Kole lands is presented in Figs. 4.29 and 4.20 and mean values is given in Table 4.10. The salinity ranged from 0.04 ppt at Station 1 during December 2010 and maximum of 3.6 ppt at station 6 in September 2012. Compared to other months in the year 2010, in all stations December showed very low salinity. In station 1, salinity ranged from 0.04 ppt in December 2010 to 1.27 ppt in April 2012 with an average of 0.44±0.32, whereas in station 2 the range was between 0.05 ppt in December 2010 to 1.28 ppt in April 2012 and 0.4±0.3 being the mean salinity. The salinity showed the lowest value in December 2010 (0.06 ppt) and highest in July 2012 (0.96 ppt) with an average of 6.40±0.25 in station 3. The mean salinity in station 4 was 0.41±0.29 with the minimum and maximum being 0.05 ppt in December 2010 and 1.13 ppt in April 2012 respectively. In station 5 the range of salinity was 0.05 ppt in December 2010 and 3.54 ppt in September

2012 with an average of 0.56±0.71. The average salinity in station 6 was 0.53±0.72 ranging from 0.06 ppt in December 2010 to 3.64 ppt in September 2012. In station 7, it ranged from 0.05 ppt in December 2010 to 1.07 ppt in April 2012 with an average of 0.38±0.29, whereas in station 8 the range was between 0.07 ppt in December 2010 to 1.08 ppt in April 2012 respectively (0.37±0.27). Phase wise mean values showed that salinity was highest during paddy phase (0.35ppt) followed by channel phase (0.27ppt), wet phase (0.24ppt) and stable phase (0.23ppt) respectively (Fig.4.31). The observed difference in salinity between phases was statistically significant at5% level (P>0.05).

Table 4.10. Mean variation of salinity in Maranchery Kole wetland during the study period.

Stations	Min(ppt)	Max(ppt)	Mean±SD
Station 1	0.04	1.27	0.44±0.32
Station 2	0.05	1.28	0.42±0.30
Station 3	0.06	0.96	0.40±0.25
Station 4	0.05	1.13	0.41±0.29
Station 5	0.05	3.54	0.56±0.71
Station 6	0.06	3.64	0.53±0.72
Station 7	0.05	1.07	0.38±0.29
Station 8	0.07	1.08	0.37±0.27

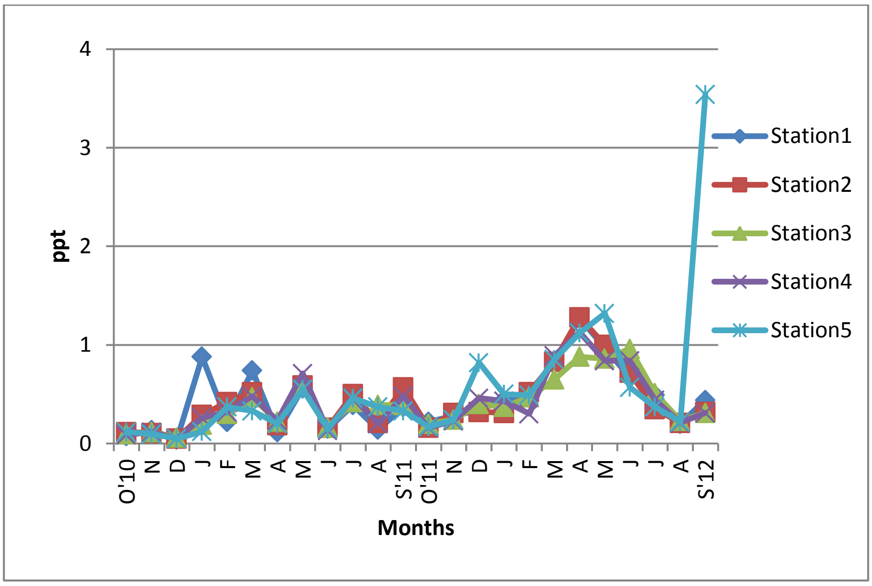


Fig.4.29. Monthly variation in salinity in stations 1to 5 in Maranchery Kole wetland during the study period.

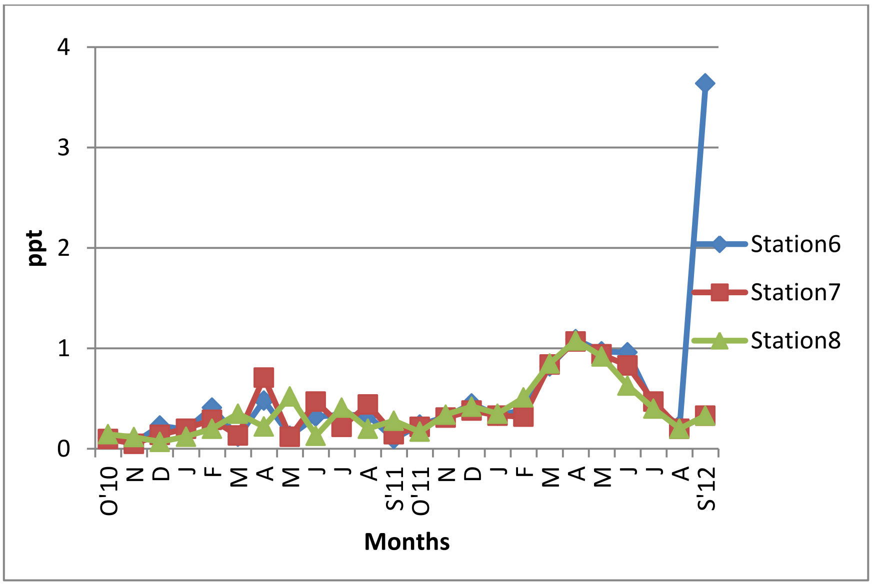


Fig.4.30. Monthly variation in salinity in stations 6 to 8 in Maranchery Kole wetland during the study period.

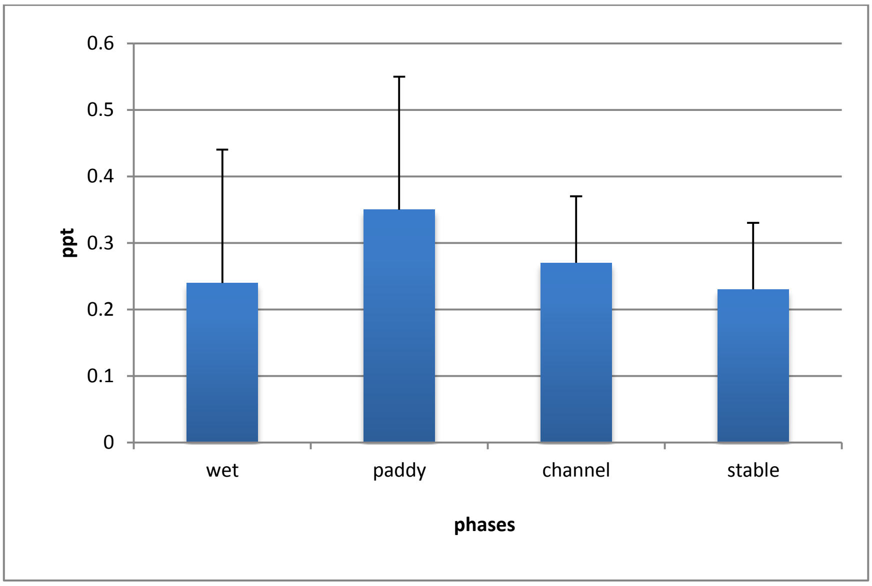


Fig.4.31. Mean variation in salinity in various phases in Maranchery Kole wetland.

4.2.12. Chloride

The results of the monthly variations in the chloride content of water at the different stations were given in Figs. 4.32 and 4.33. The mean variations in eight stations is given in Table 4.11. In present study higher concentration of chloride were recorded during May 2011 in 8 stations. The lowest chloride value(5.9 mg/L) was noted at station 8 during August 2011and the highest value(229.9 mg/L) was in the station 2 during May 2011. Chloride varied from a minimum of 14 mg/L in July 2011 to a maximum of 152 mg/L in May 2011 in station 1 with an average of 53.9$\underline{+}$40.7. It fluctuated from a minimum of 10.0 mg/L in August and September 2011 to a maximum of 229.9 mg/L in May 2011 in station 2 (65.0 ± 63.2). In station 3, it varied from minimum of 10 mg/L in August 2011 to a maximum of 134 mg/L in April 2011 showing a mean of 50.4 mg/L (±40.0). Station 4 showed a minimum value of 12 mg/L in August and September 2011 to a maximum of 191.9 mg/L May 2011 (56.4 ± 53.6). In station 5, a mean chloride of 46.7 mg/L (±37.2) was recorded with the lowest value in August and October 2011 (12.0 mg/L) and highest in May 2011 (130.0 mg/L). In station 6, it varied from a minimum of 10 mg/L in August 2011 a maximum of 120 mg/L in May 2011 (43.2 ± 31.6), whereas it fluctuated from a minimum of 12 mg/L in September 2011 to a maximum of 136 mg/L in May 2011 in station 7 with an average value of 40.9 ± 31.1. The range of chloride varied between 6.0 mg/L in August 2011 to163.9 mg/L in May 2011 in station 8 having mean value of 46.6 mg/L(±44.9). There was significant variation in chloride between wet, paddy, channel and stable phases. Chloride was maximum in the paddy phase showing a mean value of 93.4mg/L and minimum in the wet phase 18.1mg/L (Fig.4.34). ANOVA of chloride in the water showed there was 1% level significant difference between phases (P< 0.01).

Table 4.11. Mean variation of chloride in Maranchery Kole wetland during the study period.

Stations	Min(mg/L)	Max(mg/L)	Mean±SD
Station 1	14.0	152.0	53.9±40.7
Station 2	10.0	229.9	65.0±62.3
Station 3	10.0	134.0	50.4±40.0
Station 4	12.0	191.9	56.4±53.6
Station 5	12.0	130.0	46.7±37.2
Station 6	10.0	120.0	43.2±31.6
Station 7	12.0	136.0	40.9±31.1
Station 8	6.0	163.9	46.6±44.9

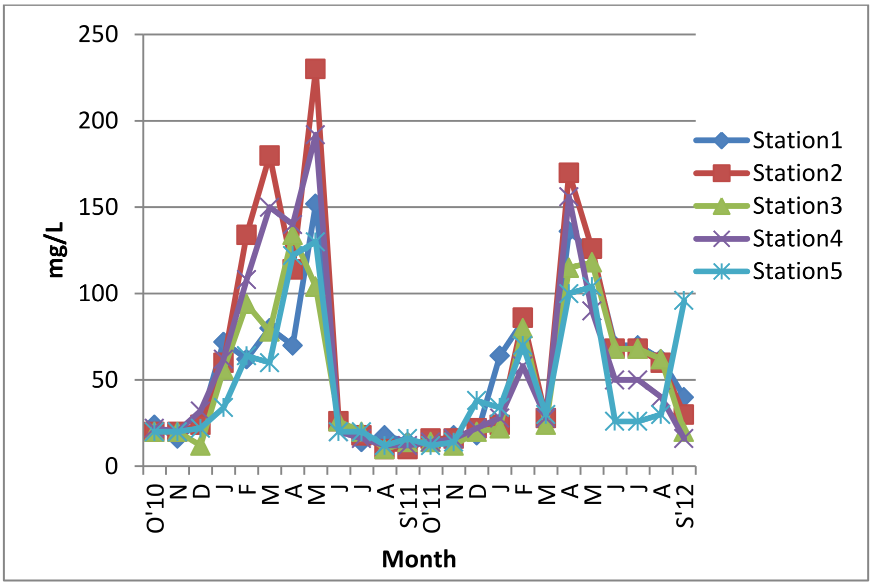


Fig.4.32. Monthly variation in chloride in stations 1to 5 in Maranchery Kole wetland during the study period.

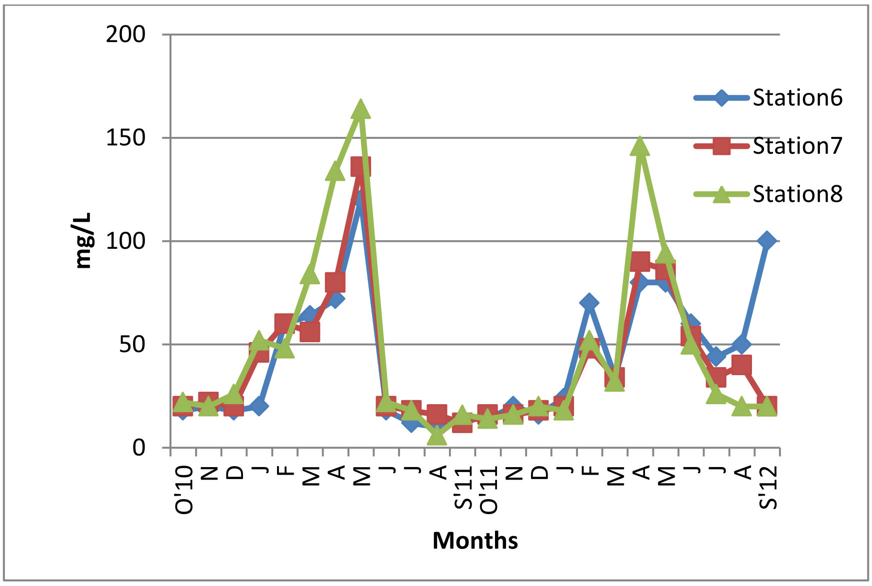


Fig.4.33. Monthly variation in chloride in stations 6 to 8 in Maranchery Kole wetland during the study period.

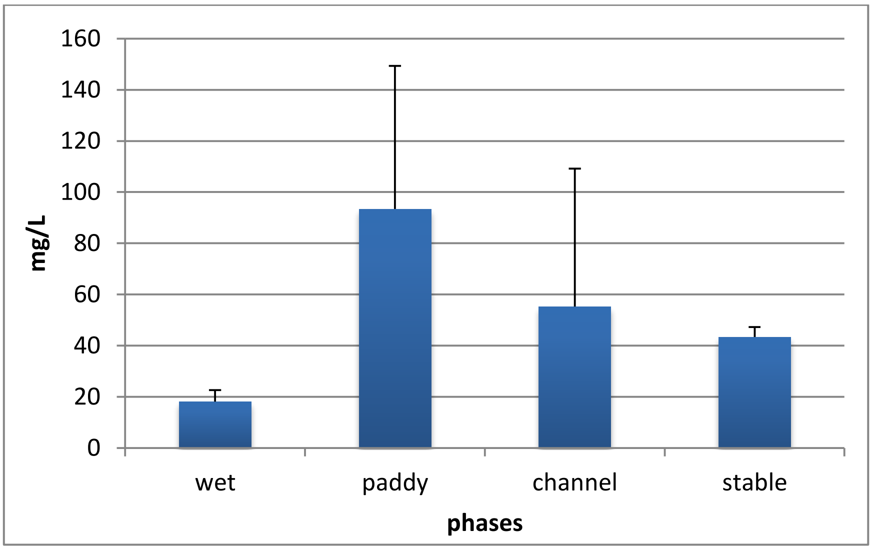


Fig.4.34. Mean variation in chloride in various phases in Maranchery Kole wetland.

4.2.13. Total hardness

The details of the hardness of water recorded during the period of study in this wetland are given in Figs. 4.35.and 4.36. The average variations in eight stations were noticed and given in Table 4.12. In general, the hardness recorded in Maranchery wetland varied from 16mg/L to 136 mg/L among the different stations. The maximum hardness was 136 mg/L at station 1 in January 2011 and station 8 in April 2011 and the lowest hardness was observed (16 mg/L) in Station 4 during June 2011period. In station 1, the maximum hardness of 136 mg/L was recorded during January 2011 and minimum of 20 mg/L in October 2010 and August 2011 with a mean value of 56.0 mg/L (± 27.3). The maximum hardness recorded in station 2 was 116 mg/L during May 2012 and minimum 16 mg/L in June 2011, the mean value being 55.5 mg/L (±27.9). In station 3 the maximum hardness value was 92 mg/L during April 2011 and minimum was 20 mg/L in November and December 2010 period. The mean hardness in station 3 was 52 mg/L (±17.2). The highest hardness recorded from station 4 was 120 mg/L during April 2011 and lowest was 16 mg/L in December 2010 with a mean of 56.8 mg/L (±28.1). In station 5, it ranged from a maximum of 108 mg/L in the months of April 2012 and September 2012 to a minimum of 24 mg/L in the months of November and December 2010 (55.6 ± 25.9) whereas it fluctuated from a maximum of 96 mg/L in September 2012 to a minimum of 20 mg/L in November 2010 in station 6 (52.0 ± 20.7). The maximum hardness in station 7 was 120 mg/L during May 2011 and minimum was 20 mg/L in November 2010 with 53.3 mg/L (±20.9) being the mean hardness. In station 8 the maximum hardness observed was 136 mg/L during April 2011 and minimum was 24 mg/L in November and December 2010 showing a mean of 56.5 mg/L (±29). When hardness was analyzed, significant variation was seen between wet, paddy, channel and stable phases (Fig. 4.37). The minimum hardness was recorded in wet phase (43.5mg/L) and maximum in paddy phase in this study period (64.6 mg/L). ANOVA result of hardness showed there was no significant difference between stations and shows a significant variation at 1% level between phases(P<0.01).

Table 4.12. Mean variation of total hardness in Maranchery Kole wetland during the study period.

Stations	Min(mg/L)	Max(mg/L)	Mean±SD
Station 1	20.0	136.0	56.0±27.3
Station 2	16.0	116.0	55.5±27.9
Station 3	20.0	92.0	52.0±17.2
Station 4	16.0	120.0	56.8±28.2
Station 5	24.0	108.0	55.7±25.2
Station 6	20.0	96.0	52.0±20.7
Station 7	20.0	120.0	53.4±20.9
Station 8	24.0	136.0	56.5±29.0

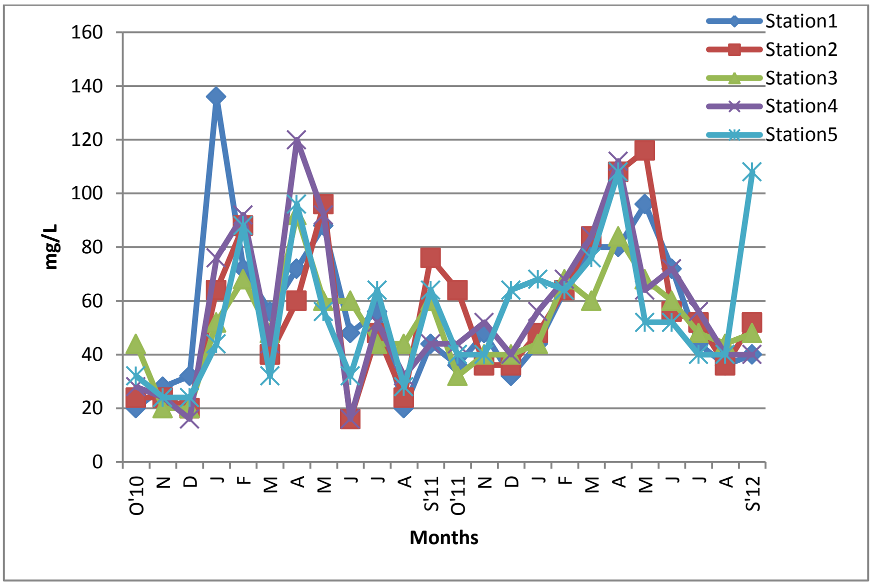


Fig.4.35. Monthly variation in total hardness in stations 1 to 5 in Maranchery Kole wetland during the study period.

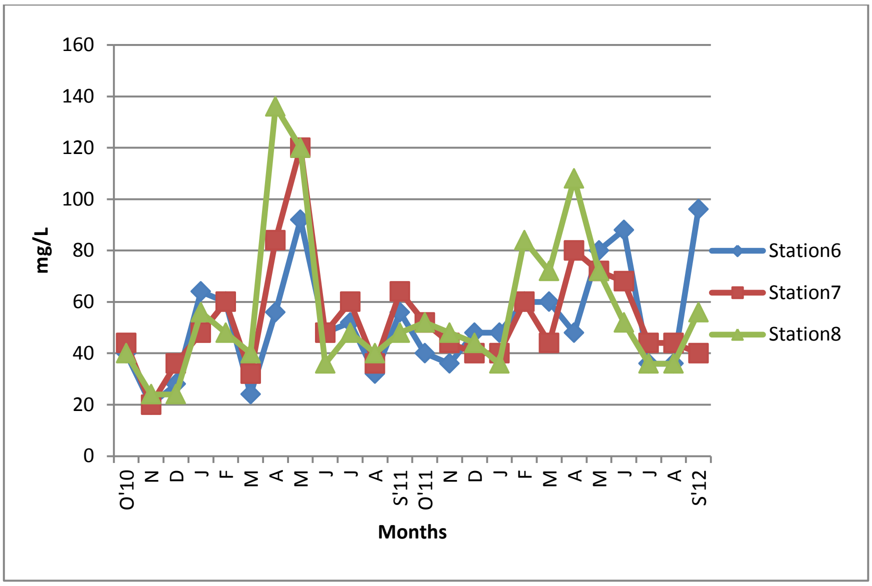


Fig.4.36. Monthly variation in total hardness in stations 6 to 8 in Maranchery Kole wetland during the study period.

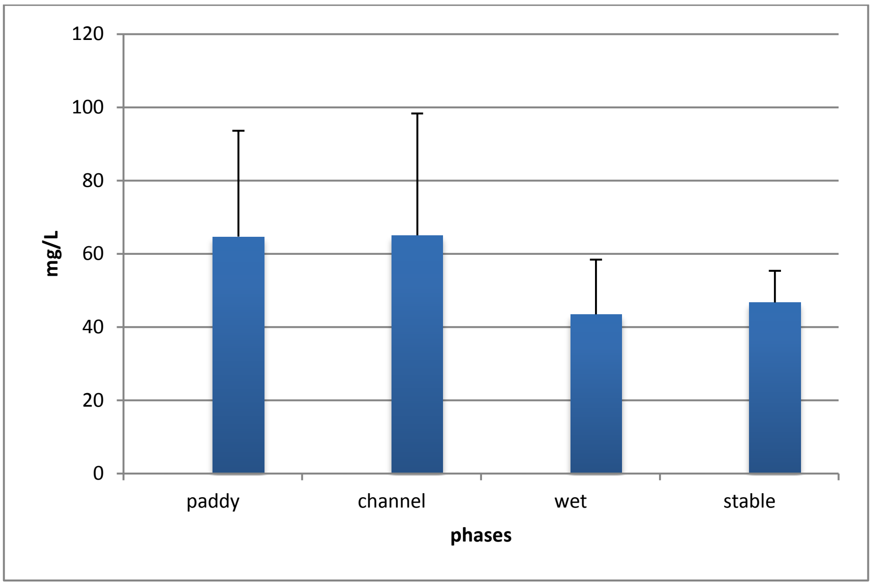


Fig.4.37. Mean variation in total hardness in various phases in Maranchery Kole wetland.

4.2.14. Calcium hardness (Ca. hardness)

The calcium concentration ranged from 8.00 mg/L to 96 mg/L (Figs.4.38 and 4.39). The mean value of calcium recorded was 31.2 mg/L for the wetland (Table 4.13). The Station 1 showed the highest amount of Ca during the period of study (96mg/L) in January 2011 followed by station 8 (92mg/L) and a minimum of 8 mg/L in Station 1 during June 2011. In station 1, it ranged from 12 mg/L in August, September 2011 and August 2012 to 96 mg/L in January 2011 with an average Ca. hardness of 32.0 mg/L ±22.5, whereas in station 2 the range was between 8 mg/L in June 2011 to 72 mg/L in May 2011 and 29.3 mg/L ±15.3 being the mean Ca. The Calcium hardness of water showed the lowest value in August 2011 (8 mg/L) and highest in May 2011 (52 mg/L) with an average of 29.5 mg/L ±12.3 in station 3. The mean calcium concentration in station 4 was 27.6 mg/L ±12.8 with the minimum and maximum being 12 mg/L in December 2010, June 2011, September 2011, 2012 and 52 mg/L in January 2011 respectively. The lowest calcium concentration recorded in Station 5 was 16 mg/L in August 2011 and September 2011 the highest was 68 mg/L in February 2011 having a mean value of 32.8 mg/L (±13.4). In station 6, the mean calcium concentration was 29.6 mg/L (±11.4) with a minimum of 12.0 mg/L in August 2011 and maximum of 56 mg/L in May 2011 while in station 7, the minimum calcium recorded was 16 mg/L in November 2010, July to September 2011 and September 2012 and the maximum of 64 mg/L in May 2011. The mean value was 26.6 mg/L (±10.6). In station 8 it ranged from 12 mg/L in August 2011 to 92 mg/L in April 2011, 29.5 mg/L (±17.7) being the mean value. The paddy phase showed the maximum value of 46.8mg/L and the wet phase showed the minimum value of 21.1mg/L (Fig. 4.40). ANOVA of calcium showed that there existed a significant variation at 1% level between phases (P<0.01).

Table 4.13. Mean variation of Ca. hardness in Maranchery Kole wetland during the study period.

Stations	**Min(mg/L)**	**Max(mg/L)**	**Mean±SD**
Station 1	12.0	96.0	32.0±22.5
Station 2	8.0	72.0	29.5±15.3
Station 3	8.0	52.0	29.5±12.1
Station 4	12.0	52.0	27.7±12.8
Station 5	16.0	68.0	32.8±13.4
Station 6	12.0	56.0	29.7±11.4
Station 7	16.0	64.0	26.7±10.7
Station 8	12.0	92.0	29.5±17.7

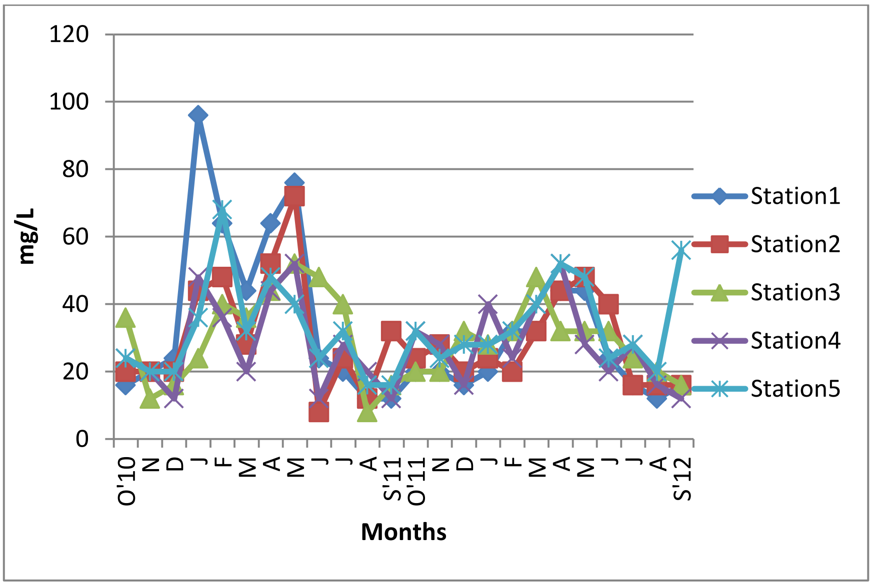


Fig.4.38. Monthly variation in calcium hardness in stations 1 to 5 in Maranchery Kole wetland during the study period.

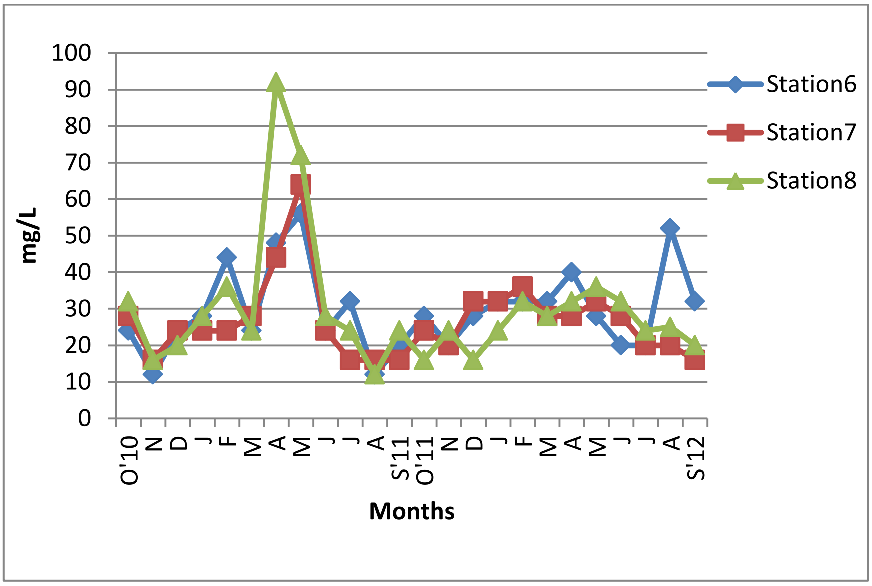


Fig.4.39. Monthly variation in calcium hardness in stations 6 to 8 in Maranchery Kole wetland during the study period.

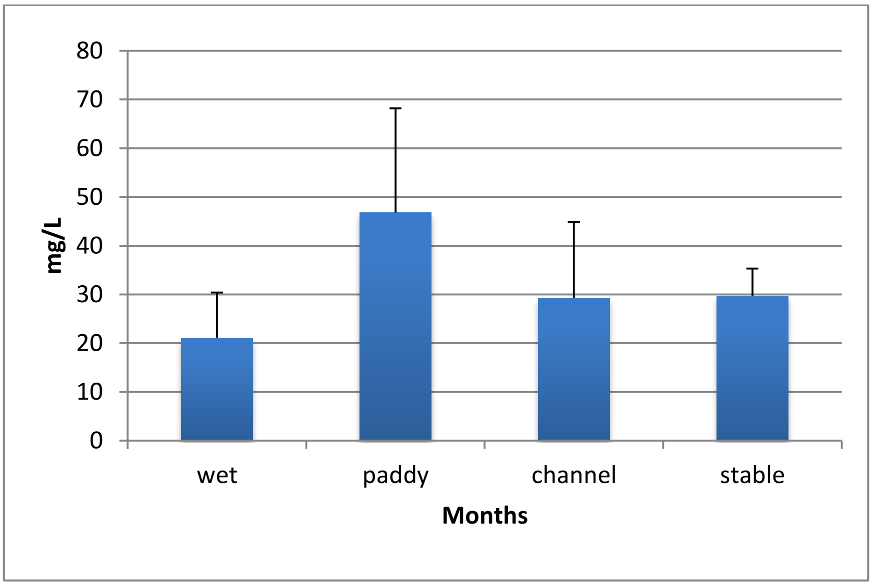


Fig.4.40. Mean variation in calcium hardness in various phases in Maranchery Kole wetland.

4.2.15. Magnesium hardness (Mg. hardness)

Magnesium hardness in water is given in Figs. 4.41, 4.42 and mean values are tabulated and given in Table 4.14. The highest quantity observed was 76 mg/ L at station 4 in April 2011 and 8 in April 2012 period and the lowest quantity observed was 4mg/L at 4, 5 and 7 stations during various months. In general, station 5 showed lower Mg content than other stations throughout the study period. The maximum Mg hardness recorded in station 1 was 52 mg/L during May 2012 and minimum 4 mg/L in October 2010, the mean value being 24 mg/L (±14.3). In station 2 the maximum value was 68 mg/L during May 2012 and minimum was 2 mg/L in December 2010 period(26±19). In station 3, the maximum magnesium hardness of 52 mg/L was recorded during April 2011 and minimum of 4 mg/L in December 2010 and July 2011 with a mean value of 22.5 mg/L (± 14.3). The mean Mg hardness in station 4 was 29.1 mg/L (±19.0) the highest hardness recorded from station 4 was 76 mg/L during April 2011 and lowest was 4 mg/L in

October, November, December 2010 and June 2011. The maximum hardness in station 5 was 56 mg/L during April 2011 and minimum was 0.1 mg/L in March 2011, 22.8 mg/L (±17.2) being the mean hardness. In station 6, it ranged from a maximum of 60 mg/L in the month of June 2012 to a minimum of 0.1 mg/L in the months of March 2011 (22.6 ± 14) whereas it fluctuated from a maximum of 56 mg/L in the month of May 2011 to a minimum of 4.0 mg/L in the month of November 2010 and March 2011 in station 7 (26.0 ± 15.2). In station 8 the maximum hardness was observed during April 2012 (76 mg/L) and minimum of 4 mg/L in December 2010 having a mean of 28 mg/L (±17.2). The comparison between the wet, paddy, channel and the stable phase showed that least difference among phases (fig.4.43). The lowest magnesium content was in the wet phase (17.7mg/L) and paddy phase (17.8mg/L) and highest in the Stable phase 22.5mg/L. The results of ANOVA showed that there existed a significant variation in Magnesium content at 1% level between phases ($P<0.01$).

Table 4.14. Mean variation of Mg. hardness in Maranchery Kole wetland during the study period.

Stations	Min(mg/L)	Max(mg/L)	Mean±SD
Station 1	4.0	52.0	24.0±14.3
Station 2	2.0	68.0	26.1±19.0
Station 3	4.0	52.0	22.5±14.3
Station 4	4.0	76.0	29.2±19.1
Station 5	0.1	56.0	22.8±17.3
Station 6	0.1	60.0	22.7±14.1
Station 7	4.0	56.0	26.0±15.2
Station 8	4.0	76.0	28.0±17.3

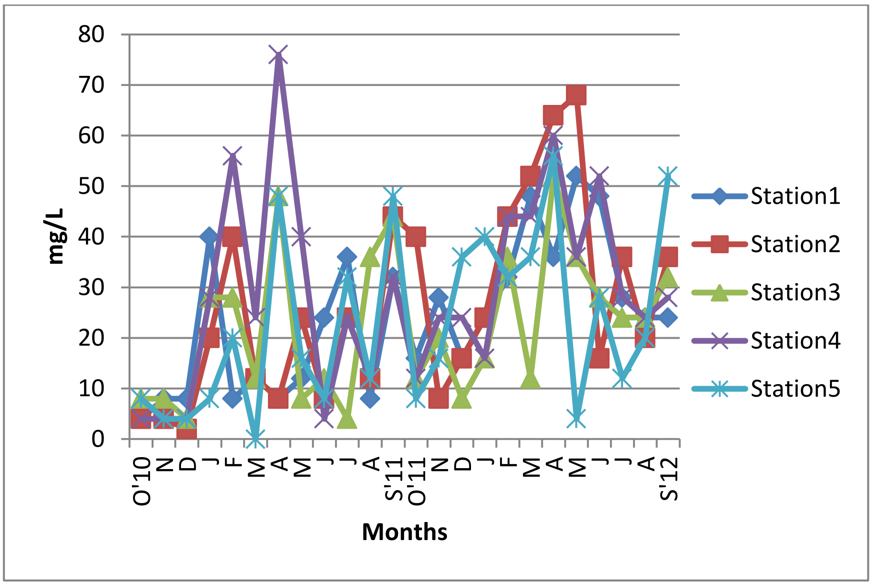


Fig.4.41. Monthly variation in magnesium hardness in stations 1 to 5 in Maranchery Kole wetland during the study period.

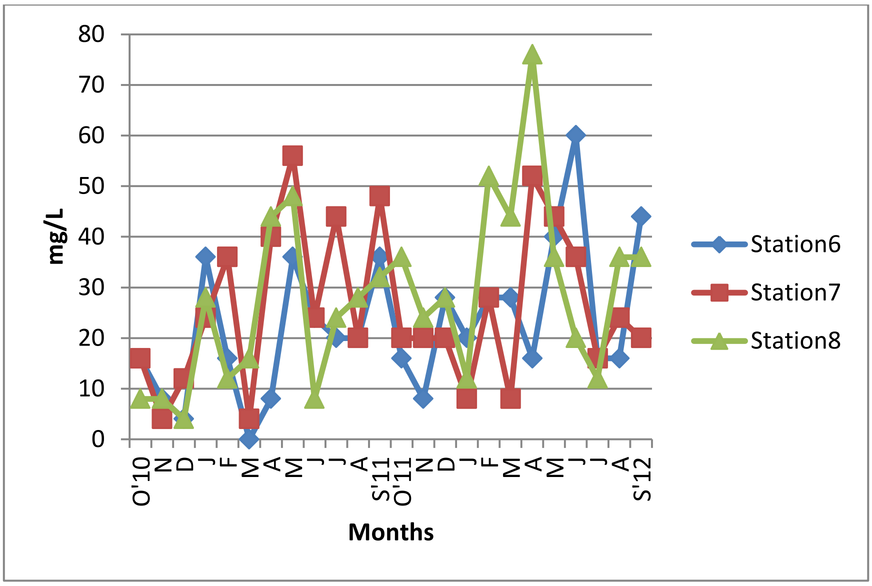


Fig.4.42. Monthly variation in magnesium hardness in stations 6 to 8 in Maranchery Kole wetland during the study period.

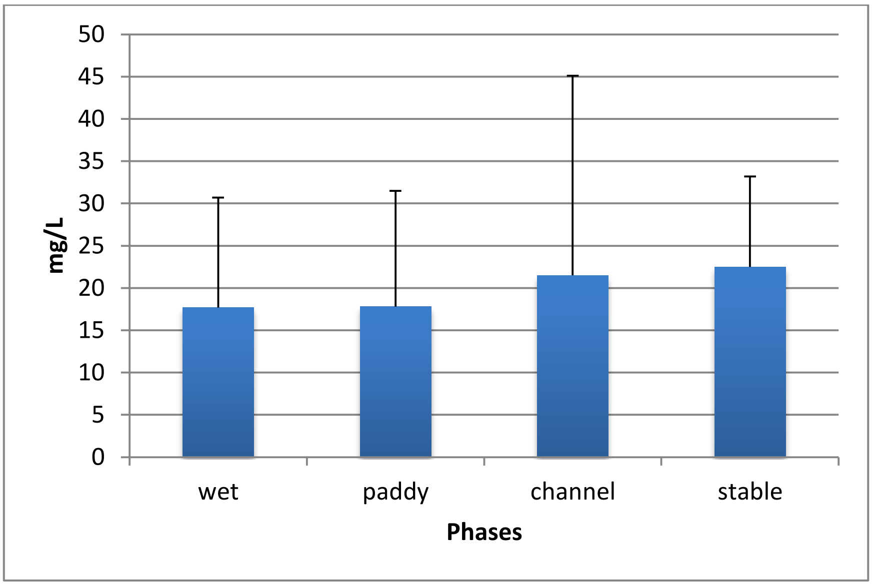


Fig.4.43. Mean variation in magnesium hardness in various phases in Maranchery Kole wetland.

4.2.16. Dissolved Carbon dioxide

The results of the monthly variations in the carbon dioxide content of water at the different stations are given in Figs. 4.44 and 4.45. The dissolved CO_2 ranged from 1 mg/L 25 mg/L and mean variations are given in Table 4.15. The mean value of dissolved CO_2 was 1.3 ($\underline{+}$5.1) mg/L. Highest dissolved CO_2 was 25.0mg/L recorded was in Station 1 during February and lowest of 1 mg/L noticed during different stations in overall study period. In station 1, April 2011 showed the lowest value of 1.0 mg/L whereas the highest value was in February 2012 (25 mg/L) showing a mean of 9.8 mg/L (±7.6). The average value of dissolved carbon dioxide was 9.4mg/L (±6.6) in station 2, the range varied from 1 mg/L in April 2012 and 22 mg/L in December 2011. It ranged from 2 mg/L in February 2011 and April 2011 to 29 mg/L in August 2012 in station 3 having a mean of 10.0 mg/L (±6.7). In station 4, it varied from a minimum of 3 mg/L in the month of February 2011 and April 2011 to a maximum of 22 mg/L in the month of July 2012 (10.5 ± 5.3). In station 5, it fluctuated from a minimum of 2 mg/L in March 2011 to a maximum of 26.4 mg/L in September 2011 (12.2±6.8). In station 6, it varied from a minimum of 1 mg/L in April 2011 to a maximum of 19.8 mg/L in the month of March 2012 (8.7 ± 5.3) whereas in station7, it ranged from a minimum of 1 mg/L in February 2011 to a maximum of 17.6 mg/L in April 2012 with a mean value of 8.3 ±4.4. In station 8 the range of dissolved carbon dioxide varied 1.5 mg/L in February 2011 to 21 mg/L in June 2011 showing a mean of 8.2 mg/L(±5.2). The comparison between 4 phases showed least variation during the study period (Fig. 4.46). Stable phase showing least mean value (9 mg/L) compared to wet phase (14.1mg/L), paddy phase(4.1mg/L) and channel phase(5.7 mg/L). Difference in CO_2 content between phases ($P<0.05$) and stations ($P<0.05$) was statistically significant at 5% level.

Table 4.15. Mean variation of dissolved carbon dioxide in Maranchery Kole wetland during the study period.

Stations	**Min(mg/L)**	**Max(mg/L)**	**Mean±SD**
Station 1	1.0	25.0	9.9±7.6
Station 2	1.0	22.0	9.4±6.6
Station 3	2.0	29.0	10.0±6.7
Station 4	3.0	22.0	10.5±5.3
Station 5	2.0	26.4	12.2±6.8
Station 6	1.0	19.8	8.7±5.3
Station 7	1.0	17.6	8.3±4.4
Station 8	1.5	21.0	8.2±5.3

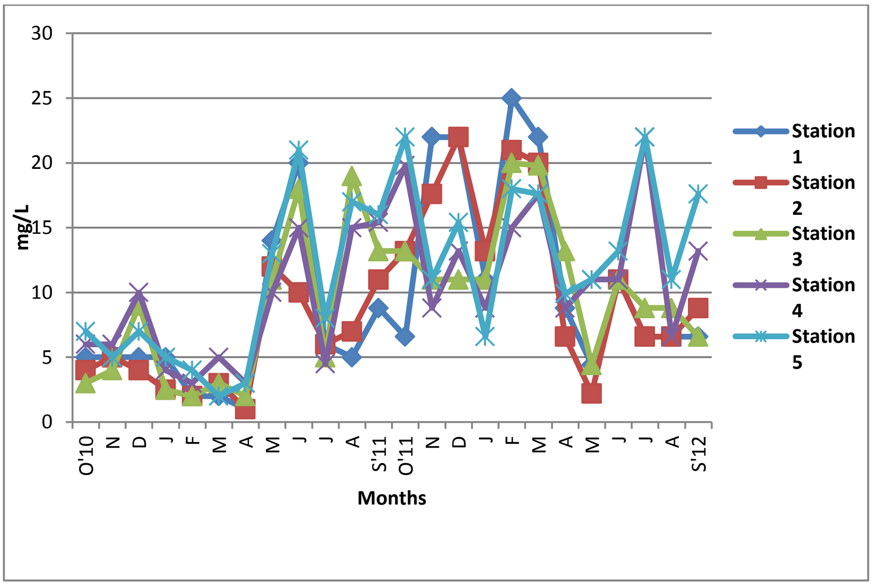


Fig.4.44. Monthly variation in dissolved carbon dioxide in stations 1 to 5 in Maranchery Kole wetland during the study period.

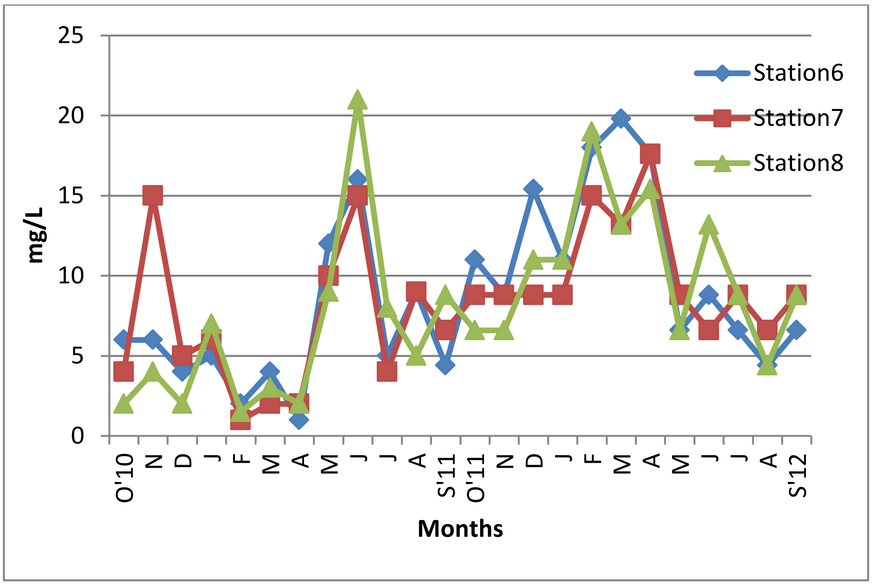


Fig.4.45. Monthly variation in dissolved carbon dioxide in stations 6 to 8 in Maranchery Kole wetland during the study period.

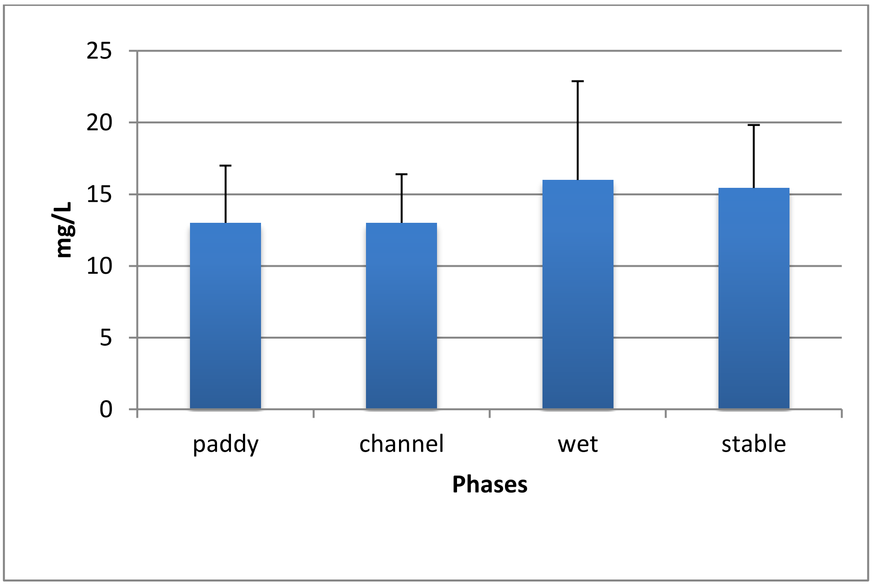


Fig. 4.46 Mean variation in dissolved carbon dioxide in various phases in Maranchery Kole wetland.

4.2.17. Biological Oxygen Demand (BOD)

The observed variations of biological oxygen demand values are illustrated in Figs.4.47 and 4.48.BOD of the Maranchery wetland varied from 0.8mg/L to 8 mg/L (Table 4.16). The average BOD values during the present study was 3.5 mg/L for the entire water body. Higher concentrations of BOD were observed during the Month of October 2010 in stations 2 to 5. When BOD was analyzed during the overall study period, no much variation was seen between wet, paddy, channel and stable phases (Fig.48). The BOD of water showed the lowest value in October 2011, February, March, April 2012 and July 2012 (0.8 mg/L) and highest in December 2011 (6.4 mg/L) with an average of 2.4±1.5 in station 1. The mean BOD concentration in station 2 was 2.5±1.3 with the minimum and maximum being 0.8 in February, March 2012 and 5.6 mg/L in October 2010 respectively. The lowest BOD concentration was recorded in Station 3 having 0.8mg/L in June 2011 whereas February 2012 had highest value of

6.4 mg/L in October 2010, having a mean value of 2.7 mg/L (±1.5). In station 4, the mean concentration of BOD was 2.7mg/L (±1.5) with a minimum of 0.8 in October, November 2011, January 2012 and July 2012 and maximum of 6.4 in October 2010 while in station 5, the minimum BOD recorded was 0.8 mg/L in June 2011, July 2011 and August 2012 and a maximum of 5.6 mg/L in October 2010, having a mean value of 2.5 mg/L (±1.3). In station 6 it ranged from 0.8 mg/L in July 2011 to 8mg/L in February 2011, 2.8 mg/L (±1.4) being the mean value. In station 7, it varied from a minimum of 0.8 mg/L in May 2011 and October 2011 to a maximum of 8mg/L in February 2011(2.7 ± 1.9) whereas in station 8, it ranged from a minimum of 0.8 mg/L in June 2011 and August 2011 to a maximum of 6.4 mg/L in April 2011 with a mean value of 3±1.8.Paddy phase showed the lowest BOD 1.9 mg/L and the highest BOD was observed in the channel phase 3mg/L (Fig. 4.49). ANOVA result of BOD showed there was 1% level significant difference between phases (P<0.01).

Table 4.16. Mean variation of BOD in Maranchery Kole wetland during the study period.

Stations	**Min(mg/L)**	**Max(mg/L)**	**Mean±SD**
Station 1	0.8	6.4	2.5±1.5
Station 2	0.8	5.6	2.6±1.4
Station 3	0.8	6.4	2.6±1.3
Station 4	0.8	6.4	2.8±1.6
Station 5	0.8	5.6	2.6±1.3
Station 6	0.8	8	2.8±1.5
Station 7	0.8	8	2.8±2.0
Station 8	0.8	6.4	3.1±1.6

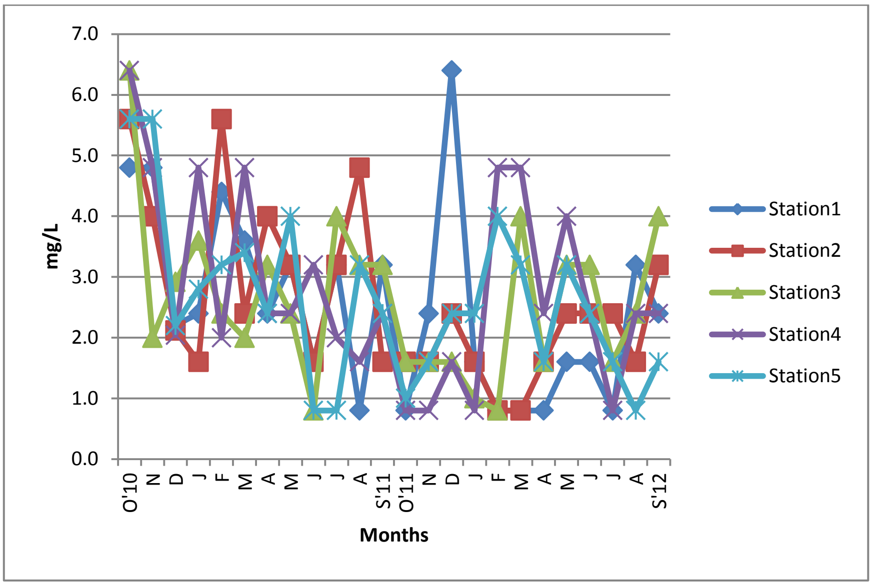


Fig.4.47. Monthly variation in biological oxygen demand in stations 1 to 5 in Maranchery Kole wetland during the study period.

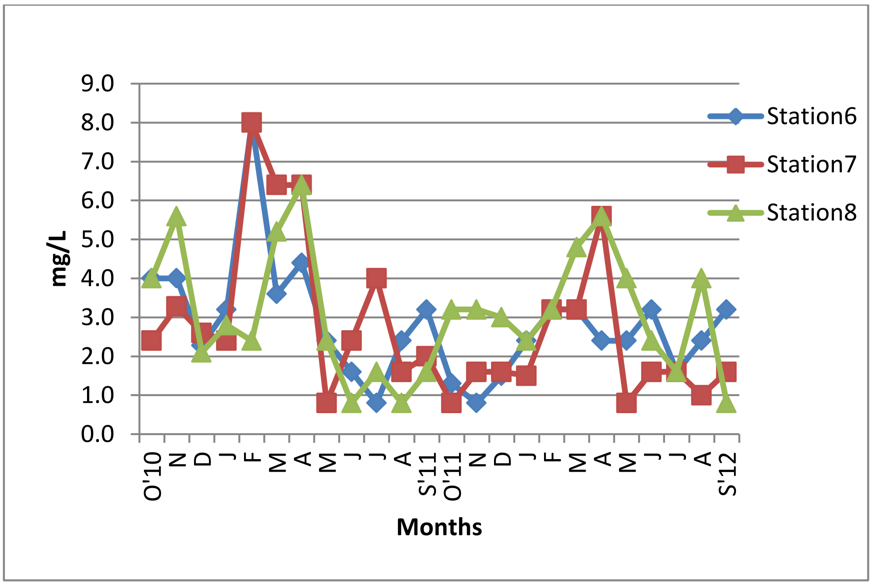


Fig.4.48. Monthly variation in biological oxygen demand in stations 6 to 8 in Maranchery Kole wetland during the study period.

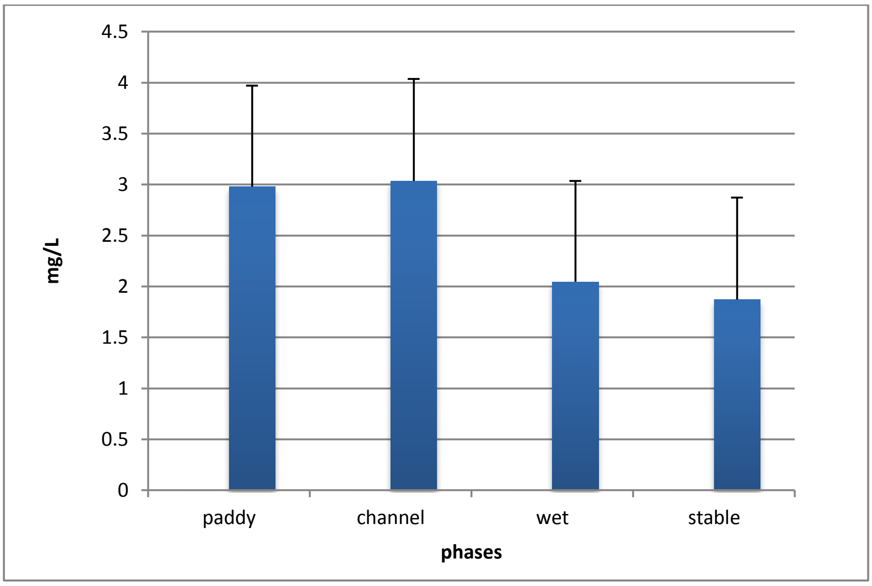


Fig.4.49. Mean variation in biological oxygen demand in various phases in Maranchery Kole wetland.

4.2.18. Nitrite-nitrogen (NO_2-N)

The results of the monthly variations in nitrite content of water at the eight stations are presented in Figs. 4.50 and 4.51. The nitrite content of water varied between 1.08 µmol/L to 0.017 µmol/L(Table. 4.17). The lowest concentration of nitrite observed was 0.017 during overall study period in all the eight study stations. In station 1, nitrite ranged from 0.017 µmol/L in September 2011 and February 2012 to 0.522 µmol/L in March 2011 with an average of 0.131±0.115, whereas in station 2 the range was between 0.017 µmol/L in September 2011 and November 2011 to 1.08 µmol/L in March 2011 and 0.145±0.218 being the mean nitrite value. The nitrite showed the lowest value in April, May 2012 (0.017 µmol/L) and highest in February 2011 (0.557 µmol/L) with an average of 0.114±0.112 in station 3. The mean nitrite in station 4 was 0.149±0.153 with the minimum and maximum being 0.017 µmol/L in April 2011, 2012 and February 2012 and 0.748 µmol/L in February 2011 respectively. In station 5 the range of nitrite was 0.017 µmol/L in April 2012, July 2012 and 0.435 µmol/L in December 2010 with an average of 0.182±0.126. The average nitrite in station 6 was 0.177±0.161 ranging from 0.017 µmol/L in April 2011 to 0.748 µmol/L in December 2010. In station 7, it ranged from 0.017 µmol/L in July 2011, August 2011, 2012 to 0.713 µmol L in November 2010 with an average of 0.151±0.157, whereas in station 8 the range was between 0.017 µmol/L in July 2011, August 2011, 2012 and January 2012 to 1 µmol/L in November 2010 respectively (0.201±0.231). Nitrite content was the highest in channel and paddy phase showing similar trend in concentration of nitrite (0.276 µmol/L) during wet phase (0.110 µmol/L) and lowest during stable phase (0.078 µmol/L) (Fig. 4.52). The difference in nitrite values between phases was statistically significant at 5% level ($P<0.05$).

Table 4.17. Mean variation of nitrite-nitrogen in Maranchery Kole wetland during the study period.

Stations	**Min (µmol/L)**	**Max (µmol/L)**	**Mean±SD**
Station 1	0.0174	0.522	0.131±0.115
Station 2	0.0174	1.088	0.145±0.218
Station 3	0.0174	0.5568	0.114±0.122
Station 4	0.0174	0.7482	0.149±0.153
Station 5	0.0174	0.435	0.182±0.126
Station 6	0.0174	0.7482	0.177±0.161
Station 7	0.0174	0.7134	0.151±0.157
Station 8	0.0174	1.0092	0.201±0.231

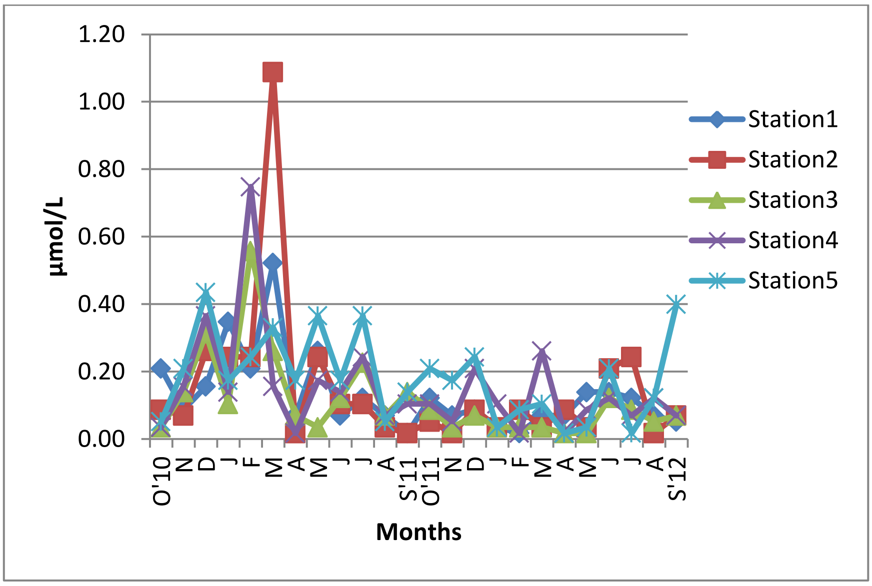


Fig.4.50. Monthly variation in nitrite-nitrogen in stations 1 to 5 in Maranchery Kole wetland during the study period.

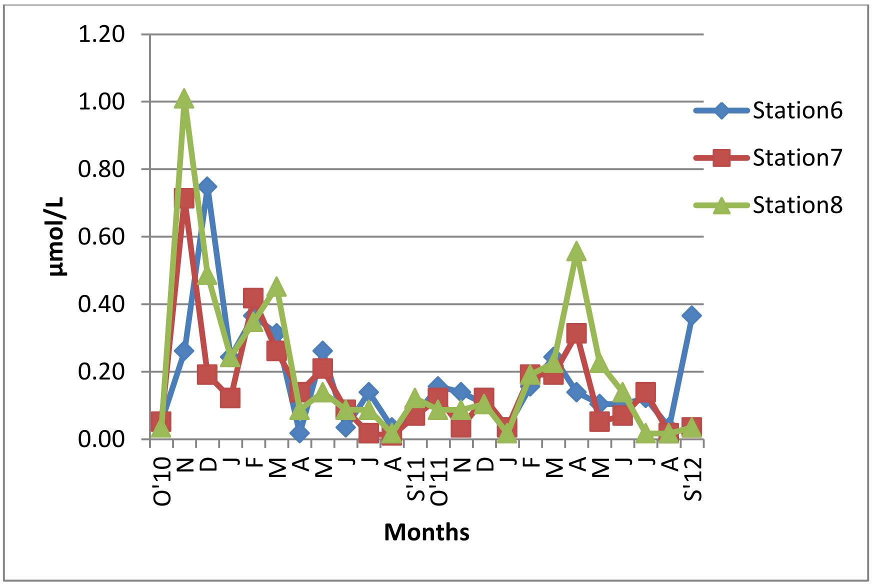


Fig.4.51. Monthly variation in nitrite-nitrogen in stations 6 to 8 in Maranchery Kole wetland during the study period.

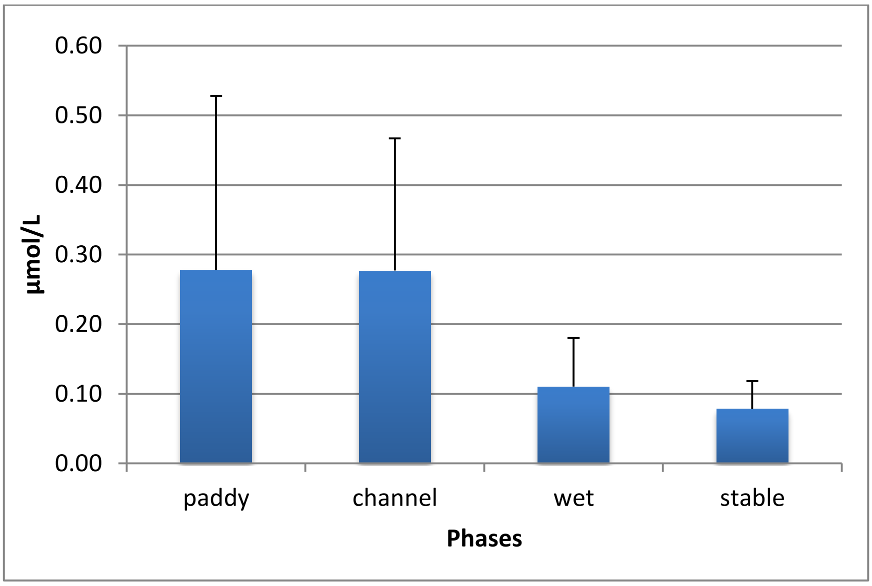


Fig.4.52. Mean variation in nitrite-nitrogen in various phases in Maranchery Kole wetland.

4.2.19. Nitrate-nitrogen (NO_3-N)

Monthly fluctuations in nitrate content of Kole lands at the different stations are presented in Figs. 4.53 and 4.54. The average nitrate content of the water ranged from 0.002µmol/L to 9.07 µmol/L(Table 4.18). Higher concentration of nitrate was noticed at station 4 in October 2011 period and lowest value 0.002 µmol/L was observed in various stations of the study. Peak values were noticed during December 2010. In station 1 the range of nitrate was 0.002 µmol/L in October 2011 and August 2012 and 4.86 µmol/L in October 2010 with an average of 0.238±0.987. The average nitrate in station 2 was 0.379±1.58 ranging from 0.002 µmol/L in August 2012 to 7.78 µmol/L in December 2010. In station 3, it ranged from 0.002 µmol/L in March 2011to 4.54 µmol/L in December 2010 with an average of 0.302±1.012, whereas in station 4 the range was between 0.002 µmol/L in November 2011 and January 2012 to 9.07 µmol/L in December 2010 respectively (0.468±1.861). The nitrate showed the lowest value in February

2011, November 2011 (0.003 µmol /L) and highest in December 2010 (7.94µmol /L) with an average of 0.338±1.616 in station 5. The mean nitrate in station 6 was 0.331±1.241 with the minimum and maximum being 0.002 µmol/L in July 2011 and 5.99 µmol/L in December 2010 respectively. In station 7 the range of nitrate was 0.002 µmol/L in July 2012 and 2.916 µmol/L in December 2010 with an average of 0.331±1.241. The mean values of nitrate in station 8 showed a value of 0.099±0.360 with minimum, that was observed during May 2011(0.002 µmol /L) and maximum value in December 2010 (1.78 µmol /L). Compared to other phases wet phase showed highest concentration of nitrate (0.21 µmol /L) and lowest concentration were noticed during channel phase (0.015 µmol/L) (Fig. 4.55). ANOVA result of nitrate showed there was 1% level significant difference between phases (P<0.01) and 5% level between stations (P<0.05).

Table 4.18. Mean variation of nitrate-nitrogen in Maranchery Kole wetland during the study period.

Stations	**Min (µmol/L)**	**Max (µmol/L)**	**Mean±SD**
Station 1	0.002	4.86	0.238±0.98
Station 2	0.002	7.78	0.379±1.5
Station 3	0.002	4.54	0.302±1.0
Station 4	0.002	9.07	0.468±1.8
Station 5	0.003	7.94	0.388±1.6
Station 6	0.002	5.99	0.331±1.2
Station 7	0.002	2.92	0.156±0.5
Station 8	0.002	1.78	0.099±0.36

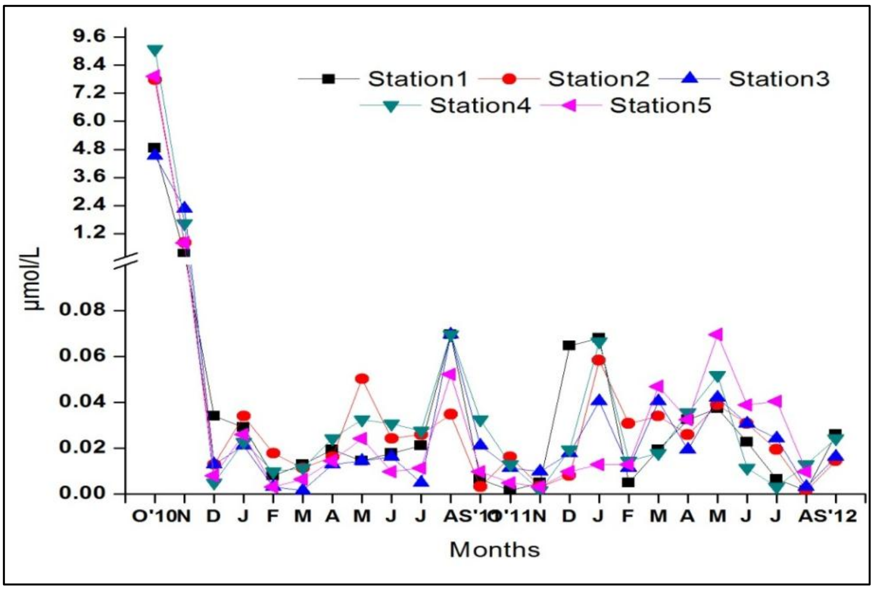


Fig.4.53. Monthly variation in nitrate-nitrogen in stations 1 to 5 in Maranchery Kole wetland during the study period.

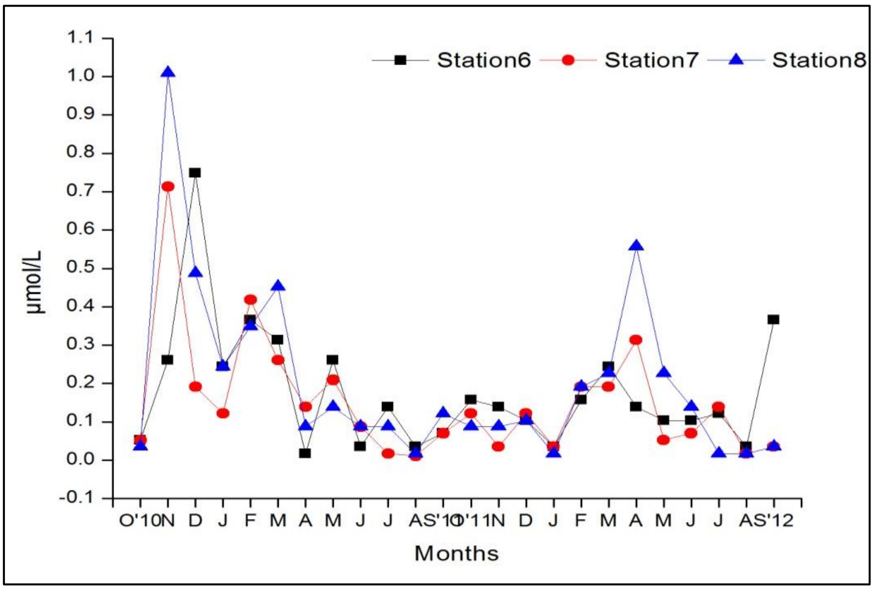


Fig.4.54. Monthly variation in nitrate-nitrogen in stations 6 to 8 in Maranchery Kole wetland during the study period.

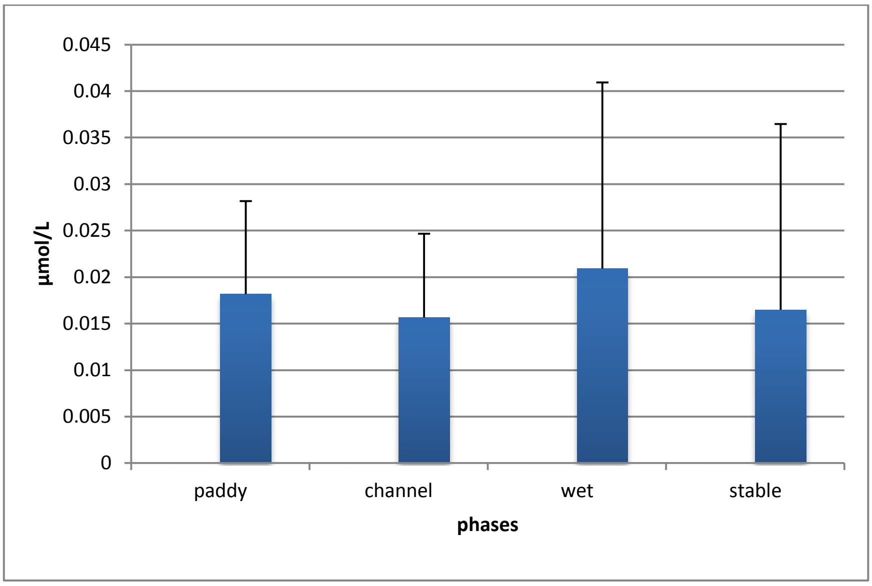


Fig.4.55. Mean variation in nitrate-nitrogen in various phases in Maranchery Kole wetland.

4.2.20. Ammonia-nitrogen (NH_3-N)

The observed variations in ammonia are illustrated in Figs 4.56 and 4.57. The ammonia values ranged between 0.05µmol/L to 65.7µmol/L (Table 4.19). The mean values of ammonia showed that maximum was observed during at station 8 in May 2011 and minimum value in station 4 in April 2012 The ammonia showed the lowest value in November, December 2011 and August 2012 (0.05 µmol /L) and highest in December 2010 (39.9µmol /L) with an average of 0.338±1.616 in station 1. The mean ammonia concentration in station 2 was 8.654±12.54 with the minimum and maximum being 0.1 µmol/L in the months of October 2010 and September 2011 and 39.1 µmol/L in April 2012 respectively. The lowest value was observed in September 2011 (0.25µmol/L) and highest in May 2011 (35.1µmol/L) with an average of 10.1±12.1 in station 3. In station 4 the range was 0.05 µmol/L in July 2011 and 32.8 µmol/L in May 2011 with an average of 8.3±11.95. The mean values of ammonia in station 5 was

7.0±12.8, the minimum being observed during November 2010 and December 2011(0.15µmol/L) and maximum in May 2012 (47.35 µmol/L). In station 6 the range of ammonia was 0.1 µmol/L in November 2010 and 20 µmol/L in April 2012 with an average of 3.6±4.6. The average ammonia in station 7 was 6.1±12.7 ranging from 0.05 µmol/L in September 2011 to 62.3 µmol/L in May 2011. The mean ammonia concentration in station 8 was 5.4±13.1 with the minimum and maximum being 0.2 µmol/L in the months of June 2012 and September 2012 and 65.8µmol/L in May 2011 respectively. The highest ammonia values obtained during paddy phase was 16.25 µmol/L and wet phase registered the lowest value 1.25 µmol/L (Fig.4.58). Ammonia was found to be 1% level significant in phases ($P<0.01$).

Table 4.19. Mean variation of ammonia-nitrogen in Maranchery Kole wetland during the study period.

Stations	**Min (µmol/L)**	**Max (µmol/L)**	**Mean±SD**
Station 1	0.05	39.95	8.13±12.8
Station 2	0.1	39.1	8.65±12.5
Station 3	0.25	35.05	10.14±12.1
Station 4	0.05	32.75	8.36±12.0
Station 5	0.15	47.35	7.01±12.8
Station 6	0.1	20	3.64±4.6
Station 7	0.05	62.25	6.17±12.8
Station 8	0.2	65.75	5.45±13.2

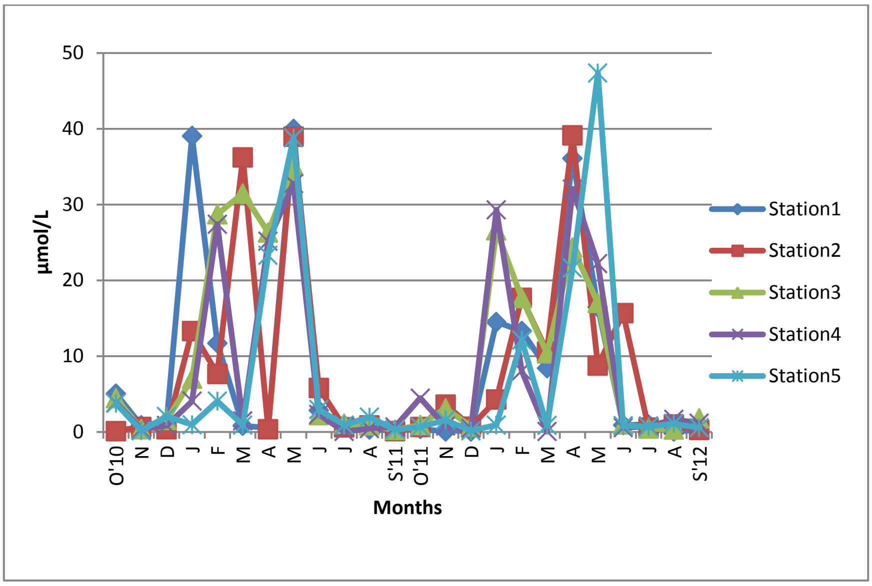


Fig.4.56. Monthly variation in ammonia-nitrogen in stations 1 to 5 in Maranchery Kole wetland during the study period.

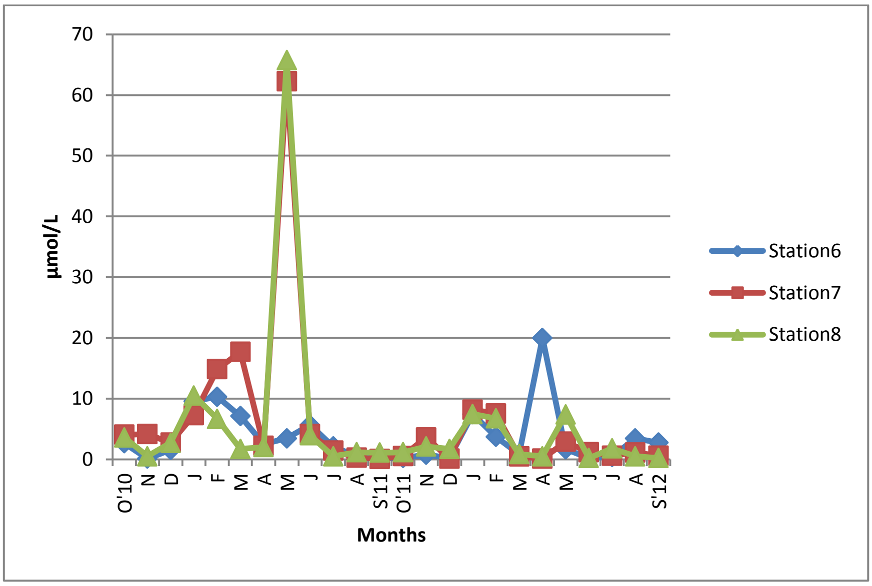


Fig.4.57. Monthly variation in ammonia-nitrogen in stations 6 to 8 in Maranchery Kole wetland during the study period.

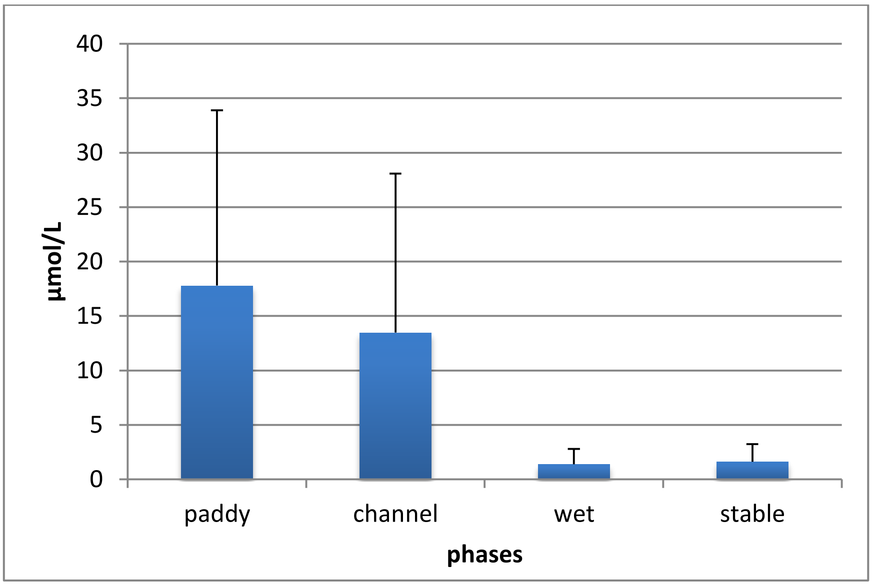


Fig.4.58. Mean variation in ammonia-nitrogen in various phases in Maranchery Kole wetland.

4.2.21. Phosphate-phosphorus (PO_4-P)

The results of the monthly fluctuations in phosphate content of water at the eight stations are presented in Figs. 4.59 and 4.60. The mean variation of eight stations was given in Table 4.20. Phosphate concentration ranged between 4.45 µmol/L at station 6April 2012and 0.10 µmol/L at station 2 in October 2011. Annual mean showed was0.667µmol/L (± 0.52). The phosphate of water showed the lowest value in November 2011, February 2012 (0.13 µmol/L) and highest in February 2011 (3.0 µmol/L) with an average of 0.699±7.0 in station 1. The mean concentration of phosphate in station 2 was 0.473±0.395 with the minimum and maximum being 0.1 µmol/L in October 2010 and 1.99 µmol/L in February 2011 respectively. The lowest phosphate recorded in Station 3 was 0.13 µmol/L in January 2011, May 2011, July 2012 and September 2012 highest was 2.04 µmol/L in December 2011 having a mean value of 0.489 µmol/L (±0.421). In station 4, the mean phosphate was 0.5 µmol/L (±0.387) with a minimum of 0.13

µmol/L in November 2011, February 2012 and maximum of 1.7 µmol/L in December 2011 while in station 5, the minimum phosphate recorded was 0.13 mg/L in May 2012 and the maximum of 1.7 µmol/L in December 2011 with mean value of 0.54 µmol/L (±0.377). The mean phosphate concentration in station 6 was 0.817±1.116 with the minimum and maximum being 0.13 µmol/L in October 2011 and August 2012 and 4.47µmol/L in March 2012. In station 7 the range was 0.13 µmol/L in October 2011 and 3.62 µmol/L in February 2012 with an average of 0.789±0.87. The average phosphate in station 8 was 0.723±0.732 ranging from 0.13 µmol/L in September 2012 to 2.89 µmol/L in March 2012. Compared to different phases, stable phase showed minimum value 0.337 µmol/L and paddy phase showed maximum value 0.863 µmol/L (Fig.4.61). The variation was 5% level significant among phases ($P<0.05$).

Table 4.20. Mean variation of phosphate-phosphorus in Maranchery Kole wetland during the study period.

Stations	**Min (µmol/L)**	**Max (µmol/L)**	**Mean+ SD**
Station 1	0.13	3.06	0.699+0.76
Station 2	0.10	1.99	0.473+0.39
Station 3	0.13	2.04	0.489+0.42
Station 4	0.13	1.70	0.500+0.38
Station 5	0.13	1.70	0.540+0.37
Station 6	0.13	4.47	0.817+1.1
Station 7	0.13	3.62	0.789+0.87
Station 8	0.13	2.89	0.723+0.73

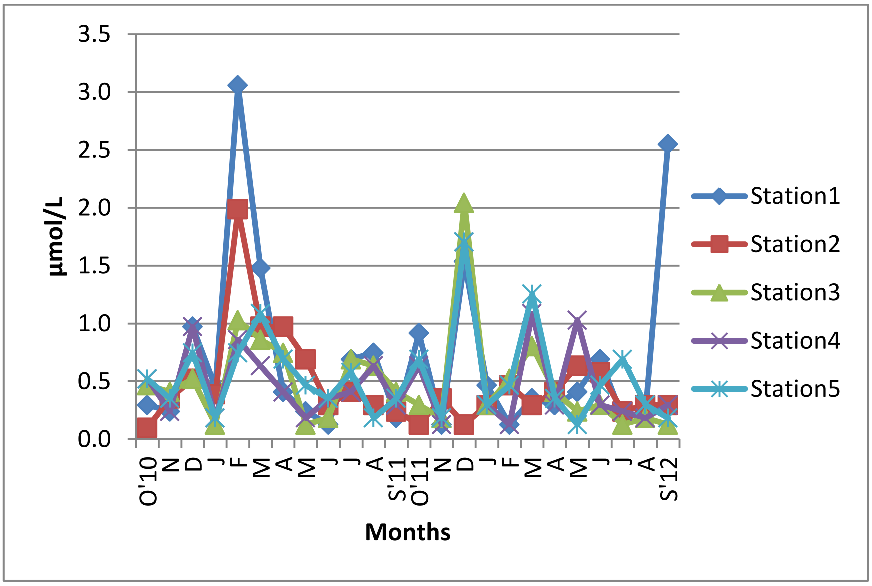


Fig. 4.59. Monthly variation in phosphate-phosphorus in stations 1 to 5 in Maranchery Kole wetland during the study period.

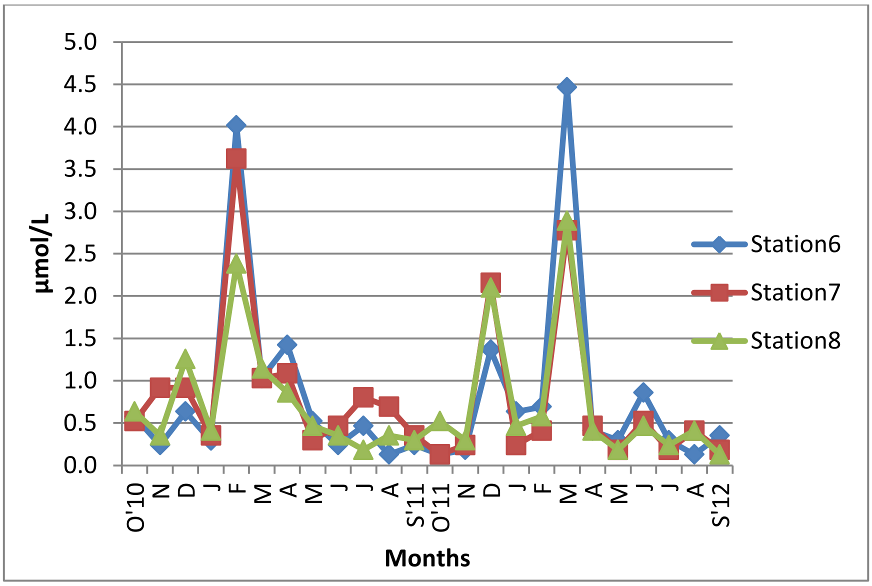


Fig. 4.60. Monthly variation in phosphate-phosphorus in stations 6 to 8 in Maranchery Kole wetland during the study period.

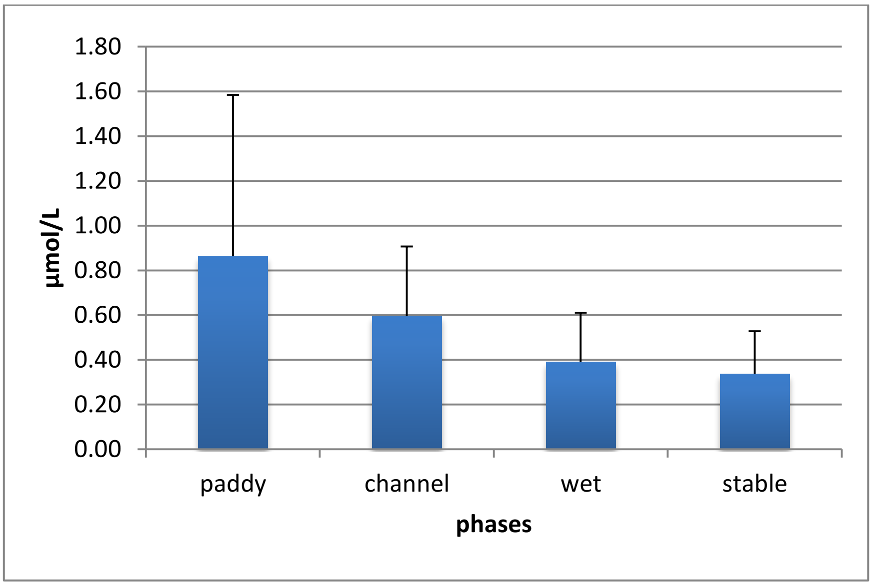


Fig.4.61. Mean variation in phosphate-phosphorus in various phases in Maranchery Kole wetland.

4.2.22. Silicate-silicon (SiO_3-Si)

Monthly variations in silicate content of water are presented in Figs. 4.62 and 4.63. The mean annual silicate concentrations at the eight stations showed significant variations (Table 4.21). The silicate concentration registered considerable monthly variations (60.21 µmol/L in March 2011 at station 2 to 2.39 µmol/L in February 2011 at station 5). The mean silicate in station 1 was 17.18±7.14 with the minimum and maximum being 6.1 µmol/L in April 2011, and 27.23 µmol/L in August 2012 respectively. In station 2 the range was 6.42 µmol/L in May 2011 and 60.2 µmol/L in March 2011 with an average of 19.73±13.78. The average silicate in station 3 was 16.24±7.93 ranging from 3.975 µmol/L in August 2011 to 34.7 µmol/L in March 2011. In station 4, it ranged from 3.6 µmol/L in February 2011 to 50.16 µmol/L in November 2011 with an average of 16.648±12.02, whereas in station 5 the range was between 2.40 µmol/L in February 2011 to 28.86 µmol/L in September 2012 respectively (13.02±8.57). In station 6, the mean silicate was 14.67 µmol/L (±8.51) with a minimum of 3.54 µmol/L in the month of April 2012 and maximum of 35.49 µmol/L in August 2012 while in station 7, the minimum silicate recorded was 4.74 µmol/L in November 2010 and the maximum of 51.3 µmol/L in December 2011. The mean was 17.31 µmol/L (±10.4). The mean silicate concentration in station 8 was 14.43±7.89 with the minimum and maximum being 3.4 µmol/L in the months of March 2011 and 29.19µmol/L in August 2011 respectively. Silicate content was the highest during paddy phase 17.78 µmol/L and the lowest during wet phase 1.4µmol/L (Fig. 4.64). The observed difference in silicate content of water was phase wise significant at 5% level ($P<0.05$).

Table4.21. Mean variation of silicate-silica in Maranchery Kole wetland during the study period.

Stations	**Min (µmol/L)**	**Max (µmol/L)**	**Mean±SD**
Station 1	6.15	27.23	17.19±7.1
Station 2	6.42	60.21	19.73±13.7
Station 3	3.97	34.67	16.24±7.9
Station 4	3.59	50.16	16.65±12.0
Station 5	2.40	28.86	13.02±8.5
Station 6	3.54	35.49	14.67±8.5
Station 7	4.74	51.30	17.31±10.1
Station 8	3.38	29.19	14.44±7.9

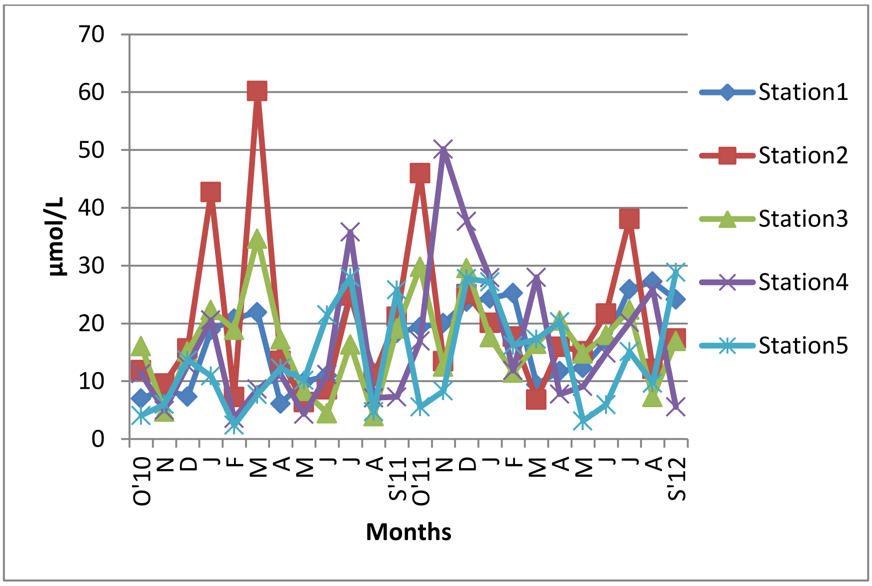


Fig.4.62. Monthly variation in silicate-silica in stations 1 to 5 in Maranchery Kole wetland during the study period.

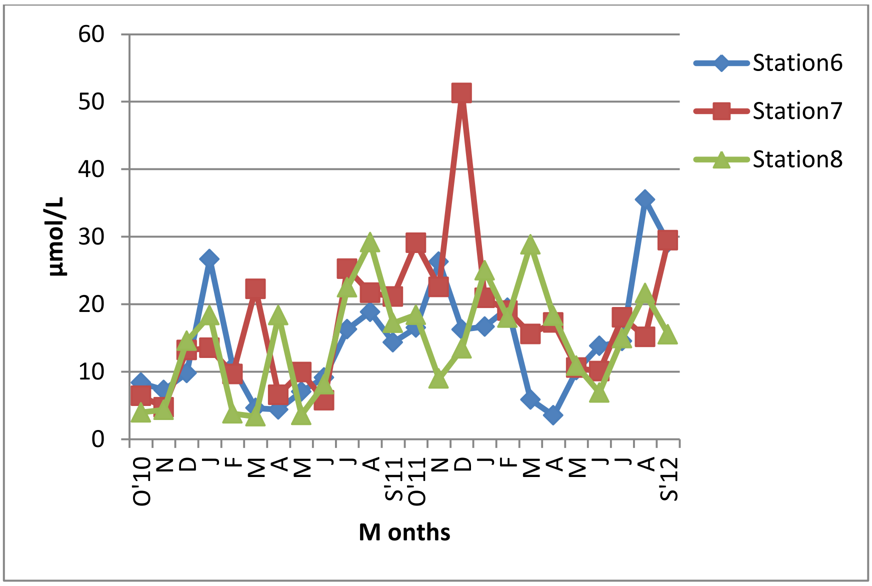


Fig.4.63. Monthly variation in silicate-silica in stations 6 to 8 in Maranchery Kole wetland during the study period.

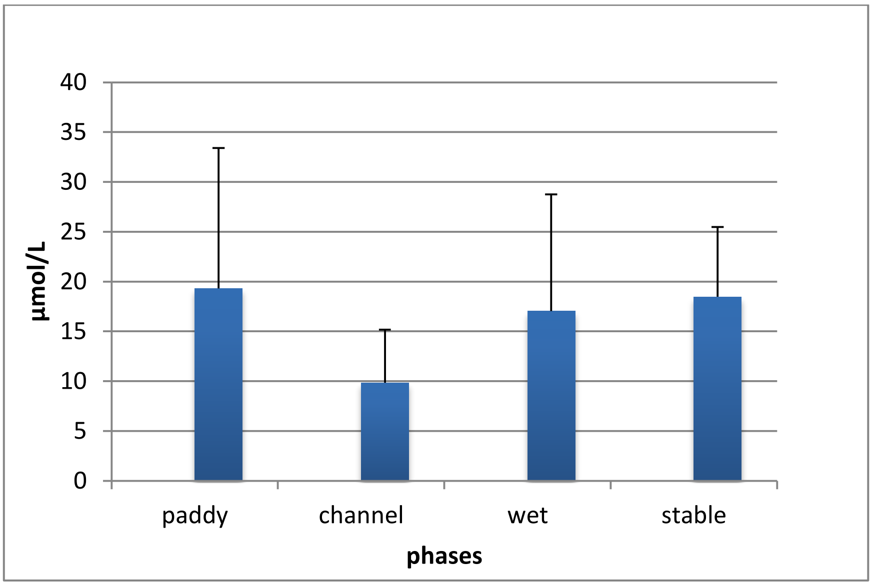


Fig.4.64. Mean variation in silicate-silica in various phases in Maranchery Kole wetland.

4.3 Principal component analysis (PCA)

A multivariate correlation analysis was carried out to determine the influence of various physicochemical parameters in the different study sites during the different phases. After rotation, the four principal components accounted 78.8% of the variation of the 5 original habitat variables (Table 4.22). The 5 components were interpreted as follows: Principal component one (PC1) explains 2.76% of the overall variance, PC2 (1.7%), PC3 (1.28%), PC4 (1.16%) and PC5 account for 0.944% respectively accounting for 78.8% of the overall variance. During the study period depth, water temperature, pH, DO, alkalinity, nitrites, ammonia phosphates and silicate were the factors that contributed to the reliable environmental variations (Table 4.23) (Fig. 4.65).

Table 4.22. Results of cumulative variations in Principal Component Analysis (PCA) of environmental parameters in Maranchery Kole wetland during the study period.

PC	Eigen values	% Variation	Cum.% Variation
1	**2.76**	27.6	27.6
2	1.73	17.3	45.0
3	1.28	12.8	57.8
4	1.16	11.6	69.4
5	0.944	9.4	**78.8**

Table 4.23. Results of component of indicators of environmental variables in Principal Component Analysis (PCA) in Maranchery Kole wetland during the study period.

Variable	PC1	PC2	PC3	PC4	PC5
Depth	0.375	0.184	0.123	-0.069	-0.226
Air temperature	0.233	-0.479	0.097	0.106	0.074
Water temperature	0.339	-0.383	0.077	0.101	-0.065
pH	0.144	0.324	0.113	0.020	0.545
Conductivity	0.270	-0.221	-0.076	-0.467	0.187
Turbidity	-0.341	-0.048	-0.109	-0.280	-0.210
Alkalinity	-0.302	0.31	0.154	-0.240	-0.097
DO	0.064	-0.251	0.502	-0.063	-0.051
T. Hardness	-0.185	-0.269	-0.077	-0.458	-0.133
D.CO_2	0.344	0.205	-0.319	-0.068	0.260
NO_3-N	0.097	-0.001	-0.416	0.074	-0.267
NO_2-N	-0.307	-0.131	-0.065	0.258	0.424
NH_3-N	-0.234	-0.311	-0.224	-0.238	0.434
PO_4-P	-0.265	-0.192	0.076	0.485	-0.054
SiO_3-Si	-0.053	0.095	0.568	-0.192	0.153

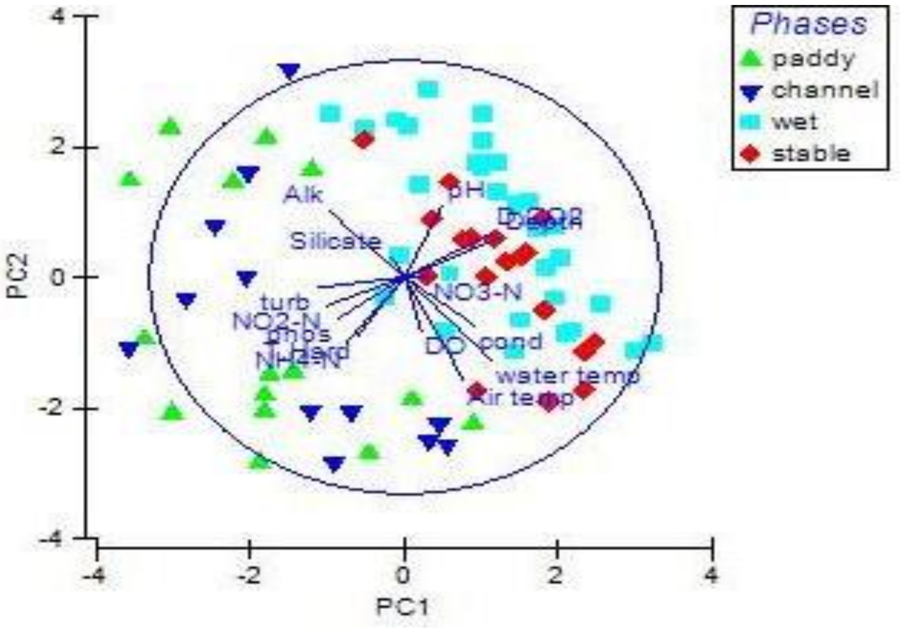


Fig.4.65. Principal Component Analysis (PCA) ordination of environmental variables in different phases in Maranchery Kole wetland.

4.4 Discussion

The Kole wetland systems in Kerala are mainly ecotones or transitional zones that occupy an intermediate position between dry land and open water. Maranchery Kole wetlands are dominated by the influence of water, that possess characteristics of both terrestrial and aquatic ecosystems but have unique properties as well. These wetlands support a wide array of flora and fauna that deliver many ecological and climatic functions. The two years of investigation enabled us to generate ample knowledge about the hydrobiology and physico-chemical characteristics of the Kole lands.

Spatial and temporal variation are evident in all the physical and chemical parameters of fresh water systems (Gupta et al., 2005). Since the morphometry of wetland is complex and the variations in water regime are common, accounting of spatial variation due to natural environmental differences was not easy in this system. However, eight field stations were identified during the present investigation to assess all the spatial variations existing in the Kole lands. Water levels in these eight stations of the wetlands are rarely stable particularly those due to the fact that the wetland is divided into distinct wet, paddy, channel and stable phases. Therefore, the two year monitoring was minimal to assess the general ecological tendencies of the system.

While monitoring wetland aquatic systems, monthly data are usually pooled and divided into four phases for getting reliable trends for explaining the features. In previous studies of Maranchery Kole wetlands (Vineetha, 2015) five phases were recognized. The major parameter which influences the water quality of wetland is the rainfall pattern and water column fluctuations. As in the case of many lakes and freshwater bodies the nutrient rich flood water changes water level, water temperature and determines the ionic content of the wetland. Survey of literature reveals that there is dearth of investigation in Kole lands especially related to environmental variables.

The paddy agro ecosystem classified under man made wetlands is characterized by physical habitat and cultivation involving a wide range of physical processes including tillage, planting, fertilizing, draining, irrigation, weeding and finally harvesting. All these are designed to give optimum conditions for crop production. The growth and yield of rice crop is the result of interaction with environmental factors, soil conditions, availability of water and nutrients in soil as well as water. The current paddy cultivation is highly varied due to new cultivation technology, application of fertilizers, herbicides and water level variations which might lead to increase or decrease in water temperature, low dissolved oxygen, high turbidity (Freda, 1986). The Kole lands are considered rice granaries of Kerala, therefore studies on the present environmental conditions of the agricultural wetlands are very relevant for future benefits in rice production and changing climatic conditions.

In the present study, the seasonal mean of rainfall was maximum during the monsoon period (June-September period) (389.7 mm) followed by post monsoon (October-January) (105.5 mm) and pre monsoon (February –May period) (53.5 mm). Annual water table fluctuation was maximum in Kole lands. In Maranchery Kole land depth ranges between 0.2 to 2.1m. Spatial variations were more prominent during the study period. A characteristic feature of paddy wetlands is their slightly inclined bottom and shallow water depth throughout the aquatic phase (Fernando, 1993). Mahdi Haroun et al. (2005) noticed that the volume of water level during the crop period was less than 0.4m. Flooded conditions of Maranchery wetland were correlated with different wetland ecosystems of India. The mean depth of Asan wetland, Himalaya was found maximum 4.3 to 1.72 m (Sharma and Rawat, 2009). Prasad et al. (2002) compared the coastal wetlands of South India, and noticed minimum depth that ranges from 30 to 50 cm with a mean depth of 1.5 m. Nagarajan and Thyagesan (1996) studied Pichavaram mangrove wetlands of Tamil Nadu, documented minimum water level was less than 30cm. Roy and Nandi (2008) surveyed wetlands of West Bengal and recorded a difference of depth 0.9 - 7.9m in Mirik Lake, 6-9 m in Adra reservoir and 9-10 m in Rabindra Sarovar. In some major Ramsar sites in

Kerala the depth range reported was, 6.4 m in Ashtamudi wetland and that in Vembanad estuary was 1.5-6 m and that in Shasthamcotta lake was 15.2m (Kokkal et al., 2008) (Retina et al., 2015). Tamire and Mengistou (2014) studied the Lake Ziway, Ethiopia, and reported that the surface area was 442 km^2,having a maximum depth of 8.9 m and an average depth of 2.5 m. The littoral area of the lake Ziway exhibited prominent vegetation. In Maranchery Kole land during inundation period prolific growth of macrophytes were recorded. Variation in depth was mainly influenced by the pattern of vegetation and buildup of nutrients. Moreover continuous spatial variation will cause soil erosion and it lead to variation in littoral zone of this wetland.

Studies carried out recently in wetlands in Southern Brazil by Rolon et al. (2010) reported that, spatial variation in fragmented wetlands can cause loss of macrophyte diversity and at the same time larger increase in the number of habitats for macrophytes in the estuarine wetlands and the great lakes of the Coastal Plain. Eisenlohr et al. (1972) studied the wet and dry cycles of Cottonwood lake in North Dakota, U.S, which shows no standing water during drought period and overflowing of water during wet period. Paddy phases of Maranchery Kole lands observed mean depth of 0.31m (±0.1m). A 5 to 7.5 cm water is considered best for optimum grain yield in flood prone areas reported by (International Rice Research Institute, 2013). Additionally the reports explain, when the rice starts to ripen, the plants need very little water and usually the fields are drained about 10 days before harvest to make the work easier and these results in a drastic shift in the composition of floral species. Maranchery Kole fields also observed a decreased growth of macrophytes in paddy phase that could be one reasons for drastic change in composition of macrophytes. According to Mitsch et al. (2012) the major factors affecting the fish and other macroinvertebrates in the rice field are the water level, temperature and dissolved oxygen. Depth of the water body showed a positive correlation significant at 1% level ($P<0.01$) with different parameters like water temperature, turbidity, alkalinity and a negative correlation with nutrients like ammonia, phosphate and silicate. To determine the effect of land use on water column depth, the PCA test gave an axis score against the proportion of the four different land use categories. PC axis was negatively correlated to paddy phase and positively correlated with stable phase (Fig. 4.65). Depth (0.375) was positively correlated with water temperature (0.339) in PC score 1.

Wahlroos et al.(2015) reported that fluctuation in air temperature of an aquatic medium regulates the biological composition of that ecosystem. The level of distribution of gases and nutrients along with the other biological processes get affected by the change in environmental temperature (Welch, 1952). Solar radiations have an impact on the surrounding temperature in the wetland. Stations 1 and 2 showed decrease in temperature during December 2012 and January 2012. Channel phase of station 5 shows higher temperature during the month of February 2012. In the present investigation, it was also found that the surface water temperature of all the eight stations followed the changes in air temperature and was always lower than air temperature. The maximum and minimum ambient temperature of Kanjia lake, Bhubaneswar, ranges from 23.43^0C to 36.85^0C (Indresha and Patra, 2014). Temperature of water was recorded always less than air temperature except sometimes during winter (Kant and Raina, 1990; Moreno-Mateos et al., 2010). According to Munawar (1970) and Sun et al. (2002) solar radiations have an impact on the ambient temperature. Fall in air temperature during paddy phases in the present study may be recognized to shorter photoperiod/ day length, oblique incident rays and increased condensation due to higher percentage of water vapours in air. Datta et al. (2011) and Zuber (2007) reported that the ambient temperature recorded a sharp fall during winter and concordant increase towards the summer season in perennial ponds.

Water temperature has tremendous effects on the biogeochemical reactions and also in the self-purification efficiency of a wetland ecosystem. Ecologists have established the importance of flow and temperature as primary variables in running water, riparian and floodplain wetland ecosystems (Erwin, 2009). As per the present study, water temperature ranged from 21^0C to 35^0C. Higher temperature in this wetland leads to increased aquatic vegetation and productivity. Guptha and Dey (2013) suggested that, comparatively higher temperature in tropical water than intemperate region is considered to be beneficial for higher productivity. Binoda and Nayar (1995) observed self-purification (breakdown of organic matter) is more rapid during summer than other seasons. Pires et al. (2016) opined that, aquatic macroinvertebrate diversity in irrigated rice fields and wetlands are highly influenced by temperature of water. Water temperature was positively correlated with atmospheric temperature, conductivity, TDS and salinity significant at 1% level ($P<0.01$). Water temperature was positively correlated with dissolved oxygen and dissolved carbon dioxide significant at 5% level ($P<0.05$). Uedeme-Naa et al. (2011) reported that, the relationship between macrophytes and water temperature was positively correlated, as the photosynthetic activity increases with increase in temperature. Antti Kanninen (2012) observed the maximum growth of' Chlorophyceae during the warmer months. Espínola et al. (2017) reported that, temperature showed an inverse relation with dissolved oxygen. This was due to the more oxygen holding capacity of water at low temperature. Present study reveals that, station wise variation was not significant compared to phases. Stable phase showed maximum temperature and paddy phase showed minimum temperature in this study. In phase wise evaluation also showed water temperature variation to be directly related to variation in atmospheric temperature. Prolific growth of hydrophytes was also observed during wet and stable phases in this wetland. Variations in the temperature of several waterbodies in Kerala have been reported. In Valanthkad backwater, Kochi the water temperature was reported to vary between 27 to 31.5^{0}C (Meera and Bijoy Nandan, 2010). In Kallada river, Kerala the variation was between 23 to 33.0^{0}C (Madhusoodhana Nair, 1992). In Ranjit Sagar wetland, Punjab, water temperature was reported to vary between 11.9 to 30.93^{0}C (Brraich et al., 2014). In Pongdam Wetland, Himachal Pradesh the variation was between 16.6to 32.2^{0}C (Negi, 2007). In Kodungallur backwater system, it was between 26.5^{0}C and 32.5^{0}C(Mukundan and Thomas, 2004) (Jayachandran et al. 2016). Uchijima (1959, 1963) investigated annual variations in water temperature and heat balance in shallow water with no rice plants and also evaluated the climatic aspects like seasonal and spatial variations of paddy water temperature in Japan and reported that, actual water temperature is influenced by the canopy density of rice plants. Vineetha et al. (2016) observed decreased temperature during paddy phase that could be due to the shades of paddy plants. This is in agreement with present results.

pH, is the negative logarithm of hydrogen ion concentration and one of the most important water quality parameters. It is the measure of acidity at a given temperature. The intensity of the acidic or basic character of water is indicated by its pH value and is influenced directly by the carbon dioxide concentration in the water, which in turn regulates photosynthetic and respiratory activities (Dülger et al. 2017). The determination of pH is an important factor because the solubility of carbon and the concentration of various carbonate species depend on the pH of water (Mandal, 2012). Maranchery Kole lands generally exhibit a neutral pH (6 and above), while in summer period it is slightly acidic in nature. Very slight variations were observed in different phases but it was neutral in condition (6-6.4). Kusumawardani et al. (2017) in their study proved that pH would be an ecological factor of major importance in controlling the activities and distribution of aquatic flora and fauna in paddy wetlands. Roy and Nandi (2008) noticed a pH between 6.2 to 8.9 in Mirik Lake, West Bengal. pH ranged between 6.8 to 8.2 in selected wetlands of Goa (Brenda and Achuthankutty, 2010) and reported low values coincided with the monsoon period. In Kanjia Lake, Bhubaneswar, rang of pH recorded was 6.84 to 8.02 (Indresha and Patra, 2014). pH of Kodungallur - Azhikode estuary ranged from 6.9 to 7.5 (Jayachandran and Bijoy Nandan, 2011) and report shows that pH of Ashtamudi wetland and Vembanad lake, were slightly alkaline in nature (Raghunathan, 2007 and Sujatha et al., 2009). John Thomas et al. (2003) noticed pH ranges from 5.0 to 7.1 in Muriyad wetlands, Thrissur. The average monthly pH values of Kole lands of Thrissur ranged between 6.32 to 6.89 and the seasonal average showed that generally the wetland was slightly acidic in nature or slightly below neutral (Tessy and Sreekumar, 2013). Similarly a reduction of pH was observed in stations 6 to 8 during May 2011 in the present study. The unusual rain fall in April 2011 lead to increased runoff and acidic organic matter buildup from adjacent areas that might be contributing to such pH conditions. In agreement with this the same month turbidity also increased in the same stations. Seybold et al. (2002) and Asha et al. (2016) observed that, increase in flood water flushed into wetlands and acidic organic compounds of the sediments reflect the slight acidic nature of pH during pre monsoon. One another reason for decrease in pH in summer was probably due to release of anaerobic gases due to the decomposition of concentrated organic matter and respiration of biota. The findings are in conformity with the recent study of Sahoo et al. (2017).

Research in Central Alberta, Canada, farmers revealed reduced infestations of weeds after application of wood ashes and agricultural liming. The use of ash as a soil amendment provides opportunity to increase the competitive ability of crop growth by increasing pH and increasing fertility of soil (Jerome Lickacz, 2002). In Maranchery wetland there is an increase in pH (9) in station 4 during January 2011 and this station served as a major channel connecting to other agricultural fields. Here the farmers applying ashes in the beginning of paddy stages and runoff from the fields might lead to increase in pH during January 2011. A positive correlation coefficient of pH significant at 1% level ($P<0.01$) was observed with the alkalinity and silicate and significant negative correlation with ammonia. Heckman (1979) reported that, the pH and DO level of the water in a rice field are positively correlated since the DO concentration increases largely as result of photosynthetic activity that uses up carbon and reduces the dissolved CO_2 (and thus H+ concentration), effectively raising both pH and the DO levels. In Maranchery ecosystem also a positive correlation coefficient significant at 5% level was observed between the pH and DO. Selmah et al. (2017) observed depth of water at all stations was between 14.76 cm and 24.39 cm, and in accordance with the depth the water pH varied from slightly acidic to neutral (5.97–7.25) in condition. This study is in agreement with the above statement; there is slight reduction in pH in March 2011, April 2011 and May 2011 during paddy phase. High pH values and dissolved oxygen concentrations were found in imidacloprid (insecticide) applying fields in Japan, in the early and the late stages of paddy cultivation period (Hayasaka et al., 2012). The channels of Maranchery wetland showed slight reduction of pH and the fluctuations observed could be linked directly or indirectly to macrophytes which at the time of decomposition releases high amount of carbon dioxide resulting in low pH. pH regulates key players of nitrification in paddy soils (Jaiang et al., 2015).pH of the wetlands directly influences the fish assemblage and macrophyte density (Cvetkovic et al., 2010). Maintenance of a constant pH in the body fluids at a given temperature is one of the most important task of the regulatory system for homeostasis of aquatic animals (Chapman et al., 2017). Hence to achieve good fish production, pH of water should be monitored regularly in order to ensure its optimum range. In Maranchery Kole wetland fish farming practice as well as rice cultivation is very common, therefore, maintaining pH value is very important.

Conductivity is the measurement of capability of a substance or a solution to conduct electric current. The values are the status of indication of the total nutrients of the water bodies; therefore, conductivity is used to indicate the trophic status (Crockett, 2015). Fresh water systems in their natural state shows very low conductivity whereas polluted water have higher conductivity (Brraich and Saini, 2015). The highest average phase value of conductivity recorded in the study area was during the channel phase (1400 µS/cm) and peak conductivity was recorded from Station 5 and 6 during the month of September 2012. The fluctuations in the values of conductivity observed during the present study could be due to variations in the rate of decomposition of organic matter, variations in the water level and evapo-transpiration (Bijoy Nandan, 2012). The present observation gets reinforcement from the views placed on record by Jameel (1998), Zuber (2007) and Bhattarai and Cronin, (2015). Zutshi and Vass (1973) reported that conductivity indicates an increasing amount of dissolved electrolytes in the water, or leaching of rock particles and this may be due to allochthonous material that comes into the water as a result of human activity. Conductivity values of 58-220 µs/cm was reported from traditional agricultural fields of Thailand by Namwong et al. (2013). Lowest electrical conductivity during wet and stable phases may be due to the increased level of water in the wetlands due to rainfall, whereas increase in electrical conductivity may be due to decrease in the water level, as a result of evaporation and increase in organic matter such as plant debris of the wetlands in dry cycles. Similar findings were made by Sulabha and Prakasam (2006) and Gerla (2013). A positive correlation coefficient significant at 1% level ($P<0.01$) was observed between the conductivity, salinity, chloride, hardness and shows a negative correlation with nitrite-nitrogen.

Total dissolved solids are any minerals, salts, metals, cations or anions dissolved in water. Trivedy and Goel, (1986) reported that high concentration of TDS near 3000 mg/L may cause distress to thelivestock and cattles. TDS has been proved as a very useful factor to determine the productivity of inland water (Hutchinson, 1975).Conductivity and total dissolved solids showed a similar trend in Maranchery wetland and shows a strong positive correlation with 1% level ($P<0.01$) significance. Total dissolved solids (TDS) fluctuated with chloride throughout the year and showed a positive correlation significant at 1% level ($P<0.01$) was noticed. The mean value of TDS in Maranchery Kole filed was 400.20 ± 739.59

mg/L.Primary sources for TDS in Kole lands are agricultural and residential runoff, leaching from soil contamination. In phase wise evaluation the range was between 142mg/L in wet and stable phases to 829 mg/L in paddy phase. The average TDS was 50.87±0.32mg/L in Bhadra wildlife sanctuary, Westernghat region (Pramod et al., 2011). TDS value ranges minimum 1.07 and maximum 7.41(mg/L), in Kolleru Lake, Andhra Pradesh (Sharma and Sujatha, 2016). Thasneem (2015) and Bhavya et al. (2016) noticed slightly higher TDS in Cochin estuary during monsoon season. TDS ranged from 303.67 to 4,456.7 µS/cm in Coimbature wetland, Tamilnadu (Chandra et al., 2009). TDS was comparatively low (0.17 to 0.35 mg/L) in Gudavi wetland in Central Western Ghat region (Manjuath and Narayana, 2016). Smitha Asok et al. (2016) and Zubair and Ahrar, (2013) recorded decline in TDS concentration during winter. The minimum values of TDS were recorded in flooded conditions during the present study which is related to their utilization by plankton and other aquatic plants and loss of nutrients into the sediment. The present observation is in complete agreement with the findings of Romanescu et al. (2013); Goldhaber et al. (2014) and Jeffries (2016). As per the Trivedy and Goel (1984) TDS of Maranchery Kole lands were not exceeded above 3000mg/L. Barnes et al. (2016) recognized that, solute concentrations are expected to be raised as a result of the process of evapo-transpiration, which dominates the water component of many wetlands in tropical and subtropical areas particularly in semi-arid regions. Salinization alters the fundamental physico-chemical nature of the soil and water, increasing ionic concentrations and altering chemical equilibria and mineral solubility. This lead to the biogeochemical cycling of major elements including carbon, nitrogen, phosphorus, sulfur, iron, and silica (Herbert et al., 2015). Increase in TDS cause decrease of population of cyanobacteria in agricultural fields was reported by Deep et al. (2013). A negative correlation coefficient was observed between the alkalinity and total dissolved solids.

Suspension of particles in water which interfere with passage of light is called turbidity. Turbidity in water is caused by mainly due to suspended and colloidal matter such as clay, silt, finely divided organic matter, plankton and other microscopic organisms. Turbidity is the most critical factor regulating the growth of chlorophyll bearing organisms (Kaushik and Saksena, 1990). Peak variation of turbidity was noticed during the month of January 2011 in stations 4, 5 and 6 in Maranchery Kole. When compared to other phases the channel phase turbidity shows 17 NTU. Bijoy Nandan and Unnithan (2004) have reported a range of 2 NTU to 35.5 NTU from Kayamkulam estuary, Krala. Macrophytes helped to reduce the turbidity by trapping suspended sediment from the water column (Norlin et al., 2005) and this may be one of the reasons for the less turbidity during wet phase. Comparatively high values of turbidity in channel phase might be due to the muddy sediment bottom, reduction in depth of the water column and reduced macrophytes in this phase. According to Kaliamurthy (1973), in shallow waters with muddy bottom, high turbidity is caused by stirring the bottom sediments up by the action of wind. In contrary to this, Vaheeda and Simon (2014) reported that the decaying macrophytes may have contributed to the turbidity in Backwaters of Kodungallur, Kerala. The aquatic environment in rice fields is characterized by shallowness, great variation in turbidity noticed by Fernando (1993). The relation between flood water turbidity and paddy fields turbidity was compared by Yamagata et al. (1988). In their study explained that, increase in turbidity during flooded condition, greater the damage to the crop. Mean value of turbidity in paddy phase of Maranchery Kole wetland was 11.4 NTU. Agriculture related activities might enhance the turbidity in this phase. Turbidity was positively correlated to alkalinity, chloride, total hardness and calcium hardness and that off strong negative correlation with nutrients significant at 1% level ($P<0.01$).

Dissolved Oxygen (DO) is free oxygen dissolved in water and it is used to assess the health of natural water. This is what the aquatic organisms breathe. The DO concentration is a function of temperature and salinity (Henning et al., 2007). Concentration of DO increases with low temperature and low salinity. Photosynthesis and physical respiration were the two major processes with the received oxygen. DO level in water indicates the quality and kinds of life, it can support. The range of DO in Maranchery wetland showed higher variation and it ranged from 2.4 to 10.4 mg/L. The following studies were recorded in this respect. Jayachandran and Nandan (2011) observed the average dissolved oxygen concentration of 5.1±1 mg/L in Kodungallore - Azhikode estuary. Kamat (2004) reported that, in wetlands of Goa, the amount of DO varied between 7.1 to 8.6 mg/L. Mandal (2012) reported nearly 2-3mg/L in wetlands of West Bengal. Pramod et al. (2011) studied the wetlands of Hebbe range, mid Western Ghat region and there DO level shows slight increase in monsoon period (7.43±21 mg/L). In Assam wetlands DO level noticed between 6.4 to 10.2 mg/L (Saud et al. 2012). Sisodia and Moundiotiya (2006) found that the Kalakho Lake of Rajasthan has poor DO values. DO varied between 1.8 to 9.4 mg/L in Kabar wetlands of Bihar (Sharma Shardendu, 2012). Chaudhry et al. (2013) observed that DO was 6.4 to 10.3 mg/L in lake of Chandigarh City, Raghunathan, (2007) reported DO of water that ranged from 2.9 to 5.3 mg/L in Ashatamudi wetlands of Kerala. Sylas et al. (2006) in Vembanad wetlands reported 6 to 9.0 mg/L. Reduction in dissolved oxygen is observed during pre-monsoon and monsoon seasons in different wetlands, of Karnataka (Jagadeeshappa and Kumara, 2013).

The mean value of DO in the Maranchery wetland (6.4 ± 0.4 mg/L) indicated that all the stations under study had reasonable amount of oxygen level. Phase wise average shows that, 6.2 to 7.9 mg/L in wet to stable phases. In Maranchery wetland during February 2011, March 2011 and April 2011 period there is a decrease in DO level noticed in stations 6 and 7. Both stations clogged with floating macrophytes like *Eichhornia*, *Salvinia* species and other aquatic weeds. It can be concluded that during the premonsoon period, the decreased rate of flow, reduction in photosynthetic activity and rapid evaporation result into decay of these macrophytes these decaying vegetation also probably affect the DO level. Majority of the macrophytes reached the senescent stage during these months. Macrophytic debris also contributes to the organic load, leading to the depletion of dissolved oxygen in different stations situated on the Perumthode of Kodungallur region was reported by Vaheeda (2008).

DO ranged from 7.8 to 8.2 was observed in Keerapalayam paddy fields of Cuddalore District of Tamilnadu (Selvi and Sivakumar, 2011). Qin et al. (2017) explained that, DO level in a rice field is the outcome of mechanical, biological and chemical processes. The mechanical processes consist of action by the wind and the resultant diffusion through the air-water interface. The major source of DO in the water column is the photosynthetic activity of the aquatic plants biomass that can lead to super-saturation in the afternoon. According to the results, early growth stage of paddy fields the DO level reaches upto 9.2 mg/L, agreeing with the above studies. Biggs et al. (1990) and Bilgrami and Munshi (1985) explained that

DO level greater than 8.0 mg/L can support many fish and other desirable forms of aquatic life, while water with DO less than 2.0 mg/L can support only worms and other decomposers. The present study is in conformity with the above statement, DO levels of Maranchery wetlands favour the growth of macrophyte as well as macroinvertebrates, and also the level indicates the enhanced growth of paddy and fish cultivation. There is continuous reduction of DO level noticed during channels of this wetlands. The decreased DO level in channels was mainly augmented by the suspended silt particles due to extensive fishery activities in the channels. More over the channels was occupied by different migratory birds, their activities also leads to suspension of clay soil particles turns to upwards. The shallow nature of channels and adjacent agricultural runoff leads to death and decay of aquatic plants and weeds such as *Ipomea* sp. *Eichhornia crassipes and Nymphaea* sp. this could be one another reason for decreased DO level during this phase. A positive correlation significant at 5% level ($P<0.05$) was observed between dissolved oxygen with water temperature and pH. A negative correlation significant at 5% level ($P<0.05$) was observed between DO with turbidity, TDS and nitrate. However, Dewan et al. (2017) established a negative correlation between dissolved oxygen and water temperature in channels of floodplains of the Ganges. Tare et al. (2017) elaborated high temperature promotes high oxygen consumption through high biological activities in the wetlands. According to Hamilton (2005) and Santoso et al. (2017) the relationships between these two parameters are of little significance, as the production and consumption of oxygen takes place simultaneously.

Alkalinity is a measure of presence of acid in water and cations balanced against them (Shastri and Pendse, 2001). Phosphates, borates and silicates, if present, also contribute to alkalinity value. Moyle (1946) noticed that water bodies having a total alkalinity greater than 200mg/L were highly productive. Alikunhi (1957) observation was that in highly productive waters the alkalinity ought to be over 100 ppm. According to Bakalial et al. (2017) high ranges total alkalinity is encountered in waters having pH value that ranges from 8.4 to 10.5. Steep increase of alkalinity was found during January 2011 in all 8 stations, it could not be correlated to productivity. Low DO in these stations during the same period and eutrophication may be the reason for this phenomena and sudden change from one phase to another phase also leads to decrease of oxygen level and increase of alkalinity in that month. In conformity with that of Thrissure Kole lands Tessy and Sreekumar, (2013) has recorded average alkalinity ranging from 23.2 to 47.6 mg/L. According to Hayes (1964) the factors responsible for higher alkalinity have been reported to be organic pollution and decomposition of organic matter in sediment. Bijoy Nandan and Unnithan (2004) have reported alkalinity up to 120 ppm in Kayamkulam wetland and have reported an increase in range of alkalinity in retting stations when compared to non retting stations. A low range of alkalinity has been reported by Sreenivasan (1971) in shallow aquatic biotopes. The alkalinity ranged between 58-123mg/L. There was a steep fall in the total alkalinity in the months of August and September in Shasthamkotta Lake (George and Koshy, 2008). In phase wise variations paddy phase shows higher alkalinity and other three phases showed a decreasing (channel<wet<stable) range of alkalinity. Rice fields are fertilized with organic and inorganic fertilizers. This might be lead to increase of alkalinity during paddy phase of this wetland. Vegetations like floating, emergent, submerged and partly floating

types were present in the wetland, and the plants might utilize different nutrients according to their growth pattern that will cause a reduction in alkalinity during wet and stable phases. Emergent macrophytes act as a biofilter thus decreasing the value of limnological characteristics (Squires and Valk, 1992 and Pramod et al., 2011). The limnological variables associated with the reduction of alkalinity were nitrate, DO, total phosphate, conductivity, bicarbonate and carbonates. Alkalinity shows a strong negative correlation with depth and a weak correlation with dissolved oxygen.

Salinity has a significant effect on the living components of an ecosystem. Maranchery Kole land is a fresh water wetland, low salinity values were recorded in all the stations except Station 5 and 6 during August 2012. No wide variations were observed in salinity during the study period. Minimum salinity value noted was 0.002pptand maximum was 3.7 ppt. Salinity was higher during paddy phase compared to other phases. Sujatha et al. (2009) reported higher salinity during May in Ashtamudi wetland. In Vembanad wetlands and Kumarakom region, Vincy et al., (2012) reported salinity of 7.5 to 8 ppt during their study related to tourism and its effects on water quality. Frequency of flooding also affects the salinity pattern (Gopakumar and Takara, 2009).Nielsen and Brock, (2009) says that salinity act as certain types of biota that can live in an particular ecosystem. Naik et al. (2008) on studies in Chilika lake exhibited highest fluctuation of salinity in northern sector. It is well-known that the soil in the Kole area especially those in the flood plain areas are heavy clay in texture and acidic in reaction (Johnkutty and Venugopal, 1993). The presence of organic peat layer in the sub-surface of the soil has made the soil extremely acidic (pH 2.6 to 6.3). Besides, in the Kole lands adjacent to the Arabian coast, sea water inundation causes salinity levels to reach to a level where it is toxic to crops (Jeena, 2010). Compared to these reports in Maranchery Kole, very low salinity was noticed during overall study period. Salinity shows a significant positive (1% level, $P<0.01$) correlation with dissolved carbon dioxide chloride and ammonia. It shows a weak negative correlation with dissolved oxygen and nitrate with 5% significance ($P<0.05$).

The minimum concentration of chloride was 5.9 mg/L in August 2011 and maximum was 229.9 mg/L in May 2011. Minimum concentration of chloride was recorded in wet phase and highest in paddy phase. The chloride contents normally increases in water as the mineral contents also increases (Kadlec and Wallace, 2008). The increasing values of chlorides in early summer months may be due to a gradual decrease of the water column. Migratory birds and buffalos pasturing in and around this wetland was noted during various sampling periods. Chlorides are not utilized for macrophytes growth and their presence in large amount is regarded as suggestive of contamination by organic matter, chiefly of animal origin. A positive correlation coefficient significant at 1% level ($P<0.01$) emerged between salinity and hardness content in the study period. Dhanapakiam etal. (1999) observed high chloride content during winter season, due to reduced flow of water and relatively large amount of waste discharge through human activities. The high chloride concentration in water indicates the presence of large amounts of organic matter (Manimegalai et al., 2010). Mohanraj et al. (2000) reported that chloride content (964.4-209.3mg/L) was increased in Ukkadam wetlands, Tamil Nadu from previous studies.

Total hardness is a measure of the mineral content in water (Walker and Wehrhahn, 1971).In the present study range of hardness recorded as 16 to 136 mg/L. In phase wise analysis maximum value was observed during paddy and channel phases. Parashal et al. (2008) reported that the hardness of water is not a pollution parameter but it indicates water quality. Sawyer (1960) classified water on the basis of hardness into three categories (i) soft with hardness from 0 to 75mg/L, (ii) moderately hard with hardness from 75 to 150mg/L and (iii) hard with hardness from 150 to 300mg/L. Considering the above statement the Maranchery wetland is soft in nature because in general the range of hardness is below 75 mg/L. According to Sreenivasan (1974) and Spence (1967) in wetlands having hardness above15.0 mg/L the growth of fish is most suitable and productive. In Muriyad wetlands, Kerala range of hardness was 16 to 33.6 mg/L (John Thomas et al., 2013). The hardness of the Kuttanad wetlands was in the range of 17 to 562 mg/L (Thomas et al.,2001). The total hardness of Thrissur Kole wetlands fluctuated between 12 to 124 mg/L (Tessy and Sreekumar, 2013). Deep fluctuation in summer months was noted by Sreekumari et al. (2016) in Shasthamkotta lake. A positive correlation significant at 1% level ($P<0.01$) was observed between total hardness with water temperature, conductivity, turbidity and TDS. A weak negative correlation observed between total hardness and pH of the water column in the study stations.

Calcium is one of the most abundant cation present in water. The content of calcium is one of the variable micronutrient which influences the growth and population dynamics of fresh water fauna and flora and it is also essential for the structural and functional integrity of cell membrane for phytoplankton growth (Eppley, 1962 and Epstein, 1965). Høberget al.(2002) reported that macrophytes utilize calcium because it is a vital micronutrient necessary for proper functioning in the aquatic food web. Beaulac and Reckhow, (1982) suggests that the concentration of calcium up to 1800 mg/L is known to have no physiological effects on human beings, yet its absence in water has been found to cause dystrophy. Kaushik and Saxena, (1999) in their study says that, in Indian freshwater bodies calcium content fluctuated from 11.2 to 390.67 mg/L. According to Weninger, (1985) on the basis of presence of calcium in water, it is classified to i) calcium 'rich' as high content of calcium, (always> 25 mg/L); ii) poor content of calcium (<10 mg/L); iii) Water with medium calcium (10 to 25 mg/L). In Maranchery Kole, compared to other stations, station 2 and 8 shows sudden variations of calcium content in different periods and phase wise the average shows that maximum values were recorded in paddy phase. The calcium hardness showed lower trend during wet phase but higher in paddy phase because of the volume of water in paddy phase were very less and the lower values for these parameters indicated that they get diluted in wet phase. Moreover the prolific growth of macrophytes and aquatic insects utilized in various growth stages also resulted to decrease of calcium concentration in wet phase. The results are in agreement with Shedlocket al. (1994); Yeole and Patil (2005). Deshkar et al. (2010) observed higher concentration of calcium during summer period. Further a strong negative correlation significant at 1% level ($P<0.01$) was observed between Ca. hardness, depth and pH of the water column.

Magnesium was present in natural water with calcium. But its concentration was normally lower than calcium. It is mandatory by chlorophyllous plants to produce porphyrin complex, and act as a micronutrient in enzymatic transformations especially in transphosphorylation by algae, fungi and bacteria (Wetzel, 1995).

According to Goldman (1960) availability of magnesium has been influenced by phytoplankton productivity in an oligotrophic lake. The range of magnesium in different sampling sites was found to be 4 to 52 mg/L. Compared to different phases, study showed marginal variations in four phases and higher concentration of magnesium was noticed during stable phase. Hydro period is largely determined by differences between precipitation and evapo transpiration of magnesium concentration, and is mediated by geology and topography (Kirkman et al., 1999). In the Maranchery wetland variation in the concentration of magnesium was highly correlated with macrophytic growth. Because, different species of macrophytes and its relative absorption of magnesium varied widely. This may be one reason for higher variations of concentration of magnesium in different stations. Higher concentration of magnesium during stable phase, in present study, is related to higher evaporation rate, higher rate of organic matter decomposition and anthropogenic activities and relatively higher concentration of magnesium in channels might be decreasing the growth of macrophytes. But in contrast with findings of Ganai and Praveen, (2014) they recorded an increase in magnesium content during summer months. A strong positive correlation observed between magnesium hardness with water temperature, conductivity and TDS. Calcium content shows a strong positive correlation significant at 1% level ($P<0.01$) between turbidity.

The major source of dissolved carbon dioxide in an aquatic ecosystem was respiration of aquatic organisms, organic matter decomposition, ground water recharging and bicarbonate salts. Dissolved carbon dioxide regulate the pH of the aquatic system. Ellis, (1937) recommended concentration of carbon dioxide less than 5 mg/L was good for fish production. Various reports says that, actively growing macrophytes will release upto 10% of their photosynthetically fixed carbon to the water as dissolved organic carbon (Tharp and Wetzel, 1969; Hough and Wetzel 1978; and Sand-Jensen and Søndergaard, 1981). Maranchery Kole, generally observed prolific growth of submerged macrophytes like *H. verticillata, U. aurea* and *H. aristata*, which leads to presence of dissolved carbon dioxide in the system. Freeman et al. (2004) and Girijakumari et al. (2011) noted that dissolved carbon dioxide may occur in the free state and it tends to vary inversely with oxygen. Dennison et al. (1993) explains that in presence of free carbon dioxide in trace amounts is good for aquatic health. But at high concentrations, it becomes harmful for the system. Mean value of dissolved carbon dioxide in Maranchery wetland was 9.6±6.0 mg/L, and minimal variations were observed during phase wise evaluation (12.8-16.0mg/L). Dissolved carbon dioxide shows a strong positive correlation significant at 1% level ($P<0.01$) between DO and nitrite and a negative correlation was observed between depth, water and air temperature. Jayachandran et al. (2013) recorded high dissolved carbon dioxide values from the Kodungallur-Azhikode estuaries. Staehr et al. (2017) observed a positive correlation between dissolved carbon dioxide and productivity in shallow estuary. In paddy phase depth of the water body was few centimeters and higher rate of circulation of atmospheric carbon dioxide was taking place in the phase. In agricultural wetlands decrease in water level causes increase in natural diffusion of atmospheric CO_2 reported by Castillo et al. (2000). According to Madsen and Gutierrez, (2017) agitation on the surface water and decomposition of organic matter leads to variation or increase in surface carbon dioxide. In Maranchery Kole land generally peak variation was noticed in May 2011 period in stations 6 to 8. Decaying of major macrophytes like *E. crassipes* were noticed in this period, decomposition may leads to increase in dissolved carbon dioxide in particular period.

Biological oxygen demand (BOD) is the dissolved oxygen used by microorganisms to biologically oxidise organic matter. BOD is also used to measure waste impact on natural water, and to evaluate their purification capacities (De, 2002). In Maranchery wetland the BOD lies between 1-6.5 mg/L. In month wise analysis wide fluctuations were observed. BOD level shows marked seasonal pattern and was high in summer and low during winter observed by Sahu et al. (2007); Rober et al. (2014) and Webster et al. (2015). Jeelani (2016) observed similar pattern in Kashmir lake. In phase wise evaluation marked difference was observed between wet and paddy phases. Extensive aquatic vegetation in the wetland supports or influences the water quality characteristics within the ecosystem. The low level of BOD also indicates insignificant levels of organic pollution. The range of water quality and the way of irrigation, the degree of acidification of the paddy fields were different from stations to stations. This also lead to marked variation in month wise BOD level. Suspended sediments was higher in the Maranchery wetland. Water requires more oxygen to oxidise these particles. So this could be the one reason for the increases in BOD level in the wetland. According to Gopal and Zutshi (1998) floating plants may eliminate oxygen completely from the water column, and promote reduction processes in natural and constructed wetlands. Peak increase in BOD level during February 2011 in stations 6 and 7 could be due to higher abundance of the weed *E. crassipes* in this station reducing the diffusion of oxygen. A positive correlation significant at 1% level ($P<0.01$) was observed between BOD with dissolved oxygen. A strong negative correlation significant at 1% level ($P<0.01$) was observed between BOD with depth and dissolved carbon dioxide.

Nutrients are elements essential to the growth and reproduction of biological organisms. According to the concepts of Lee et al. (1975) and Fisher and Acreman, (2004) wetlands have also been known to function as 'biotic filters' and 'sediment traps', trapping nutrients by serving as a biological filters for run-off water from the surroundings. Further, each wetland is unique in its own right, and has to be investigated in its totality as an ecosystem and subsystem. Reports on nutrients and their dynamics in fresh water wetlands were often fragmentary. The interplay between macrophytes and nutrient variables represents a fundamental characteristic of wetland systems, which has important implications for flow and ecological functioning (Xiao et al.,2010). Van der Valk et al. (1979) stated that differences among wetlands in their nutrient trapping capacity is chiefly the result of differences in hydrology and the interaction of seasonal fluxes of nutrients within a wetland. Hemond and Benoit, (1988) supported that, substantial amount of the nutrients taken up by rooted emergent plants may be lost to the water at the end of the phase changes through litter fall and subsequent leaching.

Nitrogen in natural waters occurs primarily in three forms, Nitrite- NO_2-N, Nitrate- NO_3-N and Ammonia- NH_3-N. The mean temporal variation of NO_2-N in the study area ranged from 0.001 to 1.7µmol/L. The peak variations were noticed in the station 2 during March 2011. Reduction in NO_2-N concentration was directly related to growth of macrophytes. The concentration of NO_2-N in Maranchery wetland was traceable amount. Macrophytes like *Nimphaea* sp. and *Nymphoides indicum* like plants store nutrients into their fruits. Thick floating mats of these two plants were covered with this wetlands. This could be one reason for low NO_2-N. This is an agreement with most of the studies on other wetland ecosystems. Al-

Kenzawi and Al-Rawi (2009) observed, nitrite concentration decreased from 0.91 µg/L to 0.44 µg/L in premonsoon to postmonsoon in the marshy areas in Southern Iraq. During the growing season there is generally noted a high rate of nutrient uptake from the water and sediments by emergent and submerged wetland vegetation. Roache et al. (2006); Brix, (1997) and Engelhardt and Ritchie (2001) explained the significant role of macrophytes in nutrient concentration, whereas the nitrogen shares in protein structure and metabolic processes, leading to increase of vegetative and reproductive growth of aquatic plants. Khatarkar and Trivedy (1993) registered the similar low concentrations from macrophyte infested lakes in Maharashtra. Boyd et al. (1997) verified that aquatic plants acting as a biofilter system were capable of removing 94% of nitrite in aquatic bodies. Pinki and Gupta (2012) reported range of NO_2-N was 0.007-0.02 mg/L in Chatla Wetland, Assam. Sujatha et al. (2009) reported that the nitirite –nitrogen concentrations were higher in Vembanad Lake compared to Ashtamudi Lake and presence of NO_2-N might be the result of oxidation of NH_3-N due to rich organic matter, in estuarine sediments. Phase wise average shows that, higher concentration in paddy fields and channels was 0.27µmol/L and lowest in stable phase 0.08µmol/L. The increase in concentration of NO_2-N may be attributed to reduced growth of macrophyte in these phases. In channels of this wetland diversity and percentage of distribution of macrophytes was comparatively lower due to mechanical as well as manual removal. Moreover due to higher temperature and decreased availability of water resulted in death of macrophytes. Leaching of this debris also leads to increase of nutrients to water column.

Kirchmann (1994); Muchovej and Rechcigl (1994); Karlen and Sharpley, (1994); Chauvelon (1998); Tong et al. (2007) and Fonge et al. (2012) reported that over use of nitrogen fertilizer threatens sustainable agriculture and this is a serious problem all over the world. Over exploitation and extensive use of nitrogen fertilizers in agriculture ultimately destruct the animal habitats, which exposes them to predators, accordingly biota got changed, leading to proliferation of macrophyte community (Johnson and Rejmankova, 2005). Wetzel, (1992) and Mueller et al. (1984) says that concentration of different forms of nitrogen are highly variable in aquatic environment duo to metabolic demands especially the nitrite-nitrogen concentration. High nitrogen application results in high nitrite-nitrogen concentration in water, where their continuous use eventually leads to acidification of the water (Kato et al., 2009). The above statement was agreement with our results. Over application of nitrogen fertilizers was observed in the paddy fields of Maranchery Kole lands and might be leads to increase of concentration of nitrite-nitrogen and further reduction in pH of water. Moreover irrigated water in agricultural fields creates an impact in nutrient level in paddy phase. Nitrite shows a strong positive correlation with dissolved carbon dioxide and a negative correlation with TDS. A positive correlation significant at 1% level ($P<0.01$) was observed between nitrite with phosphate.

The NO_3-N exhibit wide range of variation in Maranchery wetland. In station wise NO_3-N was ranged between 0.001 to 9.5µmol/L and phase wise it was 0.015 to 0.023µmol/L. In the observation of Siddiqui and Ramakrishna (2002) nitrates were loosely bound in soil and its concentration likely increases with surface run-off. Quiet early studies indicate a wide range of fluctuation in the NO_3-N concentration in different water bodies (Natarajan and Apurba, 1980; Howard, 1985; Conner et al., 1989; Sigh et al., 1991; Obot et al., 1991; Zedler and Kercher, 2005; Vincy et al., 2012; Hayasaka et al., 2012 and Kim et al., 2016). In most of the studies higher nitrate content during the rainy season was reported. The above results are in agreement with present study. There was a marginal variation observed in monsoon season of the Maranchery wetland. Raman et al. (1990) studied the Chilika lagoons and observed increase in temperature and rapid mixing of sub-surface and surface water during premonsoon season that might have favoured the nitrate replenishment mechanism in the lagoon system. Adams et al. (2008) and Meza-Lopez and Siemann, (2017) observed large concentration of PO_4-P- and NO_3-N reported together from a water body indicate the eutrophic nature of water. Frankouich et al.(2006) reported that growth of aquatic macrophytes and its distribution is associated with nutrient rich environments particularly nitrate and phosphate which have been noted to favour macrophyte growth. The major contribution of nitrate in the wetland might be macrophyte litter. There was a peak reduction in concentration of nitrate noticed during October and November 2011. Fluctuation in water column may be one of the main reason in reduction of nutrients like NO_3-N. Variation of plant biomass was also noticed during same period. Therefore, evaluation of nitrate-nitrogen concentration and its variation is closely associated with water column change and macrophyte biomass. A positive correlation significant at 1% level ($P<0.01$) was observed between nitrate with phosphate.

Ammonia (NH_3-N) was present in moderately high concentration in Maranchery water that ranged between 0.001 to 68µmol/L. In phase wise evaluation, peak variation was noticed during paddy and channel phases compared to wet and stable phases. Agricultural related activities contribute major percentage of ammonia in the wetland. Particularly after applying nitrogen-rich fertilizer to the rice fields, the concentration of ammonia was increased. Ammonia (NH_3) is an important source of nitrogen in the rice field. In its ionized form, NH_4-N is rather harmless, while its un-ionized form it is highly toxic to fish. Proportions of the different forms are dependent on the pH of the water (Roger, 1996). Lightfoot et al. (1993) found that in integrated farming, a rice field with fish has higher capacity to produce and capture nitrogen than the one without fish. The appearance of NH_4-N which is not toxic to aquatic plants (McMurtry et al., 1997). In wet and stable period, prolific growth of macrophytes were observed in the wetland. The decrease in ammonia concentration in wet and stable phase may be due to absorption by macrophytes for their growth. Earlier similar results were noticed in wetlands of the Tingitan, Peninsula, Rome by Ennabili, (1998). Tavaris et al. (2003) also noted that, ammonia is used by aquatic plants. Kinnear and Garnett (1999) reported nitrogen (NO_2-N, NO_3-N and NH_3-N) that is likely to be a limiting factor in Yellagonga Regional Park, Australia. Salmah et al. (2017) observed ammonia cal-N levels were ranged between 0.07 mg l–1 to 0.09 mg/L. Alfasane et al. (2009) examined the level of NO_3-N in beels of Bangladesh ranged between 37.5 to 107.8 µg/L. Parray et al. (2010) accounted, ammonia cal-N levels that varied between 148µg/L to 398µg/L in Sub Urban wetlands of Kashmir. The higher concentration of ammonia in channel phase may be due to the agricultural runoff from the adjacent paddy fields. Nitrogen compound reduction was not reported in constructed wetlands was noticed because the Maranchery wetland was covered with *Eichhornia crassipes* (Hammaer, 2000). This plant displays great ability to absorb high nutrient concentrations from the medium. In Maranchery Kole especially in Stations 6, 7 and 8 is highly infested with *Eichhornia crassipes.* The long fiberous root system was one of the peculiarities of this invaded water plant and this help to store large amount of nutrients. The absorption of nutrients by this plant may lead to reduction in ammonia in these stations. Ammonia shows a strong negative correlation significant at 1% level ($P<0.01$) with depth, BOD and dissolved carbon dioxide. And also shows a negative correlation significant at 5% ($P<0.05$) with nitrate. A weak negative correlation was observed between ammonia and phosphate.

Being a constituent of nucleic acids and phospholipids, phosphorus is an essential element required for all processes of a living system. Phosphorus occurs as calcium phosphate and present in rocks and soils. Plants and other microbes takes up phosphorus in the form of orthophosphate (PO_4-P), when they die, mineralization due to decaying makes phosphorus available for reuse. The major supply of phosphorus in natural water comes from weathering of rocks, leaching of soil from the catchment area by rain, cattle dung and agricultural activity in adjacent areas (Jhingran, 1982: Kutty et al., 2017). The value of phosphate ranged from 0.10 to 3.1µmol/L in the wetland. Kim et al., (2017) reported 4.20-16.55 mg/L phosphate in northern Florida Everglades. The range of phosphate content ofChilika lagoon water ranged from 0.12 to 0.40 µg/L (Barik et al., 2017). The range is between 0 to 0.03 mg/L in Thrissur Kole lands by Tessy and Sreekumar, (2013). The phosphate level in Kuttanad wetland was 0.11 mg/L (Thomas et al.,2001). Asha et al. (2016) observed higher phosphate during monsoon season in Vambanad esturine system. Mahopatro et al. (2001), Valarmathi et al.(2002) and Ansari, (2017) have reported reduction in phosphate level during premonsoon period. The range of phosphate was 1.65 mg/L to 0.18 mg/L in organic rice field of San Sai District, Thailand (Namwong et al., 2013).

Compared to phases, paddy phase showed higher concentration of phosphate followed by channels, wet and stable phases. The channels of this ecosystem was characterized by numerous fishes, apart from this the channels and paddy phase large number of migratory birds such as ducks and waders, coots, terns and many birds of prey were observed. Kole wetland is well known for its waterfowl and the large flock of Greater flamingo which enjoy greater part of year in this wetland (Jayson, 2005; Namgail et al., 2017). The input of nutrients resulting from avian excreta could have contributed in the channels and paddy fields. The lowest phosphate level was observed in stable and wet phase accumulation of phosphate in plants may be the one reason. Vegetative characters and growth forms closely related to assimilation of phosphate. Floating and submerged growth forms have limited potential for phosphate storage. Because of rapid phase changes, much of the vegetation decomposed during this stage. It will also contributed to the increasing nutrients in channels and decreasing nutrients in wet phase.

Roger (1996) examined that, mud dwelling fishes disturbing the soil, increase soil porosity and promote transfer of phosphorus into the soil. Present study was in conformity with the above statement. Cagauan (1995) and Pathak et al. (2004) enlisted different ways of how a fish influences the nutrient composition of the flooded wetlands, oxidized surface soil as well as the growth of the rice plant. Ennabili et al. (1998) explains that, macrophytes have the ability to store phosphorus in reserve organs after fruiting stage, which varies according to species, locality and seasons. Boyd and Queiroz (1997) verified that aquatic plants act as biofilters which were capable of removing 97% of phosphorus. However, the soil was responsible for removal of phosphorus from the water. Genkai-Kato and Carpenter

(2005) also had the same opinion about macrophytes and its role in phosphorus recycling. In their study they observed, phosphate highly influenced with lake morphometry and related to regime shifts. The increase in phosphate during paddy phase might be application of fertilizers and cattle dung in different stages of paddy cultivation was one another reason. Fonge et al. (2012) reported that, increase or decrease of phosphate concentration depends up on changes of land use pattern. In the present study, highest level of phosphate content was noticed in early summer period in stations 6 and 7. Prasad, (1990) reported that during summer season phosphate content was highest and this is related to high wind speed, decrease in level of water column, high evaporation rate and increased decomposition due to increase in temperature. A strong positive correlation coefficient significant at 1% level ($P<0.01$) emerged between phosphate with DO, BOD and nitrite content in the study period. A strong negative correlation coefficient significant at 1% ($P<0.01$) level emerged between phosphate with depth of the water body.

Silica is important in natural water as structural constituent of diatoms and many fresh water sponges. Availability of silica to the aquatic ecosystem is largely from weathering of soils and sediment (Habib and Yousuf, 2016). The range of silicate varied from 4.5 to 62 µmol/L. There is a decrease in silicate concentration that was noticed during channels (9.0µmol/L) compared to paddy, wet and stable phases. Large numbers of aquatic insect were observed in channels of the wetland especially, the water beetles. One of the reason for low values during the channels might be due to the removal of silicate-silicon by biological process of aquatic insect community. The reports by Murugan and Ayyakkannu (1991) and Quadros et al.(2001) corroborate with the present observation. Compared to Thrissur

Kole lands (0 to 21.98mg/L) the range of silicate were relatively low in Maranchery Kole (4.5 to 62 µmol/L). Heavy rainfall and the increased surface runoff during the monsoon season contributed higher values of silicate during the wet phase. Shivaprasad et al. (2013) noticed silicate concentration was higher during the monsoon period. Compared to stations 6 to 8 wide fluctuation was observed in the silicate concentration in stations 1 to 5. In stations 1 to 5 depth of the water was highly varied due to land use pattern and in station 6 to 8, water column remained with less variation. This indicates that depth of the water body may be highly influencing the variation in silicate concentration. A positive correlation coefficient significant at 1% level ($P<0.01$) emerged between silicate with pH.

The dataset was treated using Principal Component Analysis (PCA) to extract the parameters that are most important in assessing variation in water quality. Five principal components were obtained with eigen values >1 summing almost 78.8% of the total variance in the water dataset. The first PC, accounting for 27.6% of the total variance was correlated with depth and temperature of water column. This ‘physical’ factor may be interpreted as representing influences from change in land use pattern. The second PC, accounting for 17.3% of the total variance was correlated primarily with pH and alkalinity represents the ‘physicochemical’ source of the variability. The third PC, accounting for 12.8% of the total variance was correlated with dissolved oxygen and silicate. Silicate was probably due to the high phytolith content in soils, high silica concentration in the soil and groundwater inflow whereas DO was related to respiration of emergent macrophytes as well as biotic factors. The fourth PC was loaded on nitrite and phosphorous, probably represents water soluble N-species, NO_2; as well as decay of macrophytes. Phosphorus factor represents influences from nonpoint sources such as agricultural runoff and weathering of rock particles from paddy fields. The fifth PC was highly loaded with pH, nitrite and ammonia and is likely to represent ‘‘soil leaching as well as agricultural’’ processes. It is clearly reflected the variation in environmental quality with respect to the land use pattern as well as the macrophyte distribution, diversity and abundance by ordinating wet, stable phases together paddy and channel phases together. More over in paddy phase various agricultural activities also imparted dynamic changes in abiotic factors in the Maranchery wetland. The present study suggests that PCA techniques are useful tools for identification of important water quality parameters.

Table 4.24.The Pearson correlation analysis between water quality parameters in MarancheryKole wetland during the study period.

	Depth	Water temp	Airtemp	pH	Conductivity	TDS	Turb	Salinity	Chloride	Alkalinity	T. Hard	Ca. Hard	Mg. Hard	Dissol. CO_2	DO	BOD	Nitrite-Nitrogen	Nitrate - Nitrogen	Ammonia - Nitrogen	Silicate-Silica	Phosphate Phospharaus
Depth	1																				
Water temp	.308**	1																			
Air temp	.251**	.850**	1																		
pH	.121	-.023	-.051	1																	
Conductivity	.114	.244**	.278**	-.053	1																
TDS	-.045	.197**	.206**	-.120	.916**	1															
Turbidity	-.310**	-.116	-.145*	-.013	-.024	.061	1														
Salinity	.093	.204**	.227**	-.034	.932**	.929**	.053	1													
Chloride	-.254**	.217**	.303**	-.383**	.400**	.516**	.228**	.411**	1												
Alkalinity	-.253**	-.368**	-.297**	.268**	-.096	-.101	.474**	-.060	-.102	1											
T. Hardness	-.176*	.202**	.230**	-.347**	.498**	.564**	.280**	.531**	.681**	.034	1										
Ca. Hardness	-.318**	.044	.107	-.485**	.346**	.456**	.371**	.354**	.640**	.097	.761**	1									
Mg. Hardness	.032	.270**	.254**	-.073	.430**	.430**	.078	.471**	.436**	-.036	.805**	.235**	1								
Dissol.CO_2	.201**	.163*	.123	.062	.250**	.071	-.103	.186**	-.156*	-.163*	.009	-.122	.116	1							
DO	.016	.168*	.200**	.142*	-.162*	-.145*	-.157*	-.189*	-.066	-.081	-.059	-.059	-.029	-.206**	1						
BOD	-.195**	.045	.077	.044	-.100	.006	.048	-.076	.112	-.047	.006	.093	-.069	-.304**	.498**	1					
Nitrite-Nitrogen	-.183*	-.101	-.009	-.085	.000	.105	.130	.075	.210**	.091	-.004	.100	-.103	-.199**	-.007	.212**	1				
Nitrate-Nitrogen	.069	-.086	.000	.114	-.169*	-.184*	-.178*	-.163*	-.150*	-.080	-.218**	-.099	-.239**	-.161*	.080	.343**	-.090	1			
Ammonia-Nitrogen	-.278**	.007	.084	-.413**	.221**	.242**	.151*	.219**	.686**	-.009	.501**	.568**	.232**	-.047	-.089	-.072	.125	-.080	1		
Silicate-silica	-.078	-.081	-.067	.305**	.156*	.176*	.007	.173*	-.074	.168*	.020	-.099	.124	.067	.075	-.192**	.021	-.173*	-.034	1	
Phosphate-phosphorus	-.204**	-.019	-.093	.066	-.067	.040	.083	-.015	.013	-.025	.016	.101	-.069	-.103	.225**	.348**	.262**	-.069	-.050	.076	1

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

* * *

Chapter - 5

PRIMARY PRODUCTIVITY OF THE WETLAND

5.1 Introduction

Productivity is a critical function that supports a myriad of ecosystem services provided by wetlands (Sather and Smith, 1984; Odum, 1989). The foundation for most of the lives in the aquatic bodies is the photosynthetic activity of the aquatic plants and planktonic communities. So in a wetland ecosystem, productivity has a significant role and is considered as the pulse of these ecosystem and it refers to the amount and rate of accumulation of organic matter in a unit time. Three kinds of productivity are recognized in an ecosystem and they are a) primary productivity, b) secondary productivity, and c) net productivity. The amount of primary production is the most significant factor, which determines whether a particular body of water is important or not from the fisheries angle (Prasad, et al., 2010). Primary productivity refers to the rate at which radiant energy is stored by the photosynthetic and chemosynthetic activity of producers.

Photosynthesis is quantitatively the most important autotrophic process. Variations in the water quality parameters and the abundance of phytoplankton of the aquatic body can be explained in terms of the production of both biotic and abiotic resources of the ecosystems (Bijoy Nandan, 2011). Net productivity refers to the rate of storage of organic matter not used by consumers. The magnitude and dynamics of primary production has become an essential parameter to assess the state of pollution in aquatic systems. They are useful indicators of eutrophication and depict the fertility of the water analysed (Tamire and Mengistou, 2014). Biotic components of an ecosystem are interrelated and mutually dependent with each other through various kinds of trophic and non-trophic associations. These close interactions with the surroundings comprise a balanced ecosystem. Hence measurement of the primary productivity and associated pigments is important to know changes like, trophic status, fish production and production potential of the water body.

Wetlands of Kerala, such as Kole wetlands in the northern region of Kerala are faced with frequent changes in water column which is unevenly distributed in space and time. Hydrologic cycles are highly variable, due to farming activities rather than seasonal irregularities. Studies conducted by Stanley et al. (1997) sudden water column changes could result in significant changes in ecosystem size. According to different authors hydrological changes lead to change in ecotone boundaries (Johnston and Naiman, 1987) and variation in nutrient dynamics (Quintana et al. 1998) dilution of pelagic communities (Dickman, 1969). In short, the physical and chemical environment and biotic communities may be altered substantially by water inputs and outputs (Quintana et al. 1998, 1998a). Bernard and Hankinson (1971) have suggested that productivity are more likely to be controlled by abiotic mechanisms and standing crop communities in wetlands. Binson (1981) conducted a detailed study of primary productivity, decomposition and consumer activity in freshwater wetlands and discussed the fluctuation of water levels and its effects in soil organic matter. Many studies have been undertaken to determine the responses of selected biological communities to such fluctuations. Studies are mainly concerned with the evaluation of the capacity of an ecosystem to build up at the expense of external energies of both radiant and chemical energy (Vollenweider, 1968). Accurate estimation of primary production is essential for the proper management and exploitation of all the natural habitats and also it provides us with a means of assessing whether an ecosystem is being under-exploited or over exploited or the yield is as great it could be (Clarke, 1954). Atkins (1922) reported on primary productivity of organic matter by investigating on the productivity of the English Channel. Rainfall pattern and its influence on planktonic communities were studied by Twilley et al. (1992) in tropical coastal ecosystems. Patterns of longitudinal and temporal variation in rates of primary production, respiration and nitrification were investigated in the Urdaibai estuary, Spain by Iriarte et al. (1996). The study also reveals the good correlation of primary productivity with dissolved oxygen and a negative correlation observed between salinity and chlorophyll ‘a’. Angeler et al. (2000) reported changes of water inflow in fresh water wetlands of Central Spain and he attempted to describe changes in plankton biomass, also proved flooding and inundation are shown to be significant factor in spatial heterogeneity. Elmaci et al. (2009) observed the trophic state of lake Uluabat, Turkey. According to their assessment phosphorus was found to be the primary limiting nutrient and it influenced the productivity and chlorophyll content in lake Uluabat. Al-azri et al. (2009) initiated a study of seasonal variation in chlorophyll estimation and its relation with phytoplankton in Gulf of Oman. Albrecht, (2012) investigated the trophic status of selected lakes and ponds of Yellow Stone national park, U.S. and detailed the variations in the rate of change of eutrophication..

Phytoplankton, primary production and chlorophyll concentration in various aquatic biotopes are interesting, as they throw light on the relative fertility and potentiality of water. But regarding agricultural wetlands very few studies were noticed in relation to productivity. Hasanuzzaman et al. (2010) studied the productivity and plant growth characters of agricultural fields of Bangladesh. Tessy and Sreekumar (2008) evaluated the algal studies of Thrissur Kole wetlands and found different pollution tolerant algae in their observation. Studies of productivity and pigment composition can provide information on the productive capacity and trophic status of the wetland ecosystem. An attempt is made in this chapter to elucidate the spatio-temporal variations in the productivity of Maranchery Kole wetland and has been discussed in the context of the prevailing physico-chemical condition of the water body.

5.2 Results

5.2.1 Gross primary productivity (GPP)

The gross primary productivity (GPP) shows wide variation during the study period (Table 5.1). GPP showed an average of 1.42 ± 0.46 gC/m^3/day. Station wise mean values of GPP were highest at station 1 (5.25± 1.38 gC/m^3/day) and lowest at station 6 (0.38 ± 1.36 gC/m^3/day) (Figs. 5.1 and 5.2). In station 1, it varied from a minimum of 0.39 gC/m^3/day in January 2011 and to a maximum of 5.25 gC/m^3/day in July 2011 (1.38± 1.02). Station 2, showed a range of 0.75 gC/m^3/day to 3 gC/m^3/day with minimum values recorded in various months of February, March 2011, October, November 2011, April, May, July and August 2012 and maximum in January 2011, May, June 2011 and March 2012(1.48± 0.85). In Station 3, the GPP fluctuated from a minimum of 0.75 gC/m^3/day in the months of December 2010 and October, November 2011 and March 2012 to June 2012 and August and September 2012 to a maximum of 6 gC/m^3/day in February, 2011 (1.12 ± 1.48). The mean GPP was 1.58 gC/m^3/day (±1.10) in station 4, that varied from 0.75 gC/m^3/day in various months to 4.5 gC/m^3/day in December 2010. In station 5, April 2012 it showed the lowest GPP of 0.75 gC/m^3/day during different months, October and November 2011 and February to May 2012 whereas the highest was in June 2012 (3.75 gC/m^3/day) with a mean value of 1.43 gC/m^3/day (±0.89). Station 6 showed the lowest GPP of 0.375 gC/m^3/day in April 2011 period and highest GPP of 3 gC/m^3/day in November 2010, February 2011 and May 2011 with a mean of 1.36 gC/m^3/day (±0.76). In station 7, the minimum GPP was recorded in different months of the study periods (0.75 gC/m^3/day) and maximum in January 2011 (4.5 gC/m^3/day) the mean GPP being 1.42 gC/m^3/day (±1.02). In station 8 GPP varied between 0.75 gC/m^3/day to 2.25 gC/m^3/day in July 2012 showing a mean of 1.26 gC/m^3/day (±0.6). The comparison between the wet, paddy, channel and the stable phases showed that the lowest GPP was in the stable phase showing 1.35 gC/m^3/day and highest in the channel phase 2.06 gC/m^3/day (Fig. 5.3).

Table 5.1. Mean variation of GPP in eight stations of Maranchery Kole wetland.

Stations	Min	Max	Mean ± SD
Station 1	0.375	5.3	1.38±1.02
Station 2	0.75	3.0	1.48±0.85
Station 3	0.75	6.0	1.42±1.18
Station 4	0.75	4.5	1.58±1.10
Station 5	0.75	3.7	1.43±0.89
Station 6	0.375	3.0	1.36±0.76
Station 7	0.75	4.5	1.42±1.02
Station 8	0.75	2.3	1.26±0.60

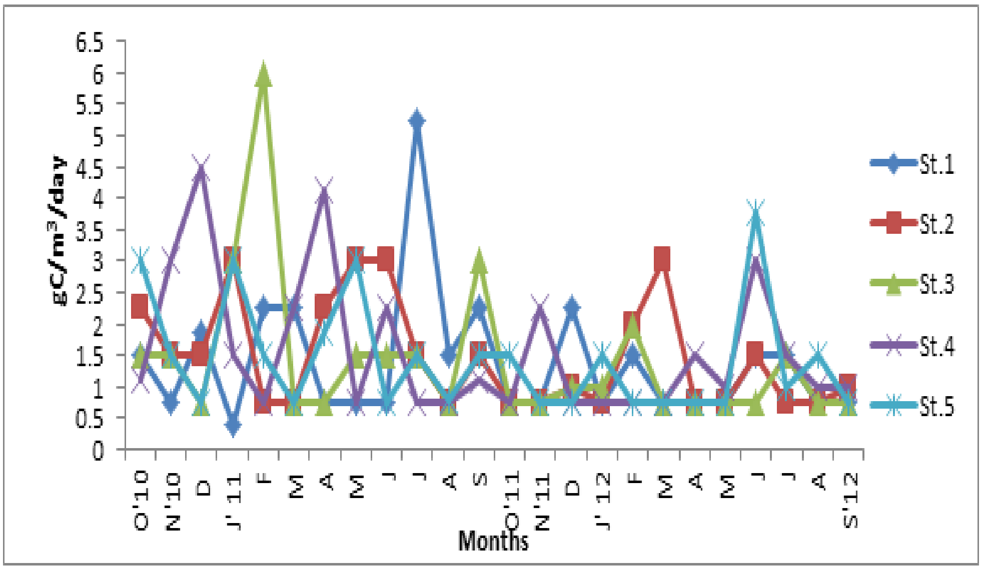


Fig 5.1. Monthly variation in GPP in stations 1 to 5 in Maranchery Kole wetland during the study period.

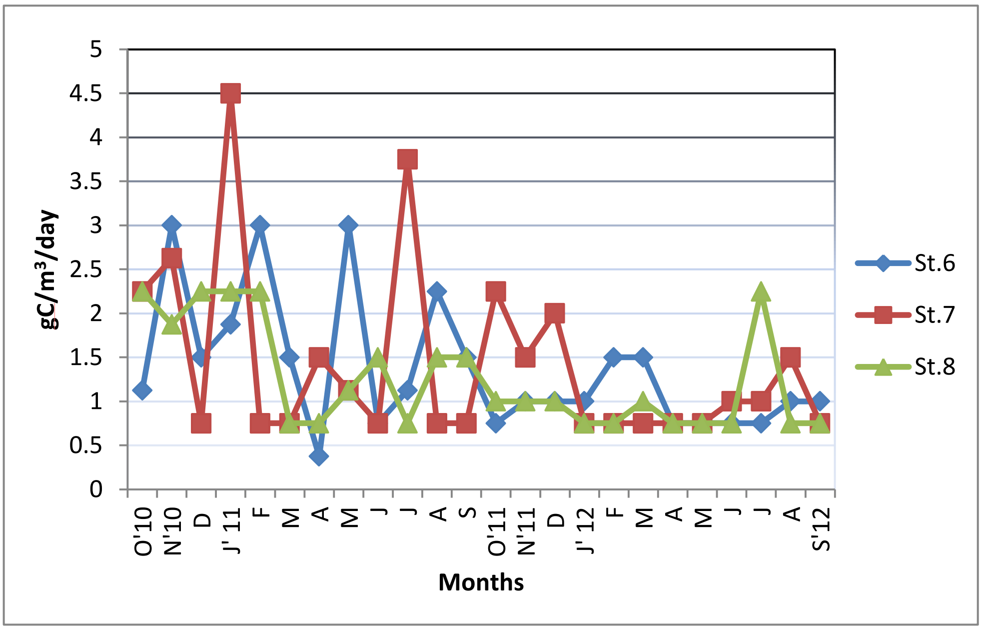


Fig 5.2. Monthly variation in GPP in stations 6 to 8 in Maranchery Kole wetland during the study period.

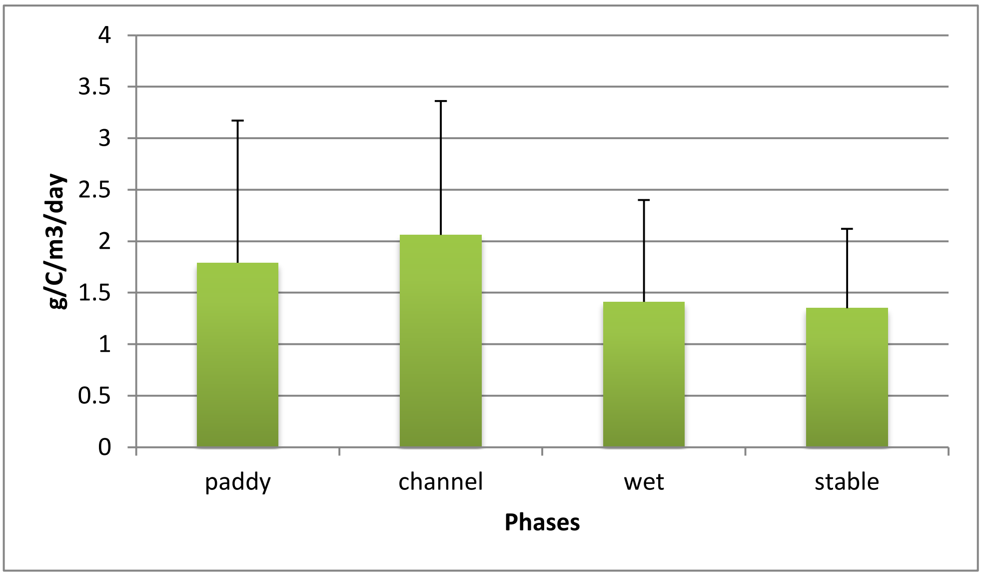


Fig . 5.3. Phase wise variation in GPP in Maranchery Kole wetland during the study period.

5.2.2 Net primary productivity (NPP)

The results of the monthly variations in net primary productivity (NPP) at the eight stations are presented in Figs. 5.4 and 5.5. The NPP values ranged from 0.01 gC/m^3/day to 5.25 gC/m^3/day (Table 5.2). In station1, it varied from a minimum of 0.02 gC/m^3/day in April, 2012 to a maximum of 3.0 gC/m^3/day in July 2011 (0.54 ± 0.78). In station 2, the mean NPP was 0.66 (±0.71) that ranged from 0.02 gC/m^3/day in August 2012 to 2.25 gC/m^3/day in January 2011 and June 2011. Station 3 showed the lowest GPP of 0.01 gC/m^3/day in May 2012, June 2012 and August 2012 and highest value of 5.25 gC/m^3/day in February 2011 with a mean of 0.63 (±1.10). In station 4, May 2011 and October 2011 months showed the lowest NPP of 0.02 gC/m^3/day whereas the highest value was in April 2011 (2.25 gC/m^3/day) showing a mean of 0.68 (±0.67). In station 5, NPP fluctuated from a minimum of 0.01 gC/m^3/day in May 2012 and September 2012 to a maximum of 2.25 gC/m^3/day in October 2010 and May 2011 (0.59±0.77). The mean NPP was 0.58 (±0.55) in station 6, the range varying from 0.02 gC/m^3/day in June 2012 to 1.5 gC/m^3/day in the months of November 2010, January and February 2011, May 2011 and August 2011. In station 7, it varied from a minimum of 0.02 gC/m^3/day in March 2011 to a maximum of 1.75 gC/m^3/day in July 2012 (0.54 ± 0.57) whereas in station 8, NPP ranged from a minimum of 0.01 gC/m^3/day in August 2011 to a maximum of 1.5 gC/m^3/day in December 2011 (0.46 ± 0.47). Phase wise trend in NPP is given in Fig. 5.6. There was wide variation seen in 4 phases. Channel phase showed higher NPP (1.07 gC/m^3/day) followed by paddy (0.98 gC/m^3/day) stable (0.60 gC/m^3/day) and wet phases (0.56 gC/m^3/day).

Table 5.2. Mean variation of NPP in eight stations of Maranchery Kole wetland.

Stations	Min	Max	Mean ± SD
Station 1	0.015	3	0.54± 0.77
Station 2	0.02	2.25	0.66 ± 0.71
Station 3	0.01	5.25	0.63 ± 1.09
Station 4	0.02	2.25	0.68 ± 0.67
Station 5	0.01	2.25	0.59 ± 0.76
Station 6	0.02	1.5	0.58 ± 0.54
Station 7	0.02	1.75	0.54 ± 0.56
Station 8	0.01	1.5	0.46 ±0.46

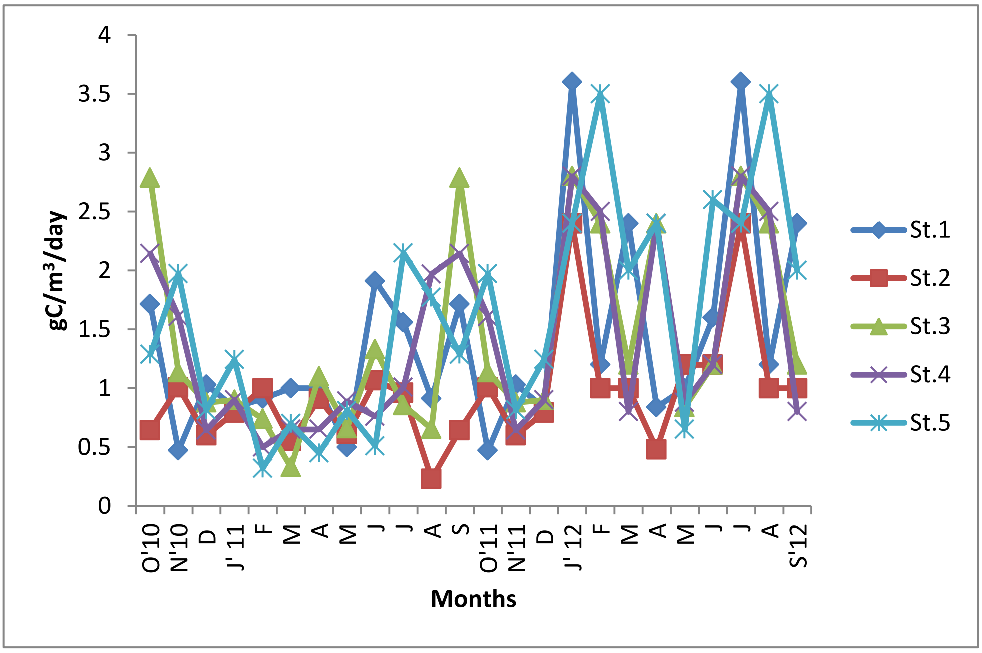


Fig. 5.4 Monthly variation in NPP in stations 1 to 5 in Maranchery Kole wetland during the study period.

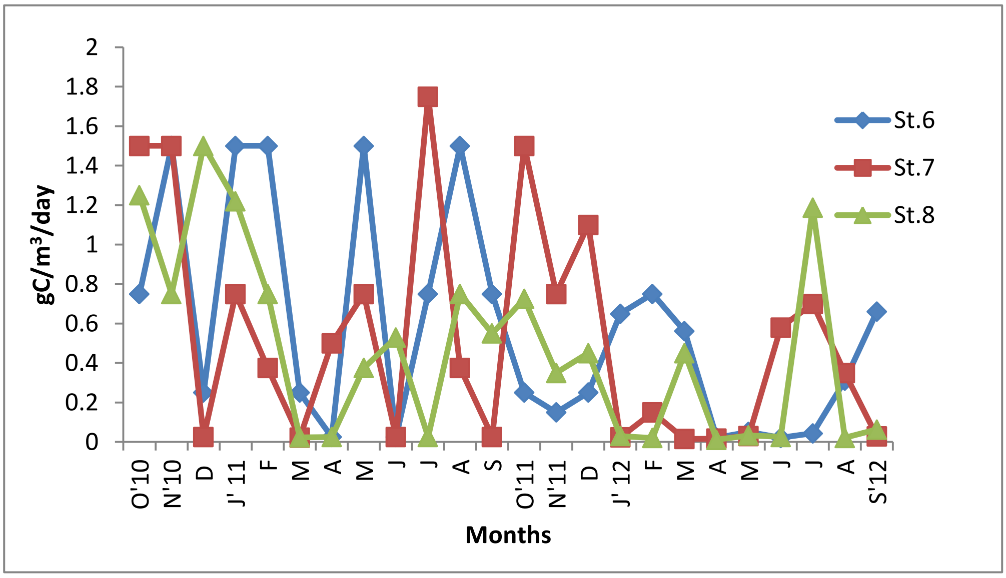


Fig. 5.5 Monthly variation in NPP in stations 6 to 8 in Maranchery Kole wetland during the study period.

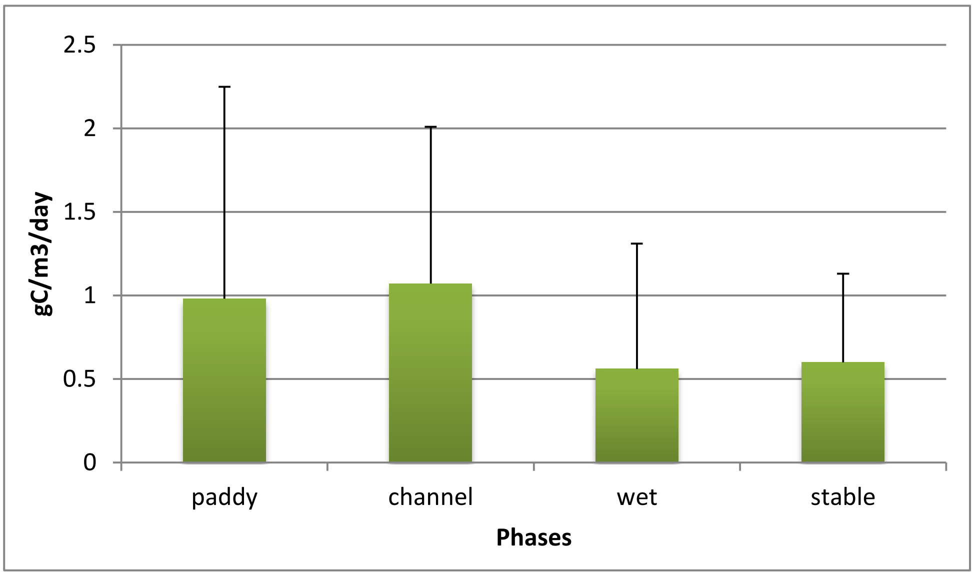


Fig. 5.6. Phase wise variation in NPP in Maranchery Kole wetland during the study period.

5.2.3 Chlorophyll *a* (Chl *a*)

Figures 5.7 and 5.8 gives the Chlorophyll *a* values of different stations of Kole wetland during the period of study. Chl *a* fluctuated between a minimum of 0.66 mg/m^3 at Station 2 in November 2011 to a maximum of 109.4 mg/m^3 in September 2011 at Station 7(Table 5.3). In station 1, it varied from a minimum of 1.19 mg/m^3 in January 2011 to a maximum of 39.6 mg/m^3 March 2012 (10.67 mg/m^3 ± 8.63). The minimum Chl *a* was recorded in November 2011 (0.66 mg/m^3) and maximum in June 2012 (46.06 mg/m^3) from station 2 showing a mean value of 13.92 mg/m^3 (±14.2). The mean Chl *a* in station 3 was 14.87 mg/m^3 (±19.9), ranging from 1.40 mg/m^3 in November 2010 to 94.74 mg/m^3 in September 2012. In station 4, May 2011 showed the lowest Chl *a* value of 1.83 mg/m^3 in October 2010 whereas the highest value was in March 2012 (31.99 mg/m^3) showing a mean of 11.91 mg/m^3 (±7.29). The mean Chl *a* was 10.05 mg/m^3 (±5.61) in station 5, the range varied from 2.87 mg/m^3 in February 2011 to 22.82 mg/m^3 in April 2012. In station 6, the mean Chl *a* was 13.62 mg/m^3 (±15.4) varying from 0.68 mg/m^3 in September 2011 to 63.29 mg/m^3 in March 2011. The Chl *a* ranged from 1.37 mg/m^3 in June 2011 to 109.4 mg/m^3 in July 2012 in station 7 with a mean of 13.13 mg/m^3 (±21.1). In station 8, the mean Chl *a* observed was 12.34 mg/m^3 (±9.7) with a minimum value in November 2011 (1.12 mg/m^3) and maximum in July 2012 (46.72 mg/m^3). Phase wise variation in Chl *a* values is given in Figure 5.9. The phase wise assessment of Chl *a* showed that wet phase (9.56 mg/m^3) followed by channel phase (9.48 mg/m^3) paddy phase (9.15 mg/m^3) and stable phase (8.16 mg/m^3) was noted. Significant variation at 1% level in Chl *a* values was observed in stations ($p<0.01$) and phases ($p<0.01$).

Table 5.3. Mean variation of Chlorophyll *a* in eight stations of Maranchery Kole wetland.

Stations	**Min**	**Max**	**Mean ± SD**
Station 1	1.19	39.36	10.67± 8.1
Station 2	0.66	46.06	13.92± 14.2
Station 3	1.40	94.74	14.87± 19.9
Station 4	1.83	31.99	11.9±17.2
Station 5	2.87	22.82	10.05± 5.6
Station 6	0.68	63.29	13.62±15.4
Station 7	1.37	109.48	13.13± 21.1
Station 8	1.12	46.72	12.34± 9.72

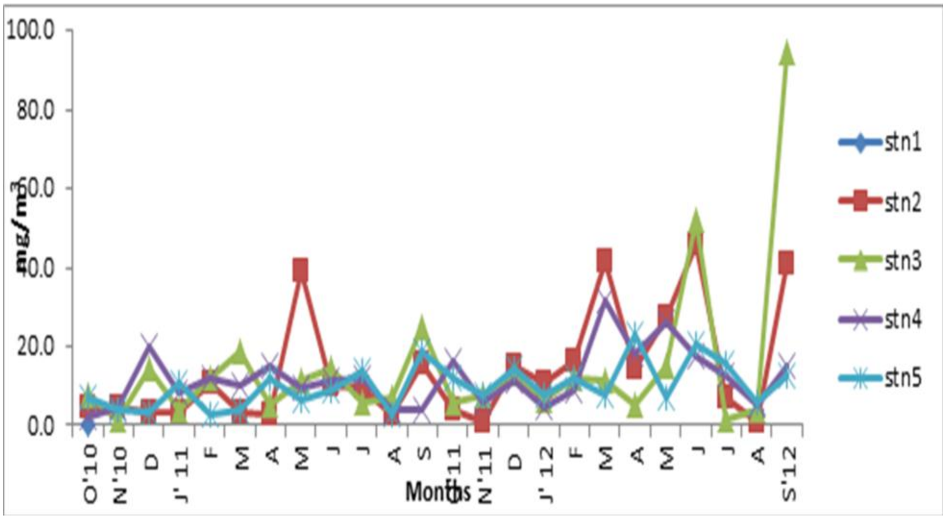


Fig. 5.7. Monthly variation in Chlorophyll *a* in stations 1 to 5 in Maranchery Kole wetland during the study period.

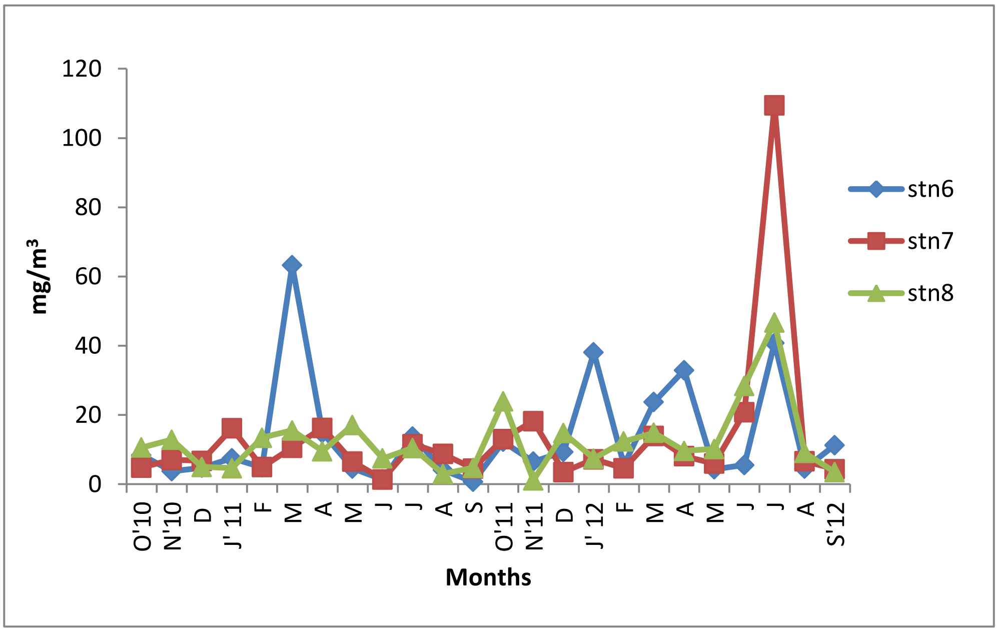


Fig.5.8 Monthly variation in Chlorophyll *a* in stations 6 to 8 in Maranchery Kole wetland during the study period.

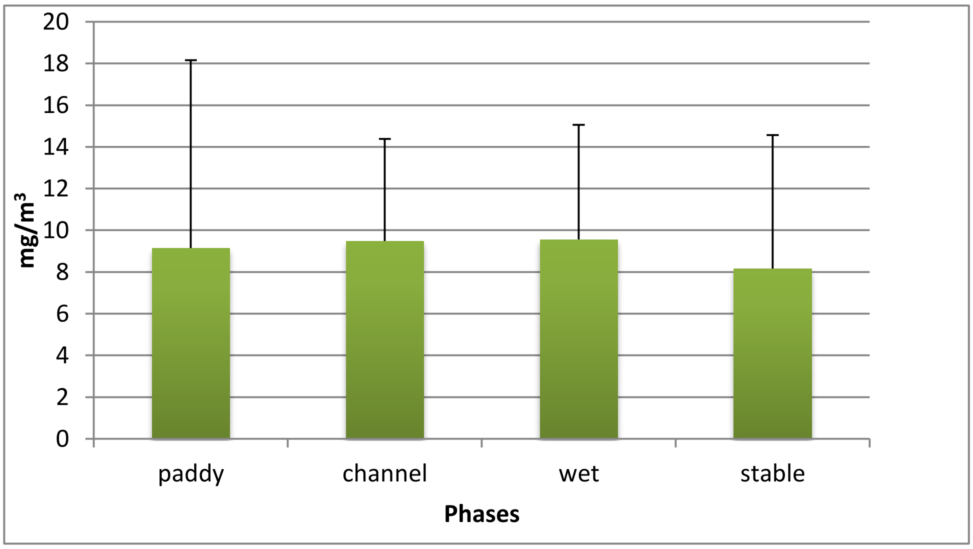


Fig. 5.9. Phase wise variation in Chlorphyll *a* in Maranchery Kole wetland during the study period.

5.2.4 Chlorophyll *b* (Chl *b*)

The chlorophyll *b* (Chl *b*) ranged from 0.03 mg/m^3 to 18.0 mg/m^3 (Figs.5.10 and 5.11).the station wise average is given in Table 5.4. In station 1, it ranged from 0.18 mg/m^3 in April 2012 to 3.95 mg/m^3 in March 2012 with an average Chl *b*. having 1.49 ±0.99 mg/m^3, whereas in station 2 the range was between 0.04 mg/m^3 in April 2012 to 11.76 mg/m^3 in July 2012 and 1.38 ±2.5 mg/m^3 being the mean Chl *b*. The Chl *b* showed the lowest value in November 2011 (0.06 mg/m^3) and highest in February 2011 (4.37 mg/m^3) with an average of 1.54 ±1.3 mg/m^3 in station 3. The mean Chl *b* concentration in station 4 was 3.59 ±4.6 mg/m^3 with the minimum and maximum being 0.03 mg/m^3 in August 2012, 18 mg/m^3 in September 2012 respectively. The lowest Chl *b* concentration recorded in Station 5 was 0.04 mg/m^3 in March 2011 and the highest was in August 2011 (4.32 mg/m^3) having a mean value of 1.38 ±1.0 mg/m^3. In station 6, the mean Chl *b* concentration was 1.58 mg/m^3 (±2.3) with a minimum of 0.04 mg/m^3 in September 2011 and maximum of 8.68 mg/m^3 in January 2012 while in station 7, the minimum Chl *b* recorded was 0.1 mg/m^3 in August 2011 and the maximum of 2.98 mg/m^3 in June 2012. The mean was 1.29 mg/m^3 (±1.0). In station 8, it ranged from 0.08 mg/m^3 in June 2012 to 3.62 mg/m^3 in July 2011, 1.29 mg/m^3 (±0.5) being the mean value. The difference in Chl *b* content in the wet, paddy, channel and stable phases was studied. The channel phase showed the maximum value of 2.50 mg/m^3 and the wet phase showed the minimum value of 1.29 mg/m^3 (Fig. 5.12).

Table 5.4. Mean variation of Chlorophyll *b* in eight stations of Maranchery Kole wetland.

Stations	**Min**	**Max**	**Mean + SD**
Station 1	0.18	3.95	1.49+ 1.0
Station 2	0.04	11.76	1.38 +2.5
Station 3	0.06	4.37	1.54+1.3
Station 4	0.03	18.00	3.59+4.6
Station 5	0.04	4.32	1.38+1.0
Station 6	0.04	8.68	1.58+2.3
Station 7	0.10	2.98	1.29+1.0
Station 8	0.08	3.62	1.29+0.95

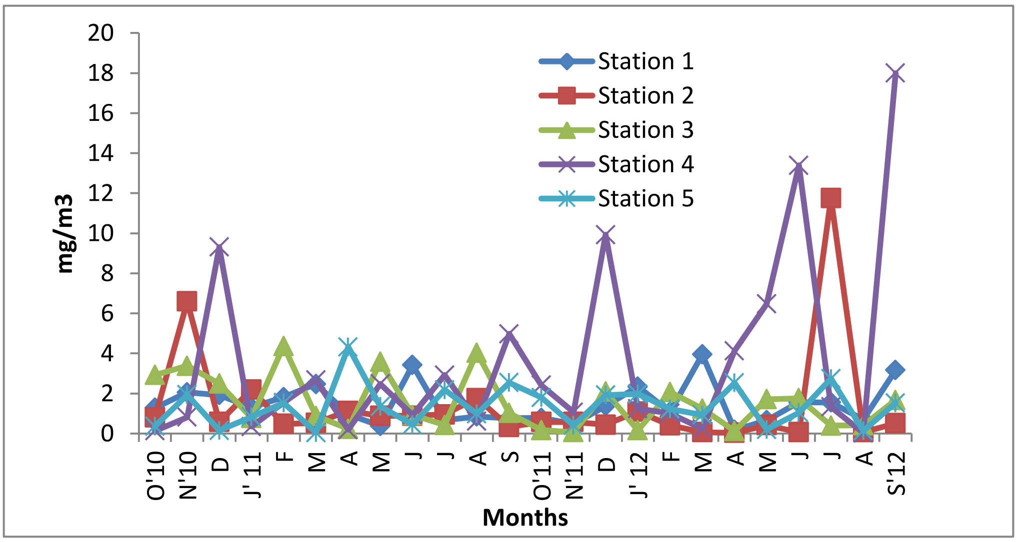


Fig.5.10 Monthly variation in Chlorophyll *b* in stations 1 to 5 in Maranchery Kole wetland during the study period.

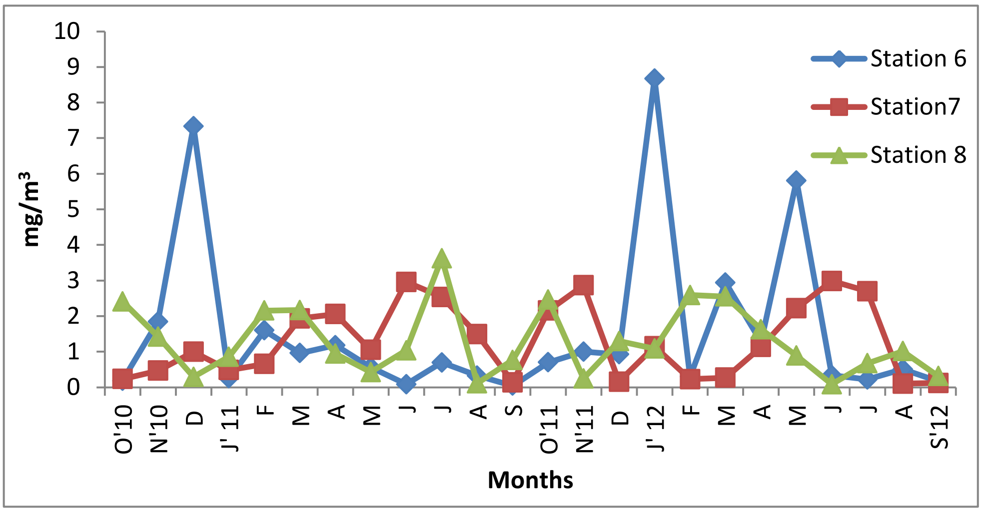


Fig. 5.11 Monthly variation in Chlorophyll *b* in stations 6 to 8 in Maranchery Kole wetland during the study period.

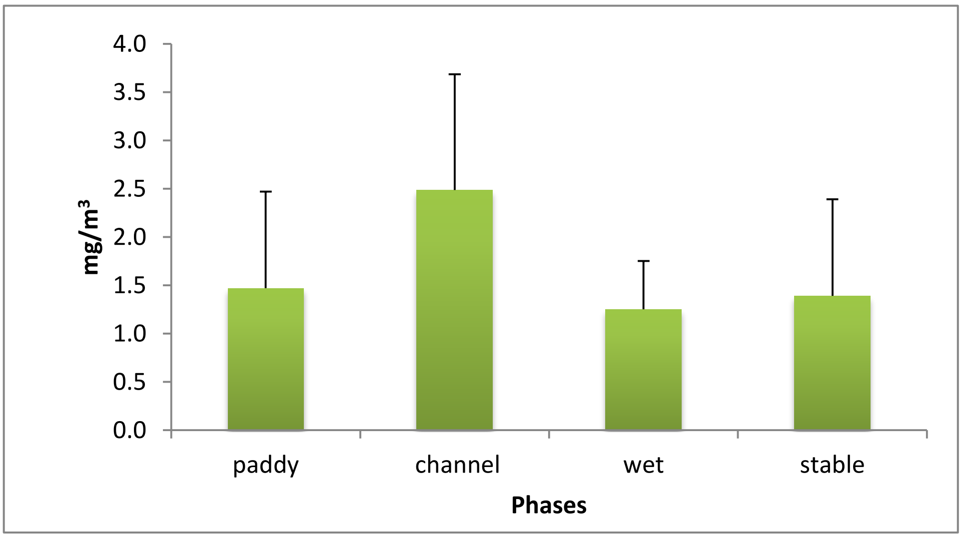


Fig .5.12 Phase wise variation in Chlorophyll *b* in Maranchery Kole wetland during the study period.

5.2.5 Chlorophyll *c* (Chl *c*)

Chlorophyll *c* (Chl *c*) varied between a minimum of 0.01 mg/m^3 at Station 2 in October 2011 to a maximum of 23.06 mg/m^3 in September 2012 at Station 4 (Fig.5.13 and 5.14). Station wise averages are represented in Table 5.5. In station 1, the mean Chl *c* concentration was 1.21 mg/m^3 (±1.1) with a minimum of 0.026 mg/m^3 in July 2012 and maximum of 3.51 mg/m^3 in September 2012 while in station 2, the minimum Chl *c* recorded was 0.01 mg/m^3 in October 2011 and the maximum of 3.84 mg/m^3 in April 2011. The Chl *c* showed the lowest value in November 2011 (0.02 mg/m^3) and highest in September 2012 (4.98 mg/m^3) with an average of 1.58 mg/m^3 ±1.4 in station 3. In station 4 it ranged from 0.18 mg/m^3 in August 2011 to 23.06 mg/m^3 in September 2012, 4.28 mg/m^3 (±6.4) being the mean value. The average Chl *c* concentration in station 5 was 1.25mg/m^3 ±0.97 with the minimum and maximum being 0.13 mg/m^3 in February 2012, 3.61 mg/m^3 in November 2010 respectively. The lowest Chl *c* concentration recorded in Station 6 was 0.04 mg/m^3 in November 2011 highest was 3.10 mg/m^3 in July 2012 having a mean value of 1.03mg/m^3 (±0.83). In station 7, the mean Chl *c* was 1.04 mg/m^3 (±1.3) with a minimum of 0.04 mg/m^3 in March 2012 and maximum in July 2012 was reported (6.49 mg/m^3). Station 8, the minimum Chl *c* recorded was 0.02 mg/m^3 in November 2011 and the maximum of 11.63 mg/m^3 in July 2011(2.04 $\pm$2.3 mg/m^3). Phase wise analysis of Chlorophyll *c* is given in Figure 5.15. The channel phase showed higher mean variations (3.52 mg/m^3) and paddy phase showed least mean variations (1.70 mg/m^3). The ANOVA of chlorophyll *c* existed a significant variation at 1% level in stations ($P<0.01$) and phases ($P<0.01$).

Table 5.5. Mean variation of Chlorophyll *c* in eight stations of Maranchery Kole wetland.

Stations	**Min**	**Max**	**Mean + SD**
Station 1	0.01	3.51	1.21+1.2
Station 2	0.01	3.84	1.21+0.96
Station 3	0.02	4.98	1.58+1.4
Station 4	0.18	23.06	4.28+6.5
Station 5	0.13	3.61	1.25+0.98
Station 6	0.04	3.10	1.03+0.83
Station 7	0.04	6.49	1.04+1.3
Station 8	0.02	11.63	2.04+2.4

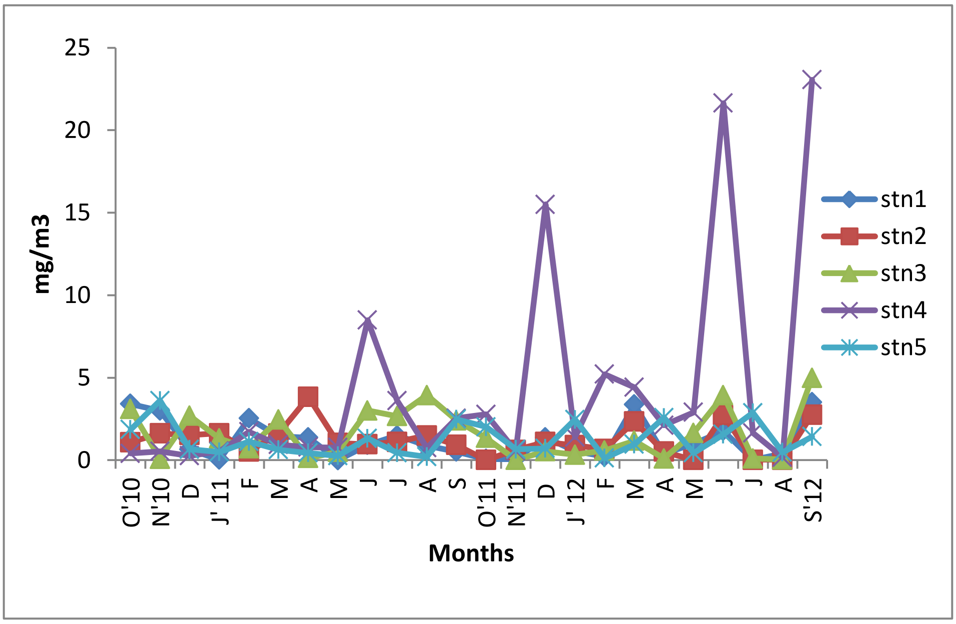


Fig. 5.13. Monthly variation in Chlorophyll *c* in stations 1 to 5 in Maranchery Kole wetland during the study period.

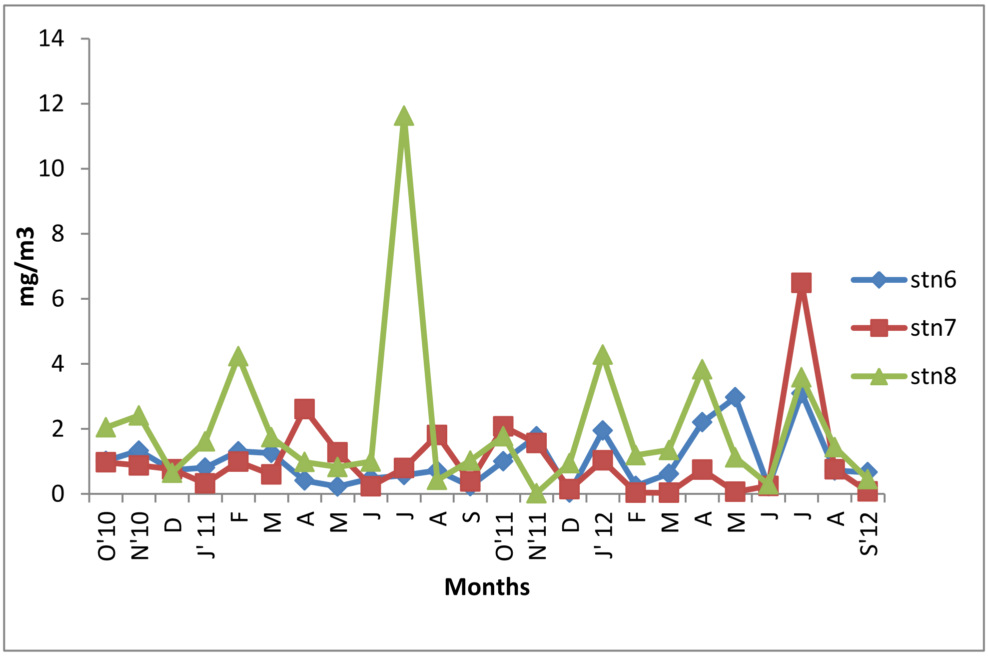


Fig. 5.14. Monthly variation in Chlorophyll *c* in stations 6 to 8 in Maranchery Kole wetland during the study period.

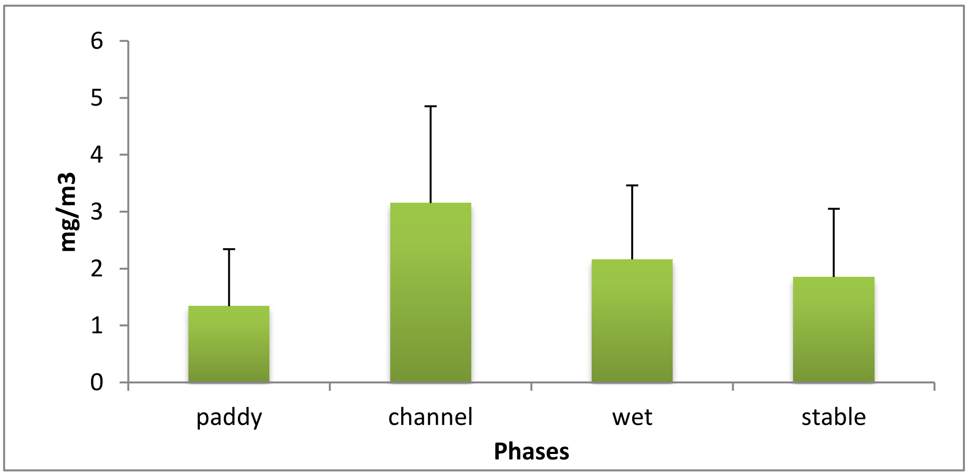


Fig. 5.15. Phase wise variation in Chlorophyll *c* in Maranchery Kole wetland during the study period.

5.2.6 Algal biomass

In Maranchery Kole land algal biomass ranged between a minimum of 0.02 mg/m^3 at station 4 in October 2010 to a maximum of 88.3 mg/m^3 in March 2011 at Station 7 (Figs.5.16 and 5.17). Table 5.6 gives the mean variation of algal biomass in stations. The mean algal biomass in station 1 was 6.24 mg/m^3 ±4.8 with the minimum and maximum being 0.44 mg/m^3 in July 2012, 20.50 mg/m^3 in May 2011 respectively. The lowest algal biomass recorded in station 2 was 0.75 mg/m^3 in January 2012 highest was 53.49 mg/m^3 in May 2011 having a mean value of 8.61 mg/m^3 (±11.06). In station 3, the mean algal biomass was 6.58 mg/m^3 (±4.8) with a minimum of 0.03 mg/m^3 in October 2010 and maximum of 25.53 mg/m^3 in March 2012 while in station 4, the minimum algal biomass recorded was 0.02 mg/m^3 in October 2010 and the maximum of 42.4 mg/m^3 in July 2011(11.67$\underline{+}$ 11.1). In station 5 it ranged from 1.66 mg/m^3 in June 2011 to 28.01 mg/m^3 in March 2011, 10.27 mg/m^3 (±7.7) being the mean value. In Station 6, the minimum algal biomass recorded was 0.91 mg/m^3 in July 2011 and the maximum of 34.89 mg/m^3 in April 2012(10.27 $\underline{+}$ 7.7). In station 7, the average algal biomass was 17.8 mg/m^3 (±24.0) with a minimum of 0.72 mg/m^3 in July 2012 and maximum of March 2011 was reported (88.3 mg/m^3). The algal biomass showed the lowest value in November 2011 (0.45 mg/m^3) and highest in September 2012 (63.48 mg/m^3) with an average of 11.66 ±15.7 mg/m^3 in station 8. The variations in phases are plotted in Figure 5.18. Channel phase (11.9mg/m^3) shows higher deviations compared to other phases. The ANOVA of algal biomass existed a significant variations at 1% level in stations (P<0.01) between stations within phases (P<0.01).

Table 5.6. Mean variation of algal biomass in eight stations of Maranchery Kole wetland.

Stations	Min	Max	Mean ± SD
Station 1	0.4	20.5	6.2± 4.8
Station 2	0.8	53.5	8.6 ±11.1
Station 3	0	25.5	6.6± 4.9
Station 4	0	42.4	11.7 ±11.2
Station 5	1.7	28.0	10.3 ±7.7
Station 6	0.9	34.9	11.1± 9.9
Station 7	0.7	88.3	17.8± 24.0
Station 8	0.5	63.5	11.7± 15.7

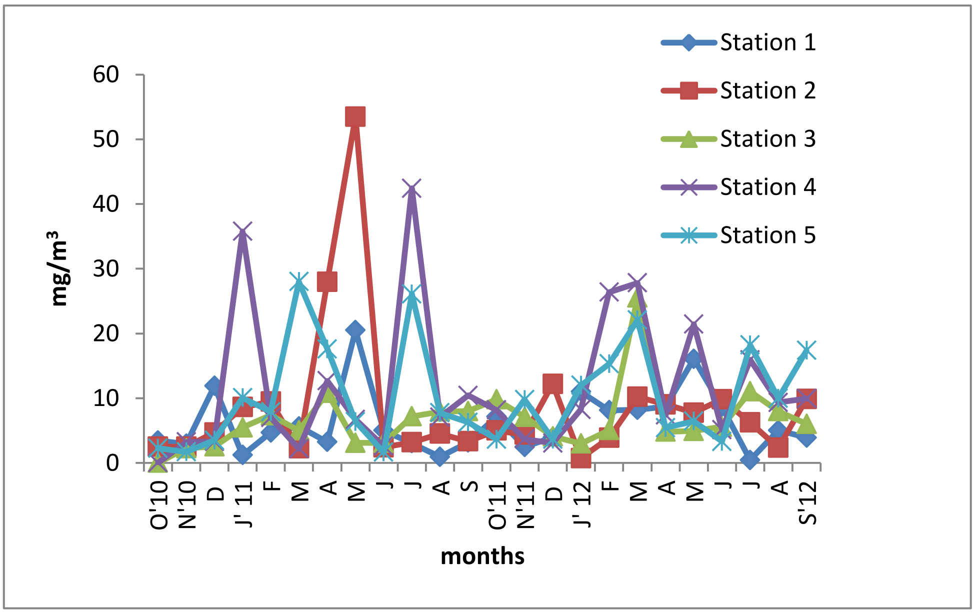


Fig.5.16. Monthly variation in algal biomass in stations 1 to 5 in Maranchery Kole wetland during the study period.

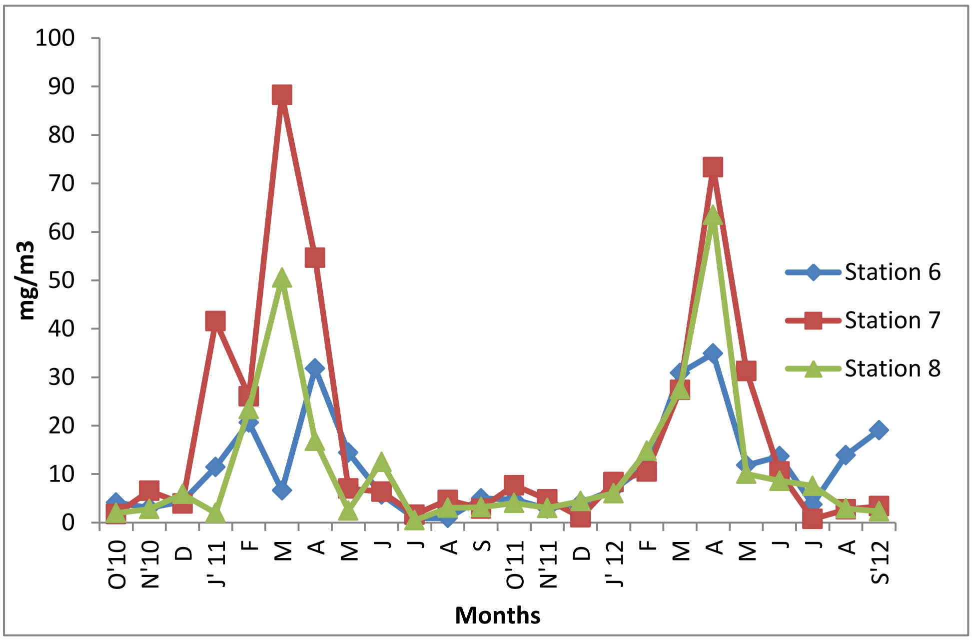


Fig. 5.17. Monthly variation in algal biomass in stations 6 to 8 in Maranchery Kole wetland during the study period.

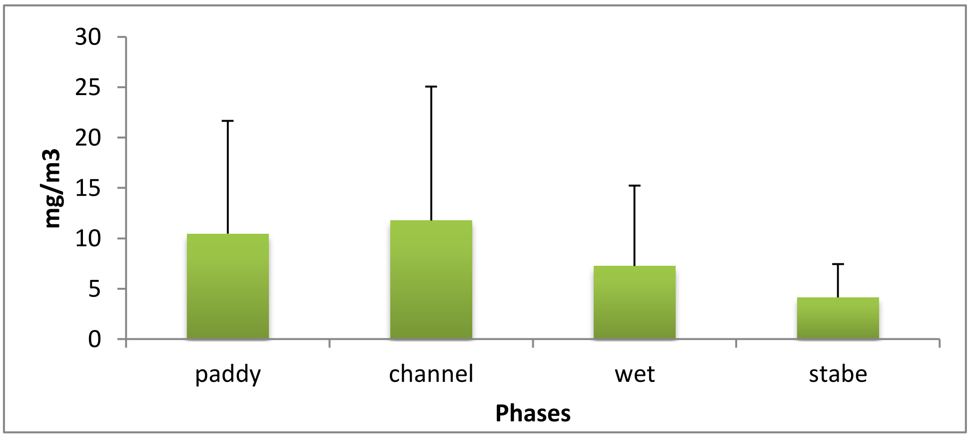


Fig. 5.18. Phase wise variation in algal biomass in Maranchery Kole wetland during the study

5.3 Hierarchical clustering and Multi- Dimensional Scaling analysis

5.3.1 Cluster analysis

In station wise evaluation dendrogram of the similarity showed three clusters (Fig.5.19). Station three formed the first cluster with a distance of 3.3. The second major cluster was formed between stations 1 and 2 with a distance of 1.5. The third cluster is formed by the stations 4, 5 , 6, 7 and 8 with a distance of 0.86. In phase wise evaluation, 2 clusters were formed. Wet and stable phases formed in a single cluster and channel and stable phases grouped in another cluster with a distance of 2.3 (Fig.5.20). The dendrogram of the primary production of the wetlands showed that the spatial variation will significantly influence the primary productivity. Station wise chlorophyll estimation three major clusters were formed (Fig. 5.21). In cluster 1, station 1 and 2 formed similar cluster with a distance of 3.2. In cluster 2 distance was 2.78, and station 4 and 5 grouped together in this cluster. And the third cluster includes station 7 and 8 with a distance of 2.3. Phase wise dendrogram was also plotted, where three clusters were observed with a distance of 2.9(channel), 2.8 (wet) and 2.3(stable and paddy) phases respectively (Fig. 5.22).

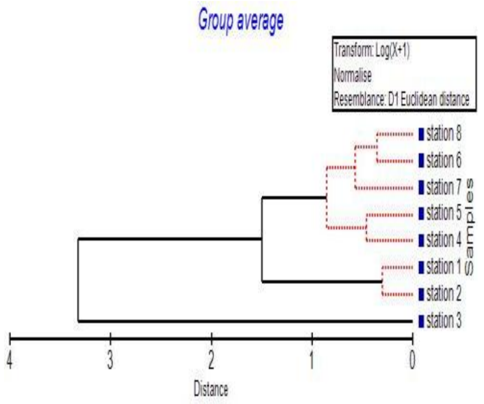


Fig.5.19. Dendrogram showing distance formed by mean station wise values of primary roduction (GPP, NPP) in Maranchery Kole wetland.

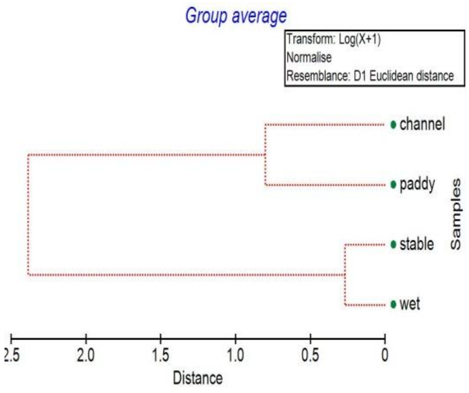
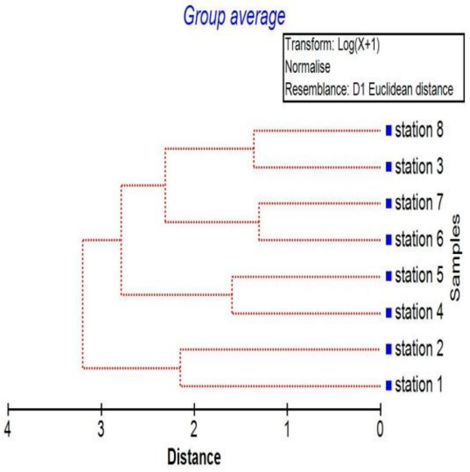


Fig.5.20. Dendrogram showing distance formed by mean phase wise values of primary production (GPP, NPP) in Maranchery Kole wetland.



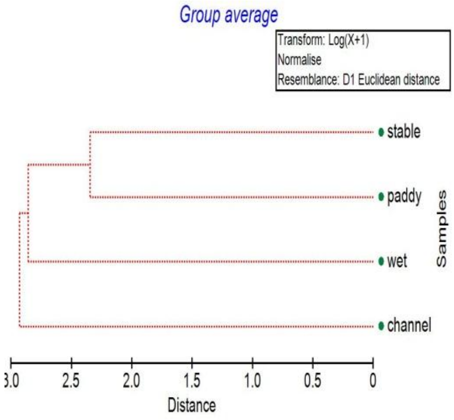


Fig.5.21. Dendrogram showing distance formed by mean station wise values of Chlorophyll (*a* ,*b*, *c*) in Maranchery Kole wetland.

Fig.5.22. Dendrogram showing distance formed by mean phase wise values of Chlorophyll (*a* ,*b*, *c*) in Maranchery Kole wetland.

5.3.2 Non - metric Multi-Dimensional Scaling Plots (MDS)

Station wise and phase wise variation of productivity analysis in Maranchery Kole wetland, MDS plot gave a good ordination having the stress value of 0.0. In station wise plot showed two distinct groups, among which station 3 was standing apart from other stations. Stations 1 and 2 standing together with a distance of 1.3, whereas stations 4 and 5 shows a distance of 0.67. Compared to other stations, station 6 and 8 standing very close and showed a good similarity (Fig. 5.23). In phase wise MDS plot showed 2 distinct groups. Group I comprised of paddy and channel phases and the group II comprised of wet and stable phases (Fig. 5.24). For chlorophyll analysis lower stress value for stations (0.06) and phases (0.0) shows that the dissimilarity between the phases is good (Figs. 5.25 and 5.26). For station wise chlorophyll analysis MDS plot gave three distinct groups, whereas phase wise evaluation of chlorophyll concentration in Maranchery Kole lands was entirely different in four phases.

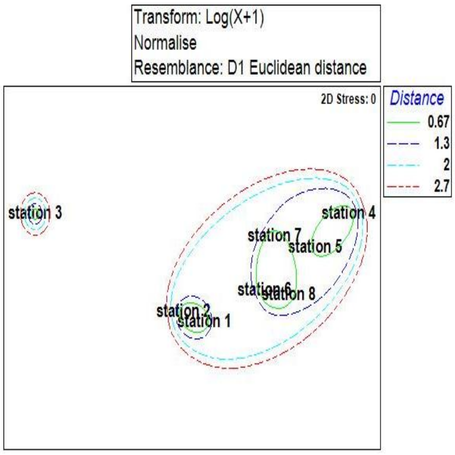


Fig.5.23. MDS ordination plot showing mean station wise variation of primary production (GPP, NPP) in Maranchery Kole wetland.

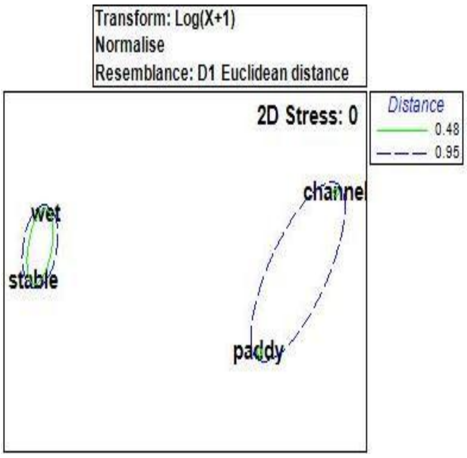


Fig.5.24. MDS ordination plot showing mean phase wise variation of primary production (GPP, NPP) in Maranchery Kole wetland.

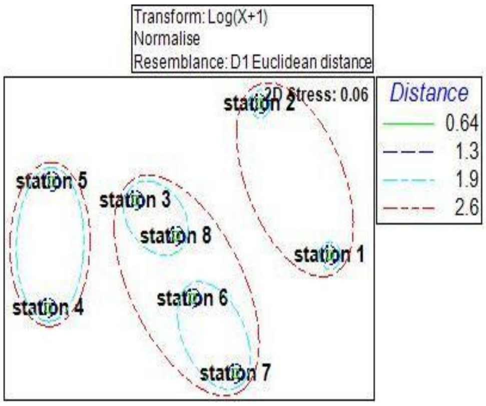
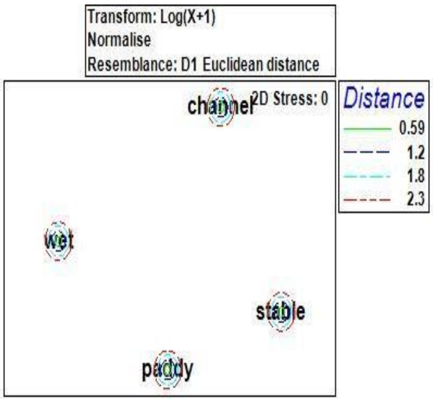


Fig.5.25. MDS ordination plot showing mean station wise vari ation of chlorophyll (*a* ,*b*, *c*) in Maranchery Kole wetland.



. MDS ordination plot showing mean phase wise variation of chlorophyll (*a* ,*b*, *c*) in Maranchery Kole wetland.

5. 4. Discussion

Studies of freshwater wetlands are often narrowly focused on a very limited set of internal wetland processes that are not closely related to other internal processes or to controlling external factors and processes. Important internal wetland processes include primary production, storm surge suppression, aquifer recharge, sediment trapping, toxin processing, organic matter processing, nutrient binding, and nutrient assimilation and dissimilation. External processes are those which affect the internal processes of the wetland (Correl and Weller, 1989). Channel and paddy phases of Maranchery wetland showed higher primary productivity. Pierobon et al. (2010) reported that net ecosystem production (NEP) indicates the status of an ecosystem and it is the balance between GPP and community respiration. According to Clapcott et al. (2012) GPP and NPP vary spatially and temporally with the changes in the hydrographic and biological conditions of an aquatic ecosystem. Fluctuating water column may results from natural inflows and outflows, or form changes in ground water level. Wetland soils typically become anaerobic when flooded and frequently contain much organic matter, that also leads to changes in productivity pattern of this wetland. Temperature and light are important limiting factors as well as macrophytes growth and productivity also related for primary productivity. More over for primary production, nutrients are not a limiting factor, because this wetlands is nitrogen limited (compared to phosphate availability) and oligotrophic that contain sparse amount of nutrients in wet phase. The rainfall increases the turbidity and increase growth of macrophytes which inhibits the light penetration in the water column which may result in decreasing production in the wet phase.

Primary production significantly varied throughout the study period. Station 3 had significantly higher values (6.0 gC/m^3/day) of GPP in February 2011. Station 7 also showed higher values during January 2011. Average GPP of this wetlands varied between1.57±1.10 gC/m^3/day to 1.26±0.60 gC/m^3/day whereas NPP was 0.67±0.6 gC/m^3/day to 0.46±0.4 gC/m^3/day. The correlation analysis of primary production also shows significant results to most of the hydrographic parameters. Price et al. (2007) used the primary productivity as a sensitive and accurate indicator of eutrophication and the volumetric expressions of primary productivity that prove to be the most sensitive and most reliable measures to use when evaluating the eutrophication status of coastal wetlands. Jayachandran and Bijoy Nandan, (2011) reported primary productivity is closely associated with nitrogen concentration in Kodungallur-Azhikode estuary and also encounter with the N: P ratio in the water column which was well above the Redfield ratio during south west monsoon period. Barber et al. (2001) noticed a positive correlation with dissolved oxygen and productivity in riparian wetlands. The GPP ranging from zero to 0.29 gC/m^3/day was recorded from Kadinamkulam estuary by Bijoy Nandan and Abdul Azis (1994) and Bijoy Nandan (2004). Perry and Macdonald (2002) noticed low light penetration with increasing depth and turbidity lead to reduction of GPP and NPP. Abiotic parameters such as temperature, salinity, turbidity, solar radiation and light penetration, depth, nutrients and water flow and biotic parameters such as abundance of phytoplankton and top-down regulation by grazers affect productivity and the energy transfer in an ecosystem (Sterner and Elser, 2002; Cloern et al., 2014). However, Mitsch et al. (1999) commented pH, conductivity and divergence in macrophyte community alter biogeochemistry and productivity of wetlands in subsequent years. Therefore balance between GPP and NPP of a particular ecosystem determines its trophic status and any disturbance in the ratio leads to a shift in carbon sources and energy flow which in turn cause trophic cascade in food web (Odum, 1956; Power et al., 2008). The higher variation of GPP in station 3 might be due to higher chlorophyll during the same period. In station 7 thick growth of floating macrophytes like *Salvinia molesta* was observed, this might be to create a eutrophic condition in this station and further increase of primary production. Nutrient and light conditions are the major factors affecting net primary productivity (Arias et al., 2014).

In month wise analysis GPP and NPP of this wetland was continuously varied throughout the study. Vass (1980) explained that, generally primary production of an aquatic habitat refers to phytoplankton productivity except where dominant producers are various types of macrophytes. In Maranchery wetland, macrophytes comparatively dominated, therefore the decaying and regenerating plants affect the productivity pattern. This could be one reason for continuous variation in productivity of this wetland. Hickel (1973) reported that, ponds in Kathmandu showed low plankton concentration during dry winter and mass development of algae in summer or before arrival of monsoon. Langeland (1974) observed that increase in phytoplankton biomass is one of the most pronounced features of eutrophication. Talukdar (2017) analysed seasonal variation and productivity pattern of Urmaal wetland, Assam. In this study maximum GPP was obtained during post monsoon period. Kantz and Deal, (1999) explained during the growing season of macrophytes, photosynthesis and respiration was significantly changed in each plants. Nitrogen dissimilation as a result of denitrification in the wetland can also cause variation in GPP as well as NPP ratio (Schalles and Shure, 1989). In Maranchery Kole wetland also increase in algal biomass was noted during paddy and channel phases and directly lead to change in production process.

Like GPP, net primary production (NPP) of this wetland was more or less similar pattern in all the stations and phases. Higher NPP was noticed in stations 2 to 5 in this wetland. Increased net productivity due to anthropogenic inputs and trophic change from an autotrophic to a heterotrophic condition probably induce shifts in the food chain and consequently alter the trophic level of this wetland. Cermeño et al., (2006) explained that, in an aquatic ecosystem net productivity is the difference between gross productivity and community respiration which provides an overall insight into the biogeochemical functions and also determines the balance between autotrophy and heterotrophy at the different trophic level. In Maranchery wetland photosynthesis of emergent, floating and submerged macrophytes contributed increase of respiration which in turn increase net heterotrophy and ultimately lead to net source of CO_2. Nutrient loading and physical changes causes preferential increase in biomass of macrophytes and net production in the wetland. Greenway (2003) reported that increased net production and organic carbon altered wetland ecosystem from an autotrophic to a heterotrophic conditions and further leads to net sources of CO_2 to the atmosphere. Wetlands are an inter phase between agricultural uplands and seep open waters which receive large inputs of nutrients and organic carbon from both environments and support high rates of metabolism and primary production (Wetzel, 2005). Cvetkovic et al. (2010) elaborated wetlands are source of greenhouse gases especially CO_2. Occurrence of maximum abundance of heterotrophic as well as autotrophic organisms increased the metabolic rate due to higher temperature and larger export of organic matter increased the net productivity. In Maranchery wetland *Hydrilla verticillata, Utricularia aurea* were more prominent submerged macrophytes observed throughout the study period and that could be one reason for increased net productivity during wet phase. Fennessy et al. (1994) noticed submerged vegetation increases the primary production of created freshwater wetlands.

In paddy phase of this wetland, the role of nutrients and productivity relationships not only reveals mechanisms that may explain variation in species richness and occurrence of threatened species, but it also may be important for nature management practices. During the study period, nutrients like phosphate, nitrate, and ammonia were increased in channel and paddy phases. The higher values of productivity observed in paddy and channel phases might be the result of nutrient addition through runoff from these agricultural fields. In channel phases growth of macrophytes were comparatively poor as excess growth were removed by addition of weedicides and by manual removal also taking place during this period. Therefore, the increase in productivity of phytoplankton which occupies the first level in trophic level might be due to the nutrient runoff from the paddy fields and finally leads to increase of productivity. Increase in phytoplankton biomass during channels of Maranchery Kole wetland was observed by Bijoy Nandan (2012). Wetz and Yoskowitz, (2013) and Sterner and Elser, (2002) state that an increase in nutrients might be due to increase of parameters like, primary production and nutrient content of primary producers, especially when light is the limiting factor. Sha et al. (2011) studied the riverine wetland ecosystem and also agreed with the above statement. Species composition and tropho-edaphic conditions also influence the productivity across a range of altitudes (Kirkman et al., 2000 and ChangTing et al., 2008). Xue et al. (2017) reported that in a rice field ecosystem productivity was highly correlated with rainfall pattern and precipitation. In a wetland ecosystem, internal conditions and given rates and composition of external inputs are maximized by their use of the available free energy, chemical substrates, and physical conditions. Because physical and chemical conditions within a wetland are constantly changing, the relative importance of various internal processes also constantly shifts in response to alterations in the limiting factors. Various physical, chemical, and biological feedback mechanisms can also exert a stabilizing effect on internal processes that ultimately change to productivity pattern (Madsen et al., 2001). GPP and NPP of agricultural fields were directly related to canopy of paddy plants Xin et al. (2017).

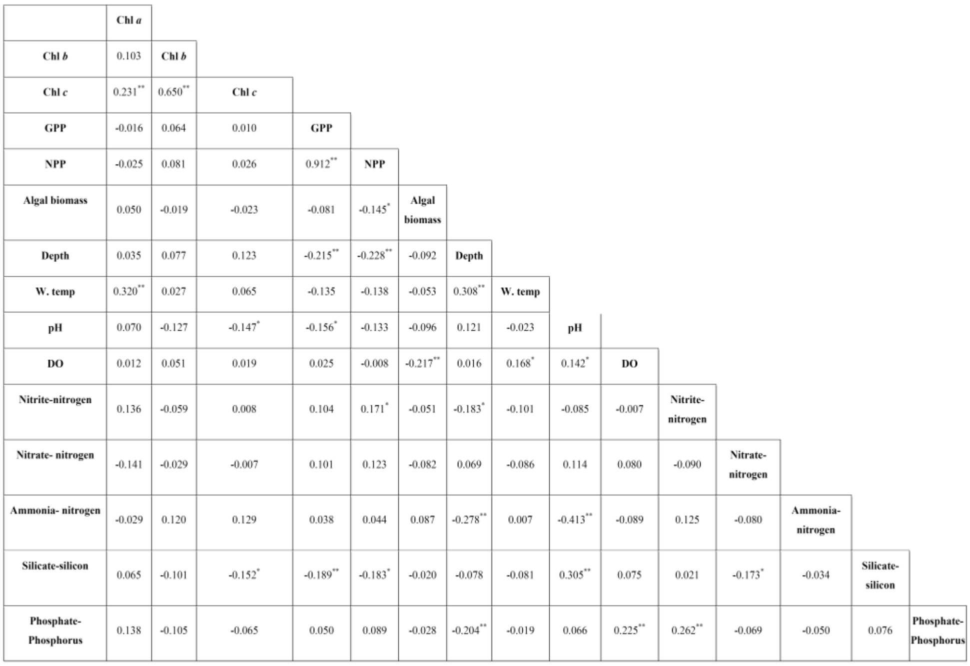
One other reason for increase in productivity in channels of this wetland was internal geomorphic control factors that include channel morphology, soil nutrient content, soil geochemistry, and hydraulic conductivity. Morphometry of channels or external shape and dimensions of landforms is important because it controls the contact time of water transiting a wetland. The more diffuse or less channelized the flow, the more contact occurs between the water and the wetland. Soil nutrient content may be important in determining the potential primary productivity of the wetland (Song et al., 2014). Soil geochemistry determines important factors such as chemical binding or exchange capacity and the potential for geochemical reactions. The hydraulic conductivity of the soils determines the proportion of transiting water that can move as soil to water. In very sandy systems, almost all movement is via soil water, but in fine silt and clays, almost all movement is via surface water flows. This will further cause reduction in productivity (Chen et al., 2013). Currie et al. (2014) opined that in a wetland channels control factors that result from direct wetland management include burning, grazing, logging, inputting waste, draining, and damming. The net and gross primary production were strongly correlated, significant at 1% level ($P<0.01$). In the present study, the correlation analysis of primary production shows negative correlation with the water temperature, pH and silicate. Nair et al. (1984) and Renjith et al. (2004) in their study also reveals that no correlations were observed between productivity and physico-chemical parameters of water body. Nitrite and nitrate concentration were depleting with increase in primary productivity (Jayachandran et al., 2012; Vijayakumaran, 2005). This is an indication of rapid uptake of these salts leading to depletion or lowering of nutrient concentration at the peak production period. The present results are not agreeing with the above statement and increase in concentration of these nutrients were observed during channel phase and a positive correlation emerged between GPP with nutrients like nitrate, nitrite and ammonia.

Chlorophyll analysis of this wetland shows wide spatial and temporal variations. Higher chlorophyll rate was observed during channel phase and chl *a* concentration was subsequently increasing during wet period. Chlorophyll *a* ranged from 0.670 mg/m^3 to 109.4 mg/m^3. Compared to other stations, Station 2 showed higher variation during entire study period. In the case of chl *c* station 4 shows wide variations throughout the study period. The mean values of total chlorophyll pigments ranged from 5.4 to 7.5 mg/m^3. Earlier studies on chlorophyll ‘a’ conducted in Vembanad estuary reported an annual range of 2-21 mg/m^3 (Bijoy Nandan et al., 2015) similar results were observed in Thrissur Kole wetlands (Tessey and Sreekumar, 2008). Luxurious growth of macrophytes, variation in abundance and species composition of plankton might have contributed to the higher Chl. *a* content in station 2. The fluctuation of the concentration of chl *a* has direct significant positive correlation with variation in water temperature and also observed a negative correlation with nitrate. Watson et al. (1997) says that, Chlorophyll *a* is an indicator of abundance of phytoplankton. Brand et al. (2010) in their study in San Francisco Bay channel stated that, sediment organic matter has an important role in water column production. However, Vineetha et al. (2015) reported that there is a increase in organic matter in paddy phase of Kole wetlands. This is the agreement with the present study. There is increase of productivity and chlorophyll pigments, were observed in paddy phase that might be due to increase of sediment organic matter in paddy phase of the wetland. Teng et al. (2016) reported high chlorophyll content in agricultural fields. Anuradha (1995) reported that nutrients are seem to be a limiting factor in the synthesis of Chlorophyll 'a'. Chl *a* was observed three times more in early monsoon period than pre monsoon and post monsoon periods (Gupta et al., 2009). Nair and Azis (1987) and Gowda et al. (2002) have observed the peak variation of chlorophyll content during pre and post monsoon periods in different estuaries. Vaheeda et al. (2012) noticed a direct relation between phytoplankton productivity, Chl. *a* and silicate-silica in brackish waters of Kodungallure and reported that the concentration of chlorophyll pigment indicates the magnitude of the phytoplankton in the ecosystem. Zhou et al. (2016) observed that, gross primary production and chl *a* were synchronous in seasonal cycles, and reported, the presence of dead and inactive chlorophyll from detritus and stirred up sediment may lead to variation in seasonal cycles. Islam et al. (2005) studied the estuarine systems of Japan and the study demonstrated the role of estuarine turbidity and relation with copepod feeding and observed a negative correlation between suspended particulate matter and chl *a*. Increase of nutrients and high level of chlorophyll ‘a’, creates anoxia and hypoxia in waters and blooms of toxic and harmful algae (Kocum et al., 2002). In channel phase of Maranchery wetland an increase in Chl *b* and *c* was observed. Hunter and Laws (1981) reported that wide range in Chlorophyll ‘a’ and ‘c’ shows low growth rates and light limiting condition whereas the lowest ratio associated with nutrient limitation. Radiarta and Saitoh (2008) opined that wind condition, suspended sediment resuspension and surface heating are the mechanisms that controlled the spatial and temporal variations of chlorophyll concentrations. Chlorophyll ‘a’ showed a positive correlation significant at 1% level ($P<0.01$) with water temperature of the wetland.

The present investigation showed an increasing trend in algal biomass along with chlorophyll *a.* The channel phases showed higher concentration and stable phase showed lower concentration of algal biomass. The higher concentration of algal biomass in channels might be due to variation in shallow nature of channels, variation in depth, increased temperature, runoff from fertilized organic substances from paddy fields. Nitrification has been reported to make a substantial contribution to total pelagic oxygen demand in some coastal water bodies (Relexans et al., 1988: Kausch et al., 1990; Smith and Kemp, 1995; Manna et al., 2012) and it leads to increase in algal biomass of these ecosystems. In Maranchery wetlands, with respect to the decrease in depth of water column there is a increase in productivity, chlorophyll components and algal biomass was observed. Due to decrease in depth: water column is well mixed in this condition and light penetrates to the bottom of the water body. This leads to the increase in production process. Berounsky and Nixon, (1993) is of a different opinion, the water column is more turbid and stratified condition, vertical variations in primary production and even respiration and nitrification may be more marked. Cloern et al. (1992) observed that the seasonal and inter annual fluctuations in phytoplankton biomass and primary production are the net effect of physical effects and trophic interactions in temperate lakes. Carvalho et al. (2010) analysed the role of physico-chemical variables such as pH, salinity, dissolved oxygen, water temperature, light attenuation coefficient, nitrate, nitrite, phosphate, silicate, ammonium and chlorophyll in the distribution of primary productivity during the dry and rainy season in Bacanga river estuary dam- Brazil. Phytoplankton distribution and productivity in a highly turbid, tropical coastal system were measured during the wet and dry season from Bach Dang estuary, Vietnam by Rochelle-Newall (2011). Algal biomass showed a positive correlation significant at 1% level ($P<0.01$) with turbidity and a weak positive correlation with dissolved oxygen, GPP, NPP, chlorophyll *a* and ammonia.

From the dendrogram and MDS plots applied to productivity of wetlands it is clear that station 3 was standing apart from other stations. Thick growth of submerged hydrophytes was seen in this station. Phase wise study shows that wet and stable phases standing together and paddy channel phase grouped together. From the orientation of phases it is clear that spatial variation significantly altered the pattern of productivity and chlorophyll composition in Maranchery wetlands. However, this study clearly indicates the necessity and importance of macrophytes based productivity, especially those linking plankton and macroinvertebrate diversity with nutrient concentrations and carrying capacity of the wetlands. The role of macrophyte productivity in this wetland needs thorough investigation and evaluation to help to assess the potential aquatic productivity of Maranchery wetland because higher abundance, diversity of standing crop of different macrophytes.

Table 5.7. Pearson correlation analysis between productivity and environmental parameters in Maranchery wetland.



	Chl *a*														
Chl *b*	0.103	**Chl *b***													
Chl *c*	0.231^{**}	0.650^{**}	**Chl *c***												
GPP	-0.016	0.064	0.010	**GPP**											
NPP	-0.025	0.081	0.026	0.912^{**}	**NPP**										
Algal biomass	0.050	-0.019	-0.023	-0.081	-0.145^{*}	**Algal biomass**									
Depth	0.035	0.077	0.123	-0.215^{**}	-0.228^{**}	-0.092	**Depth**								
W. temp	0.320^{**}	0.027	0.065	-0.135	-0.138	-0.053	0.308^{**}	**W. temp**							
pH	0.070	-0.127	-0.147^{*}	-0.156^{*}	-0.133	-0.096	0.121	-0.023	**pH**						
DO	0.012	0.051	0.019	0.025	-0.008	-0.217^{**}	0.016	0.168^{*}	0.142^{*}	**DO**					
Nitrite-nitrogen	0.136	-0.059	0.008	0.104	0.171^{*}	-0.051	-0.183^{*}	-0.101	-0.085	-0.007	**Nitrite-nitrogen**				
Nitrate- nitrogen	-0.141	-0.029	-0.007	0.101	0.123	-0.082	0.069	-0.086	0.114	0.080	-0.090	**Nitrate-nitrogen**			
Ammonia- nitrogen	-0.029	0.120	0.129	0.038	0.044	0.087	-0.278^{**}	0.007	-0.413^{**}	-0.089	0.125	-0.080	**Ammonia-nitrogen**		
Silicate-silicon	0.065	-0.101	-0.152^{*}	-0.189^{**}	-0.183^{*}	-0.020	-0.078	-0.081	0.305^{**}	0.075	0.021	-0.173^{*}	-0.034	**Silicate-silicon**	
Phosphate-Phosphorus	0.138	-0.105	-0.065	0.050	0.089	-0.028	-0.204^{**}	-0.019	0.066	0.225^{**}	0.262^{**}	-0.069	-0.050	0.076	**Phosphate-Phosphorus**

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

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

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Chapter - 6

DIVERSITY AND DISTRIBUTION OF AQUATIC MACROPHYTES

6.1 Introduction

Macrophytes are important ecological components of aquatic systems. The Indian subcontinent offers large diversity of aquatic habitats differing in size, hydrological regimes, sediment characteristics and nutrient status (Albert and Minc, 2004). Large spatial and temporal variability in rainfall brought about by monsoons results in large changes in water level, and often periodic drying during the summer (Thiebaut and Muller, 1998). Combined effects of hydrology, local bedrock geology and wetland morphology, referred to jointly as hydro geomorphic factors, tend to be the primary regional determinants of plant community structure in wetlands and littoral systems. Accordingly, the aquatic vegetation is also highly varied (Keough et al., 1999). Macrophytes, are macroscopic aquatic plants that are a heterogeneous group of taxa: flowering plants, mosses and macroscopic algae such as charophytes. They share the common feature of inhabiting in an aquatic environment; growing either permanently submerged or rooted in temporarily inundated areas. Macrophytes can be functionally classified into different life-forms based on the occurrence of emergent, floating and submerged leaves. The destruction and shrinkage of the fragile, yet dynamic aquatic ecosystems have resulted in the disappearance of many important species, thus causing a serious genetic erosion of crop, medicinal and other valuable plants (Vaheeda, 2008). According to Ehrlich and Wilson, (1991) biodiversity loss is undesirable from the aesthetic, ecological, economic and ethical point of view. Hence documentation of the biodiversity prevailing in a wetland ecosystem is crucial. In early 1923 Agharkar assessed a search for the position of our knowledge of aquatic flora of India. The state of our knowledge of the aquatic vegetation in the subcontinent, as a component of the aquatic ecosystems has been revealed by Gopal (1990). In the Census of India’s biodiversity the diversity of flora has been revealed to be only two percent (Khoshoo, 1995). Cook (1980) had made attempts to determine the status of certain endemic wetland species and prepared a monograph of ‘Wetland plants of India’.

Macrophytes have several important functions in a wetland ecosystem. They act together with microscopic algae, they are the most important primary producers in an ecosystem (Krause-Jensen and Sand-Jensen 1998; Nõges et al., 2010). Macrophytes having a complex physical structure, they provide habitat and shelter for fish, zooplankton and benthic invertebrates as well as a substrate for the growth of phytobenthos (Grasset et al., 2017; Gasith and Hoyer, 1998). Cowx and Welcome (1998) listed the number of characteristics of aquatic plants which are important for fishes. Macrophytes are essential for a healthy fish stock in a natural water body (Schriver et al., 1995). Hansson et al. (2010) reported, many fish species use macrophyte beds for spawning and some macrophytes are food for fish and avifauna. The use of aquatic macrophytes in modern drugs and pharmaceutical industries was reported by Kio and Adams (1987). Dykyjová (1979) says that aquatic macrophytes such as duckweeds (*Wolffia*, *Spirodela* and *Lemna* species) and *Ceratophyllum dermesum* are widely used for water purification.

The macrophytes found in wetlands can be grouped variously on the basis of their life forms and their position in the food-chain (Duarte and Kalff, 1990). Emergent macrophytes form an interface between the surrounding land and the water and act as buffers against direct nutrient run-offs and are prone to reflect land use changes in the direct vicinity of the lake shoreline (Wetzel, 1990). Studies on the aquatic macrophyte communities had begun in the early part of last century in India and Blatter (1905) and Cooke (1901-1908) were pioneers to investigate on the aquatic plants of the west coast of India. Studies on aquatic and marshy vegetation were carried by International agencies like, International Union for the Conservation of Nature (1987), World Wildlife Fund-India (1993). The book “Ecology and management of aquatic vegetation in the Indian Subcontinent” edited by Brij Gopal (1990) is a very useful work dealing with diversity, vegetation of aquatic flora, role of aquatic vegetation in ecosystem functioning and their uses. Some of the endeavours during the last few decades to bring the aquatic plant diversity in Indian wetlands into light and their ecological characteristics are enumerated.

The conditions of aquatic vegetations are varied according to the types of habitats and their contact with the soil, air and water into the following groups (modified from Panda and Das, 1995). Akasaka et al.

(2010) recognized that diversity of macrophytes in a water body may vary with rich nutrient status and zonation of the water column and wide littoral areas. According to Chappuis et al. (2011) water immediately surrounded with small trees, shrubs and herbs are considered as meadow stage. After that, in most of the cases the water body follows floating plants which provide a transition zone to submerged plants. With increasing depth, illumination of light becomes insufficient to further plant growth, therefore the deep lightless zone is devoid of macrophyte vegetation.

Wetlands are generally rich in their floristic and faunal diversity which is much higher than that in many other communities (Tamire and Mengistou, 2014). In a coastal wetland ecosystem, especially in the Kole lands of Kerala different land use pattern can interfere the species composition, adaptability and growth forms of macrophytes. Climatic, geological and biological factors interact to produce a fascinating variety of habitats inhabited by a range of distinct species. Thus, this chapter explains the macrophyte composition, distribution and diversity patterns in the Kole wetland especially in the wet and dry phases. The knowledge on macrophyte is also significant to our understanding on the associated invertebrates in the wetland ecosystem.

6.2 Results

6.2.1 Aquatic macrophytes diversity and distribution

In the Kole wetland, a total of 21 aquatic and semi aquatic species belonging to 20 genera and 16 families, were recorded. The Angiosperms were represented by 12 families and the Pteridophytes or water ferns by 3 families. There were 9 Dicotyledonous families of which 2 belonged to Polypetalae, 3 to Gamopetalae and 1 to Monochlamydae, 3 families belonged to Monocotyledonae (Table 6.1). The maximum species were represented by Poaceae (4 species) and water ferns (3 species) followed by Convolvulaceae and Pontederiaceae (2 species). Major macrophytes identified in this wetlands was given in Figure 6.1 (a to p). In the present study, it was noted that *Eichhornia crassipes, Salvinia molesta, Nymphaea pubescens, Nymphoides indicum, Hydrilla verticillata, Utricularia aurea, Ludwigia adscendens and Limnophila heterophylla* were found to form monospecific communities in this area. Other macrophytes were generally found associated with dominant macrophytes. At the time of dry periods, apart from *Oryza sativa*, the plants like *Hydrilla verticillata, Utricularia aurea and Marsilea quadrifolia* were colonized. Station wise and phase wise frequency table of macrophytes are represented in Table 6.2 and 6.3. The different growth forms of the aquatic plants encountered during the present study are given in Figure. 6.2.

Based on the standard reference of Panda and Das, (1995) the growth forms of aquatic plants in Maranchery Kole lands are catogorised into free floating (FF): Plants which usually grow on the surface of water in contact with air, they usually present in sheltered habitats and stagnant water bodies; Emergent-anchored hydrophytes (EA): Plants which grow most part of their life in water, but produce aerial representative organs; Submerged-anchored hydrophytes (AH): Plants which grow below the surface of water and usually anchored; Anchored hydrophytes with floating leaves (AF): Plants usually grow in shallow stagnant waters. They tide over the unfavourable periods by perennating organs like rhizomes, tubers or stolons; Anchored hydrophytes with floating shoot (FS): Usually plants grow to the substrate, produces ranches which rise to the surface of water, thereafter creep along the surface of water, often producing rooting at internodes; Wetland plants (WH): Plants grow water saturated soil for their survival.

Table 6.1. Macrophytes recorded from the Maranchery Kole wetland during October 2010 to September 2012 period.

Division	Family	Genus/Species	Exotic/Native/Un Known	Growth form	Rare sp./Common sp.
Dicots Polypetalae	Onagraceae	*Ludwigia adscendens* (L.) H. Hara	N	EA	Common
	Nymphaceae	*Nymphaea pubescens* Willd	N	A F	Common
	Lythraceae	*Rotala* sp.	N	EA	Common
Gamopetale	Menyanthaceae	*Nymphoides indicum* Thw.	N	AF	Common
	Convolvulaceae	*Ipomea pes-capre* (L.) R.Br.	N	EA	Common
	Convolvulaceae	*Convolvulus* sp.	N	EA	Common
	Lentibulariacae	*Utricularia aurea* Lour.	N	FS	Common
	Scrophularaceae	*Limnophila heterophylla* Benth.	N	AF	Common
Monochlamideae	Amarantaceae	*Alternanthera* sp.	Un Known	WH	Common
Monocots	Pontederiaceae	*Eichhornia crassipes* (Mart.)Solms	E	FF	Common
	Pontederiaceae	*Monochoria vaginalis* (Burm.f.) Presl	N	FF	Common
	Hydrocharitaceae	*Hydrilla verticillata* Royle	N	AH	Common
	Poaceae	*Oryza sativa* L.	N	WH	Common
	Poaceae	*Sacciolepis sp.*	N	EA	Common
	Poaceae	*Hygroryza aristata* Nees	N	EA	Common
	Poaceae	Un identified	Un Known	EA	Common
	Lemnaceae	*Lemna* perpusilla Torr.	N	FF	Common
	Alismataceae	*Sagittaria* sp.	Un Known	EA	Common
Pteridophyts Water ferns	Salviniaceae	*Salvinia molesta* D.S.Mitch	E	FF	Common
	Parkeriaceae	*Ceratopteris* sp.	Un Known	FF	Common
	Marsileaceae	*Marsilea quadrifoliata* L.	N	EA	Common

Table 6.2. Station wise frequency table of aquatic macrophytes from Maranchery Kole wetland during the study period.

Genus/Species	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**	**Station 7**	**Station 8**
Ludwigia adscendens				A	B	C		B
Eichhornia crassipes				A	C	A	B	A
Monochoria vaginalis	A	A	B		A			
Nymphaea pubescens				A	B	C		
Rotala sp.		A			A			A
Nymphoides indicum.				A	B	C		A
Ipomea pes-capre						A	A	C
Convolvulus sp				A	A			A
Hydrilla verticillata	C	A	B	A				
Utricularia aurea	B	B	A	A	A			A
Sacciolepis sp.	A		A		A	A		A
Salvinia molesta		A			A	B	C	A
Oryza sativa	C	C	C					
Ceratopteris sp.				A			A	
Hygroryza aristata		A	A					
Limnophila heterophylla		B	B	A				A
Sagittaria sp.				A	A			
Marsilea quadrifoliata	A	C	B					
Lemna pupusilla.				A			A	
Alternanthera sp.				A	B			A
Un known species	A		A	B		A		

Frequency	**Percentage (%)**
Class A	1-20%
Class B	21-40%
Class C	41-60%

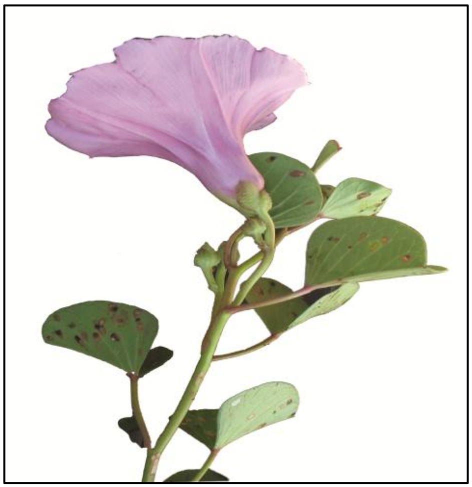
Table 6.3. Phase wise frequency table of aquatic macrophytes from Maranchery Kole wetland during the study period.

Genus/Species	Wet	Stable	Channel	Paddy
Ludwigia adscendens	B	B		
Nymphaea pubescens	B	B		
Rotala sp.	B			A
Nymphoides indicum	B	C	A	
Ipomea pes-capre	A	A	A	
Convolvulus sp.	A	A	A	
Utricularia aurea	B	B	B	B
Limnophila heterophylla	B	A		
Sagittaria sp.	A	A	A	
Alternanthera sp.	A	A	B	A
Eichhornia crassipes	B	C	A	A
Monochoria vaginalis			A	B
Oryza sativa				C
Hydrilla verticillata	C	A	B	A
Sacciolepis sp.	B	A	A	A
Lemna perpusilla	A	A		
Hygroryza aristata	A		A	B
Salvinia molesta	C	C	A	A
Ceratopteris sp.	A	A		
Marsilea quadrifoliata				C
Un known species	A	A		A

Frequency	Percentage (%)
Class A	1-20%
Class B	21-40%
Class C	41-60%

Hygroryza aristata

***Rotala* sp.**



Ipomea pes-capre

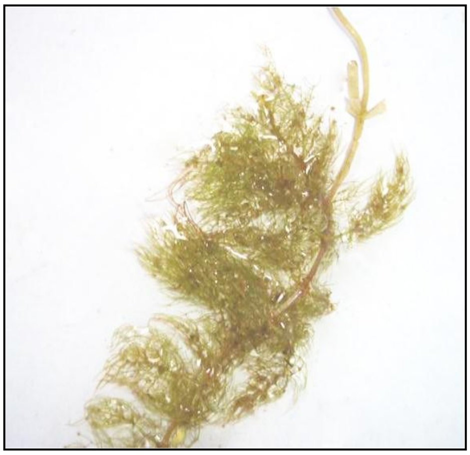
Monochoria vaginalis

***Ceratopteris* sp.**

***Alteranthera* sp.**

***Convolvulus* sp.**

Ludwigia adscendens



Utricularia aurea

***Sagittaria* sp.**

Hydrilla verticillata

Salvinia molesta

***Sacciolepis* sp.** **_Marsilea quadrifolia_**

Nymphoides indicum

Limnophila heterophylla

Fig. 6.1. Major macrophytes identified in Maranchery Kole wetland during the study period.

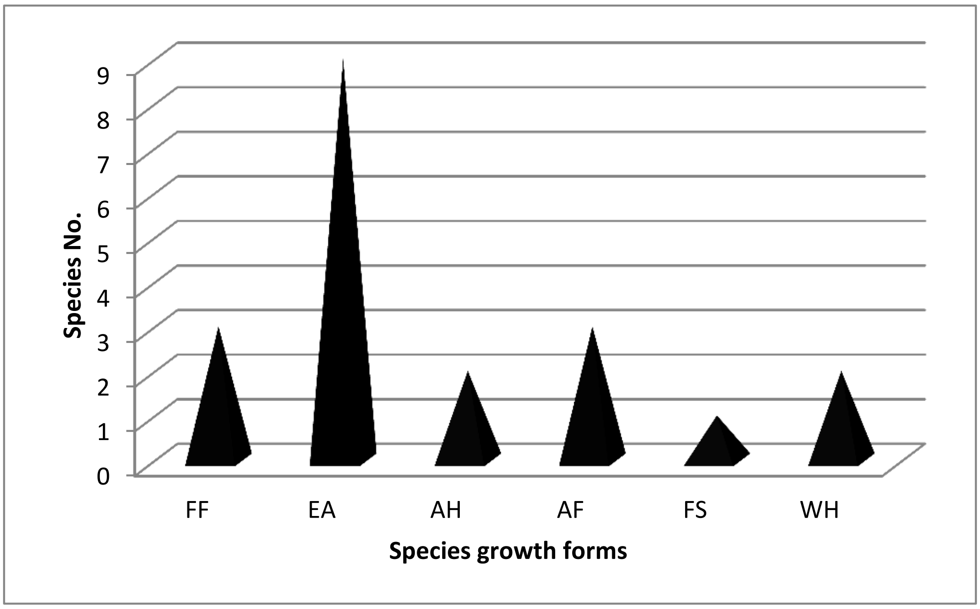


Fig 6.2. Growth forms of identified macrophytes in Maranchery Kole wetland during the study period.

6.2.2 Distribution of aquatic macrophytes in different stations in Maranchery Kole lands

Out of the 21 species recorded in the whole area, three species are free-floating species. The *Eichhornia crassipes, Salvinia molesta* (rooted floating leaved species) and *Lemna* sp. (free floating with no roots). *E. crassipes,* commonly called as water hyacinth, an aquatic flowering plant native to the Amazone in origin with broad, thick, glossy leaves. They have long, spongy and bulbous stalks in base of the shoot body. They are generally shown as vigorous growers in this wetland. *E. crassipes* had higher abundance in Station 6 followed by station 8, station 5 and station 7. S. *molesta* is an invasive weed distributed in stations 4, 5, 6, 7, 8 and occasionally seen in station 2. They covered a vast area in stations 7 and 8 that makes a threat to biodiversity of this wetland and moderately distributed in station 4 and 5. *Lemna* sp. is free floating aquatic weed, generally called as duckweed. This weed is not commonly observed in this wetland but occasionally noted in station 3 and station 7 in small patches.

The most abundant growth form was emergent-anchored hydrophytes and they were *Monochoria vaginalis, Hygroryza aristata, Ludwigia adscendens, Ipomea pes-capre, Convolvulus* sp., *Sacciolepis* sp., *Sagittaria* sp., *Marsilea quadrifolia* and *Rotala* sp. *M. vaginalis* was also less frequently present in station 1, 2, 3 and station 5. This plant is only seen through paddy and channel phases of the wetland. *H. aristata* is a genus of family poaceae was present in station 2 and 3 in less frequent and seen in small patches as emergent vegetation in open water. They are generally known as water grass, effective medicine for various diseases. They are very common in paddy fields of these wetlands. *L. adscendens,* is a flowering plant seen in stations 4, 5, 6 and 8 throughout the whole stations with *Nymphaea* sp.. This plant is a perennial herb with white spongy buoys, and can float on water surface as well as creep over the surface of wetlands. They have simple leaves and elongated stems. This plant is also observed even after dewatering of station 4 and 5. *Ipomea pes-capre* it known as beach morning glory and found creeping in nature of family Convolvulaceae. Dominated in station 8 and evenly seen in stations 6 and 7 in wetland margins. This plant is generally seen in association with other varieties. *Convolvulus* sp. is commonly called as morning glory and was moderately present in station 4 in dry period and also seen in station 7 and 8 in wetland margins. *Sacciolepis* sp. is genus of tall-emergent macrophyte which is a persistent grass with a long root-stock and fast growth. They are wide spread species in tropical and temperate regions. The inflorescence is usually a narrow, dense panicle. *Sacciolepis* sp. generally present in different patches in stations 2, 3 and 8. This was moderately present in monsoon period and decrease during dewatering of the same stations except in station 8. *Sagittaria* sp., was only present in station 4 and 5 during dry seasons. It was not observed during monsoon season or full inundation. *M. quadrifolia* is a herbaceous plant and considered as a weed in paddy fields. *M. quadrifolia* having a four paired leaves and leaves are seen erected in shallow regions. This plant generally not a common species in this wetland, its presence and absence was highly depend on variation in water column. This species was abundant in station 2 and moderately present in station 3 during paddy cultivation period. *Rotala* sp. is an outstanding beautiful bright red colour plant grows submerged and spread along the surface. *Rotala* sp. is grown in small bunches in margins of this wetland during inundated phase and it is also seen in paddy and channel phases of station 1, 2, 3 and 5.

Hydrilla verticillata is considered as submerged-anchored hydrophyte. This species was one of the common species found in different stations throughout the study period. This plant is completely submerged in full inundation period and partly submerged during dewatering period. It was present in stations 1, 2, 3, and 4 and the frequency was higher in station 1. The leaves are complex in nature and arranged in whorls of two to eight petals around the stem. *Ceratopteris* sp., are one another submerged-anchored species found in this wetland. *Ceratopteris* sp. is a water fern and was not seen frequently in these wetlands, which was rarely observed in station 4 and 7.

Anchored hydrophytes with floating leaves, 3 species of plants were observed in this growth category. They are *Limnophila heterophylla*, *Nymphaea pubescens* and *Nymphoides indicum. L. heterophylla* was present in large patches in the deeper parts in the wetlands of stations 1, 2, 3 and 8. This plant is commonly called as amphibious herb which has two distinctively different forms of leaves and observed in full inundation periods. *N. pubescens and N. indicum* are catogorised into genus of aquatic flowering plants in the family Nymphaceae and Menyanthaceae. It was common in stations 4, 5 and 6. Frequency of *N. indicum* plant was comparatively higher in station 6 having submerged root and floating leaves that hold the beautiful white flowers above the water surface. These plants shows decrease in leaf size during dewatering periods.

Utricularia aurea is largely seen in stations 1 to 5. In stations 1 to 3 major portion was covered by this plant. This plant is anchored and having a floating shoot system. Very delicate in structure and attractive yellow flowers are peculiar to this macrophyte. *U. aurea* is generally called as bladderwort and is a carnivorous plant. Wide spread in Indian aquatic bodies, this plant is observed throughout the study period in these stations.

Alternanthera sp., is a as wetland plant, spread across in stations 4, 5 and 8. They have a peculiar type of fleshy horizontal stems to differ in appearance. In station 8 it forms dense mats on the surface of water body. Very adaptive in nature it was found in dry phases of stations 4 and 5, and inundated stable phases of station 8. This plant is having complicated root systems well adaptive to its environment. Its growth is favourable for breeding mosquitoes. Paddy fields of this wetland is generally cultivated by *Oryza sativa* of the Varieties. Jyothy and Uma in past few decades and generally categorized in wetland plants. Macrophytes recorded from different stations are given in Figs. 6.3.

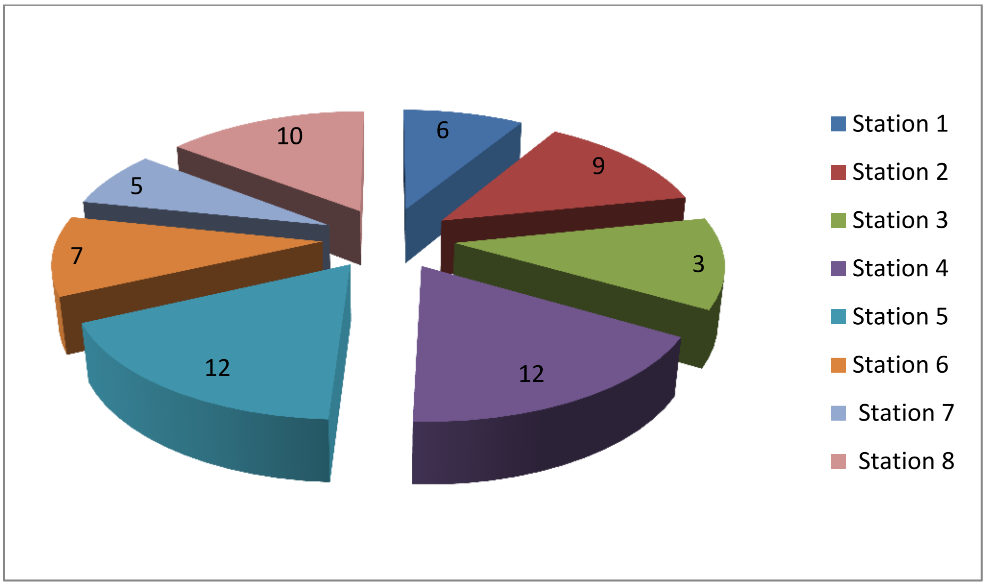


Fig. 6.3. Number of macrophytes recorded from different stations in Maranchery Kole wetland during the study period.

6.2.3 Distribution of aquatic macrophytes in different phases in Maranchery Kole land

6.2.3.1 Wet phase: Out of the 21 species recorded in the whole area, 15 species were recorded from the wet phase. Among these, three species were dominated and they are *U. aurea, H. varticillata* and *N. indicum.* Compared to other phases wet phase shows higher class frequency and abundance of macrophytes. The stagnant water and moderate nutrient concentration promote rich floristic composition in wet phase. The other major macrophytes observed in the phase were *L. heterophylla*, *N. pubescence*, *S. molesta*, *Sacciolepis* sp., *H. aristata*, *Lemna* sp., *Rotala* sp., and *Alternanthera* sp..

6.2.3.2 Stable phase: *E. crassipes* and *S. molesta* were dominating macrophytes in this phase. Increase in the two invading aquatic species in this phase might be due to the increased outflow of nutrient rich water from major channel outlets that was connected to paddy fields. Moreover intense anthropogenic activities are found in these stations. Dumping of domestic and poultry wastes, plastic wastes were observed in these areas. The other hydrophytes observed in the phase were *L. adscendens*, *N. pubescens, U. aurea, H. verticillata, Convolvulus* sp., *Sacciolepis* sp., *Ceratopteris* sp., *L. heterophylla, Sagittaria* sp., *L. purpusilla*, and *Alternanthera* sp.

6.2.3.3 Channel phase: In this phase very less macrophytes were distributed and frequency of plants were very poor, because of manual removal of macrophytes were taking place in connection with agricultural activities. Among the reported 21 species encountered, only 8 species were present in this phase and among them *U. aurea* plant showed higher frequency followed *by L. adscendens, H. verticillata*, *M. quadrifolia, N. indicum, Convolvulus* sp., *Rotala* sp., and *Ceratopteris* sp.

6.2.3.4 Paddy phase: The major species found in this phase were *O. sativa.* Apart from the wetland plants, the growth of macrophytes were comparatively low. One or two species were dominated in this phase other plants are very less in frequency of distribution. Usually the paddy cultivation begins on late November to December period and soying was done by January itself. Four months is generally taken in account as growing period. At the end of April or early May yield is obtained. Patches of water column were available in the paddy fields and macrophytes present in the patches are *H. verticillata, M. quadrifolia, U. aurea, H. aristata, N. indicum, Rotala* sp., *S. molesta* and *M. vaginalis.* No. of macrophytes recorded from different phases are given in Figs. 6.4

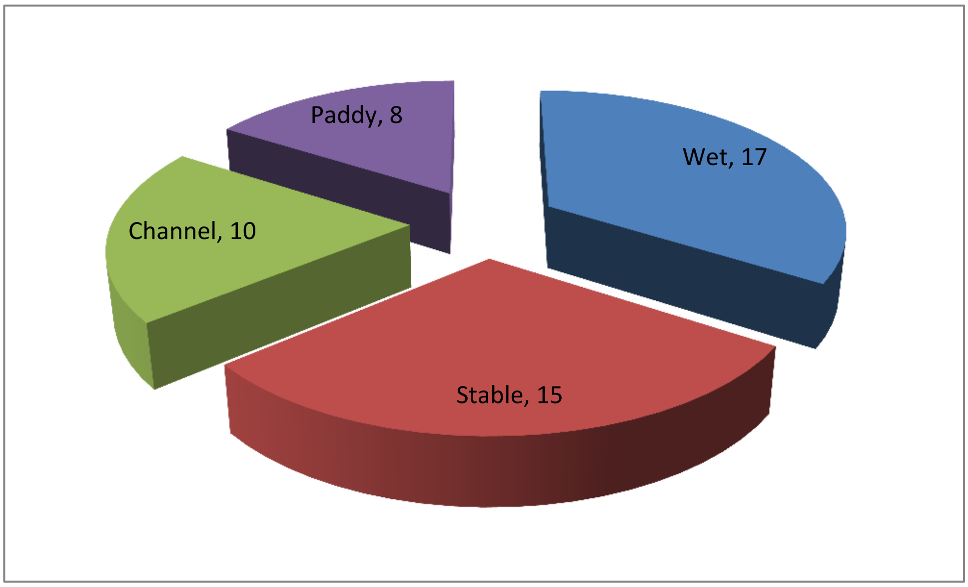


Fig. 6.4. Number of macrophytes recorded from various phases in Maranchery Kole wetland during the study period.

6.2.4 Biomass production of major macrophytes

Biomass of dominant aquatic macrophytes was calculated from monospecific patches of aquatic vegetations in each station. Table 6.4 represents the mean variations in biomass of eight stations. Dominant species of each station were represented by H. *verticillata* in station 1, *L. heterophylla* in station 2, *U. aurea* in station 3, *N. pubescens* in station 4, *N. indicum* in station 5, *E. crassipes* in station 6, *S. molesta* in station 7 and *L. adscendens* in station 8. Mean variation in above ground biomass during the study period is given in Figs. 6.5 and 6.6. Station 1 showed minimum biomass of 270 g/m^2 in January 2011 and maximum of 4800 g/m^2 in June 2011 with a mean value of 2299 (±1288). In station 2, it ranged from 320 g/m^2 in May 2011 to 5700 g/m^2 in August 2012 showing a mean value of 2202 g/m^2 (±1440). The mean total biomass was 2640 g/m^2 (±1572), and ranged from 100 g/m^2 in February 2011 to 5100 g/m^2 in November 2011 in station 3. In station 4, February 2011 showed an absence of macrophytes whereas the highest value of 4600 g/m^2 was observed in November 2011 the mean being 2294 g/m^2 (±1298). In station 5 the minimum biomass was of 160 g/m^2 in February 2011 and maximum of 3600 g/m^2 in September 2011 with a mean value of 1500 g/m^2 (±1322) in station 5. In station 6, the mean biomass was 3462 g/m^2 (±1964) varying from 300 g/m^2 in February 2011 to 9200 g/m^2 in September 2011. The biomass ranged from 200 g/m^2 in March 2011 to 5680 in July 2012 in station 7 with a mean of 2707 (±(±1272). In station 8, the mean total biomass observed was 4005 g/m^2 (±2257) with a minimum value in February 2011 (300 g/m^2) and maximum in October 2011 (8400 g/m^2). The comparison between the wet, paddy, channel and stable phases showed that the average biomass was in the channel phase was 780 g/m^2 and that in the stable phase was 4960 g/m^2 (Fig. 6.7). The results of ANOVA showed that there existed a significant variation in plant total biomass at 1% level between phases (P<0.01), and stations (P<0.01).

Table 6.4. Mean variations of total biomass of macrophytes in eight stations of Maranchery Kole wetland.

Stations	Min	Max	Mean± SD
Station 1	270	4800	2136 ±1307
Station 2	320	5700	2026 ±1323
Station 3	100	5100	2640 ±1572
Station 4	0	4600	2293±1228
Station 5	150	3600	1500±1322
Station 6	300	9200	3461 ±1964
Station 7	200	5680	2706±1272
Station 8	300	8400	4005±2257

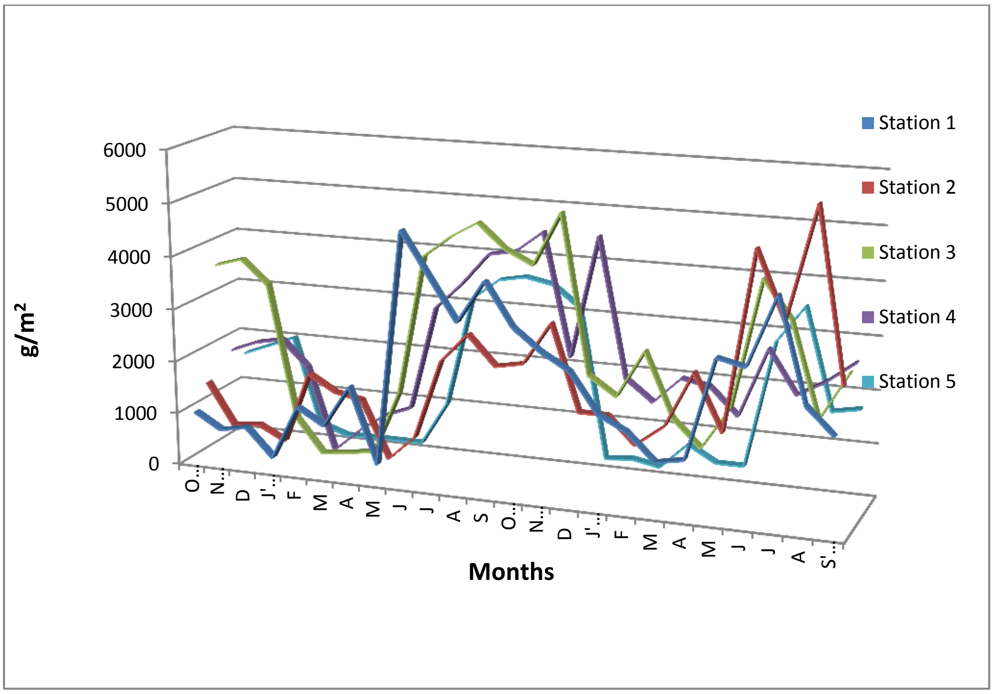


Fig. 6.5. Mean variation of total biomass of macrophytes of stations 1 to 5 in Maranchery Kole wetland during the study period.

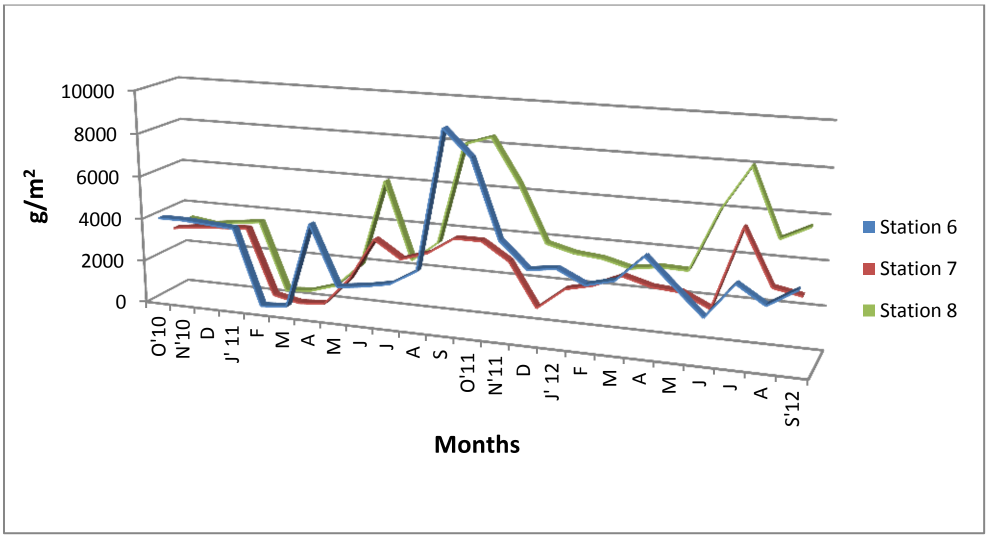


Fig. 6.6 Mean variation of total biomass of macrophytes of stations 6 to 8 in Maranchery Kole wetland during the study period.

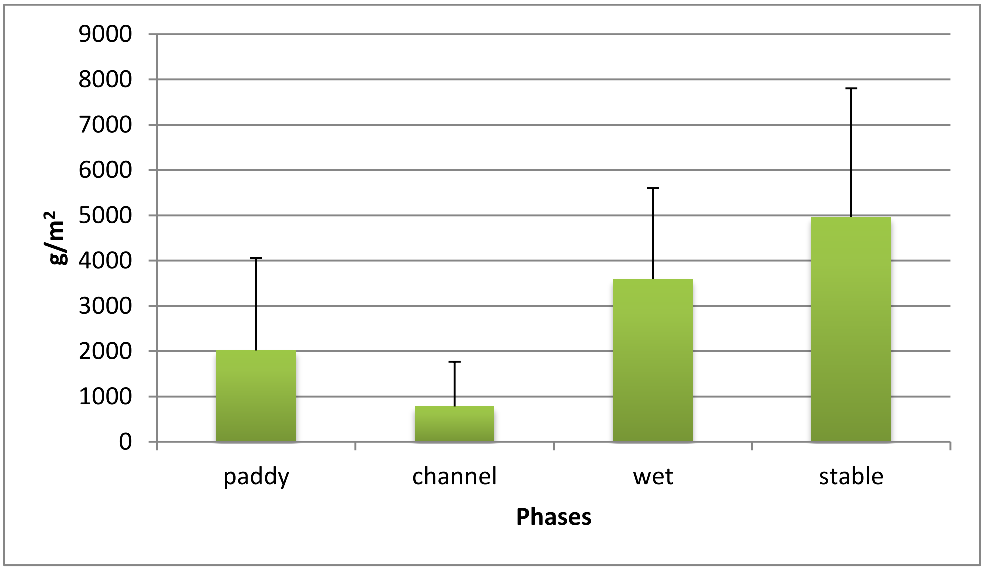


Fig. 6.7. Mean variation of total biomass of macrophytes in various phases of Maranchery Kole wetland during the study period.

6.2.5 Univariate analyses of macrophyte community structure

The community is an assemblage of species population that occur together in space and time. The diversity indices (Table 6.5), in terms of Shannon index H' showed that Station 4 had the highest diversity (3.290) and Stations 1 ranked the least with 2.187. Margalef's index for species richness indicated that Stations 4 and 5 had the richest, species wise (2.172 and 2.171), whereas Station 1 had the least value (0.868). The evenness index, in terms of Pielou's index (J') indicated the evenness values to be very low. The highest evenness index of 0.993 was recorded at Station 6. Simpson's dominance index value (1-λ') reveals that Station 4 had the least dominance (0.099) and highest was reported in station 1 (0.232). In phase wise evaluation, Shannon index H' was highest in wet phase (3.71) lowest in channels (2.63). Margalef's index value explains that species richness was highest in wet phase (3.03). Evenness of macrophytes species of the wetland showed lower value in stable phase (0.89), and dominance of vegetation was higher in channels (0.17) (Table 6.6).

Table 6.5. Mean diversity indices of macrophytes in eight stations of Maranchery Kole wetland.

Stations	D	J'	H' (log 2)	1-λ'
Station.1	0.868	0.942	2.187	0.232
Station. 2	1.737	0.932	2.955	0.138
Station. 3	1.738	0.880	2.789	0.175
Station. 4	2.171	0.951	3.290	0.099
Station. 5	2.172	0.947	3.275	0.108
Station. 6	1.086	0.993	2.567	0.163
Station. 7	1.086	0.922	2.384	0.203
Station. 8	1.086	0.935	2.418	0.200

Table 6.6. Mean diversity indices of macrophytes in different phases of Maranchery Kole wetland.

Phases	D	J'	H' (log2)	1-λ'
Wet	3.03	0.95	3.71	0.08
Paddy	1.74	0.94	2.99	0.13
Channel	1.30	0.94	2.63	0.17
Stable	2.83	0.89	3.40	0.11

6.2.6 Multivariate analyses of macrophyte community structure

6.2.6.1 Cluster analysis

In station wise evaluation dendrogram of the similarity showed three clusters (Fig.6.8). Station 1, 2 and 3 formed a single cluster with 77% similarity and within this cluster station 2 and 3 showed higher similarity (83%). The second major cluster was formed between stations 4, 5 and 6 clubbed together at 55% of similarity. The third cluster was formed by stations 7 and 8 with 53% of similarity. In phase wise analysis, wet and stable phases formed a single cluster with 71% of similarity. Channel and paddy phases were grouped in another cluster with 36% of similarity. In between channels and stable phases, showed 42% of similarity (Fig.6.9).

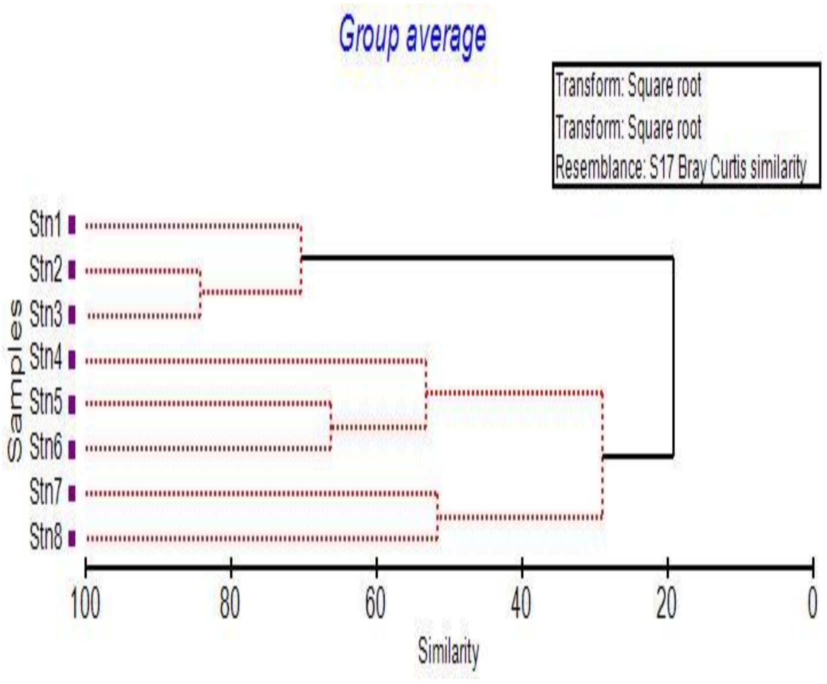


Fig. 6.8. Dendrogram of distribution of macrophytes in eight stations of Maranchery Kole wetland.

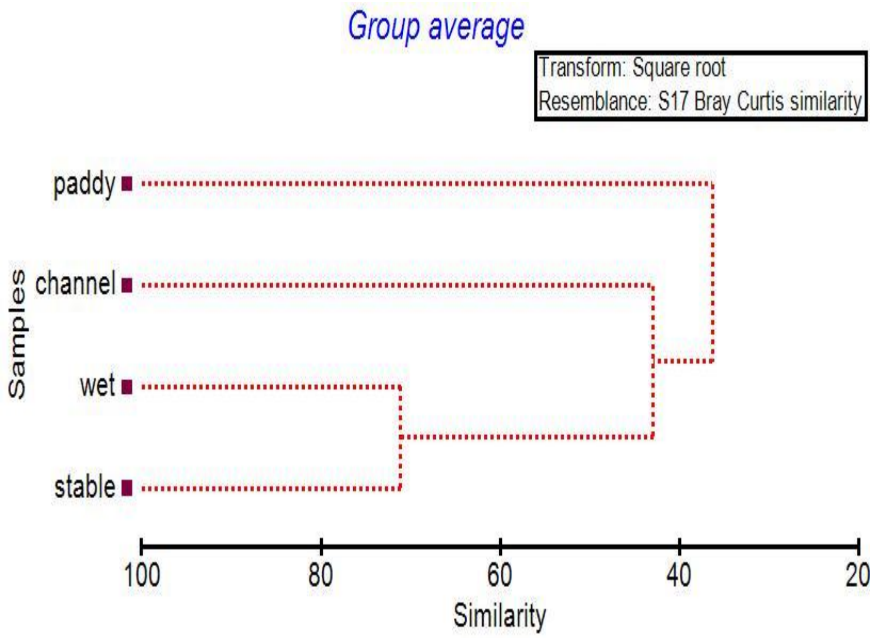


Fig. 6.9. Dendrogram of distribution of macrophytes in various phases of Maranchery Kole wetland.

6.2.6.2 MDS (Non Metric Multi Dimensional Scaling) plots

The ordination depicted from the similarity matrix revealed the same pattern as seen in the cluster analysis (Fig. 6.10). In station wise plots the stress value (0.01) obtained in MDS indicates that the data are fairly well represented. Stations 1, 2 and 3 were clustered together at 60% similarity. Stations 4, 5, 6, 7 and 8 were showed overall 20% similarity. Within this cluster stations 4, 5 and 6 grouped together and showed 60% similarity and station 7 and 8 grouped together and formed 40% similarity. In phase wise MDS shows the stress value 0.0. Wet, stable and channel phases clubbed together and showed 40% similarity. Within this cluster wet phase and stable phase were standing together at 60% similarity. Paddy phase was standing apart with overall similarity of 20% with the other phases (Fig. 6.11).

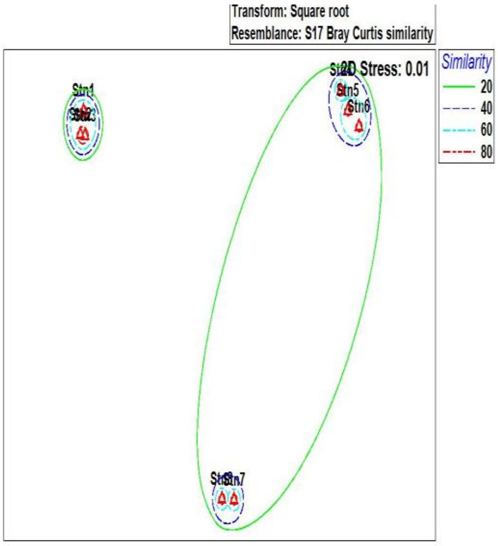


Fig. 6.10. MDS of distribution of macrophytes in eight stations of Maranchery Kole wetland.

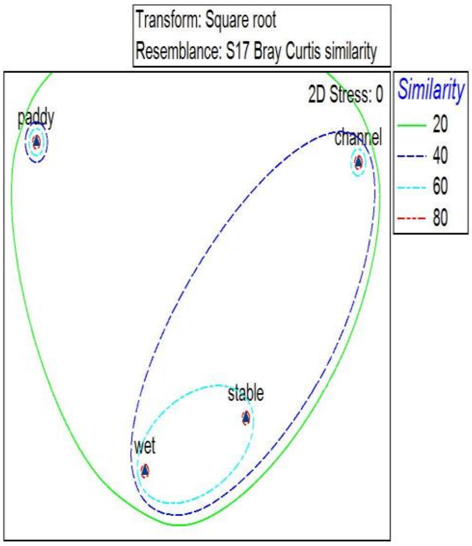


Fig. 6.11. MDS of distribution of macrophytes in various phases of Maranchery Kole wetland.

6.2.6.3 Species Dominance Curve (*k*-domiance curve)

The dominance curve for the different stations is given in Fig. 6.12. Except for the Stations 1, 6 and 7, which exhibited higher dominance and lower diversity, the *k*-dominance curves for the other stations showed slight variations and overlapping. The cumulative dominance of the Stations 6, 7 and 8 reached simultaneously cumulative 100%. Clarke and Warwick (2001) explained that, *k*-dominance curves are cumulative ranked abundance, plotted log transformed species rank or against species rank. Most elevated curves are considered to have the lowest diversity. In the present analysis it was shown that the cumulative dominance in the station 1 reached cumulative 100% and the most elevated curves of the dominance plot. Station 4 shows the deepest curve that reached cumulative 100%. In phase wise analysis it is clear that, channels have low species diversity and higher dominance and wet phase having higher species diversity (Fig. 6.13).

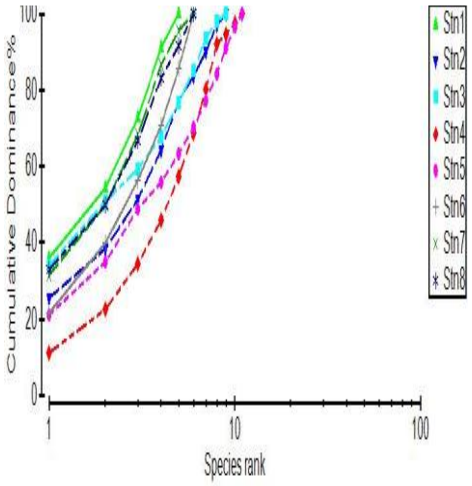


Fig. 6.12. *K*-dominance curve of macrophytes in eight stations of Maranchery Kole wetland.

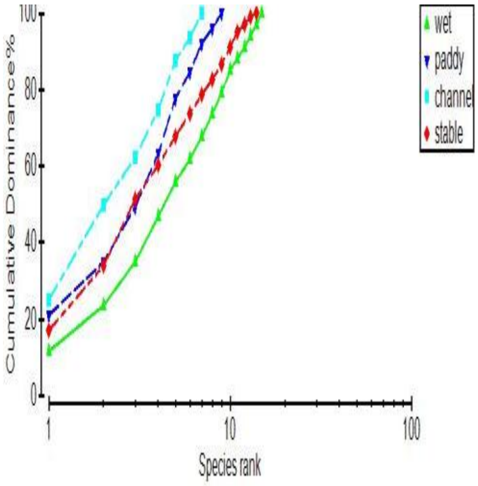


Fig. 6.13. *K*-dominance curve of macrophytes in various phases of Maranchery Kole wetland.

6.3 Discussion

A total of 21 aquatic and semi aquatic species belonging to 20 genera and 16 families, were recorded in the wetland. The maximum species were represented by Poaceae (4 species) and Pteridophytes or water ferns (3 species) followed by Convolvulaceae and Pontederiaceae (2 species). In the present study, it was noted that *Eichhornia crassipes, Salvinia molesta, Nymphaea pubescens, Nymphoides indicum, Hydrilla verticillata, Utricularia aurea, Ludwigia adscendens* and *Limnophila heterophylla* are found to form monospecific communities in this wetland. Other macrophytes are generally found associated with dominant macrophytes that are *Rotala* sp., *Ipomea pes-capre, Convolvulus* sp., *Sagittaria* sp., *Sacciolepis sp.,* and *Lemna perpusilla*. At the time of dry periods, apart from *Oryza sativa,* the plants like *Hydrilla verticillata, Utricularia aurea and Marsilea quadrifolia* shows higher frequency. The present study identified two exotic species they are *Eichhornia crassipes* and *Salvinia molesta.* From the identified macrophytes several species such as *Ludwigia adscendens, Ipomea pes-caprae, Alternanthera* sp., *Hydrilla verticillata, Monochoria vaginalis, Hygroryza aristata,* and *Oryza sativa* were found to be used for medicinal purposes. The general distribution, abundance, growth and development of aquatic macrophytes seems to be in agreement with the facts, which affect the ecology of hydrophytes in other fresh water wetlands. Jyothi and Sureshkumar (2014) collected 75 plants from Ponnani Kole lands, among these 28 species are medicinal varieties. Kumar and Thomas (2002) collected 65 species and Sujana and Sivaperuman (2008) collected 140 species of plants from Kole wetlands of Thrissur. Herbaceous flora of lower stretch of Baharathapuzha river, Malappuram District, Kerala was studied by Liji Balan and Paul (2016) and identified 170 species of Angiosperms. The wetlands of West Bengal support more than 380 no. of aquatic flora belonging to 176 genera and 81 families which represent about 60% of the diversity of the Indian aquatic vascular plants (Cook, 1996; Ghosh, 2005). Sylas, (2010) reported a total of 130 species of aquatic macrophytes from Kuttanad region of Vembanad wetland. Parameswaran et al. (2014) collected 319 species of vascular plants associated with wetland paddy fields (*Vayals*) of Wayanad District, Kerala. The rainfall pattern highly influenced macrophyte growth in this wetland. During monsoon, when wetland was completely inundated the vegetation is dominated by submerged and floating-leaved plants and when the water level decreased, the submerged floating-leaved vegetation plants are replaced by the emergent vegetation. Similar result was reported by Sunil and Sivadasan (2009) in Alapuzha regional plant survey.

The frequency of macrophytes like, *E. crassipes, S. molesta, N. indicum,* and *U. aurea* are usually higher in this wetland. Distribution of certain species like *Ceratopteris* sp., *L. purpusilla,* that are absence in paddy and channels of the Kole lands. Minor species like *Ceratopteris* sp., *L. purpusilla,* are dried or degraded when dewatering taking place, this might be the reason for absence of these species in channel and paddy fields. Higher temperature, delicate structure and less availability of water in paddy phase also cause reduction of macrophytes in these phases. Each macrophyte species shows a close relation with hydrological regime and nutrient status of this wetland. Zutshi and Gopal, (1990) reveals that, there are distinct phases over annual water cycles and growth pattern of macrophytes in Indian wetlands. In Maranchery Kole lands the increase of water weeds such as *E. crassipes* and *S. molesta* were noted, which was alarmingly increased due to anthropogenic activities, especially in stations 6, 7 and 8. Comparing with indigenous macrophytes, the exotic macrophytes are generally faster growing, more tolerant of poor water quality and more disturbances by Riis and Biggs, (2003). The present observation was in conformity with above statement. A general opinion also exists that the extensive growth of exotic macrophytes particularly in tropical and subtropical areas causes loss of water resources, which indirectly affect the economic growth of the country (Varshney and Rozska, 1976). Lake or water body exhibits a eutrophic condition where exotic aquatic plant species tend to propagate quickly and cover the entire surface of the water mainly due to lack of adequate management. This creates negative impacts on the systems by Hemond and Benoit, (1988) and Schultz and Dibble (2012). Contrary to these Williams, (2006) reported that macrophytes like *E. crassipes* and *S. molesta* were known to provide cheap, simple and efficient way of treating wastewater.

In Maranchery wetland drastic changing of land use pattern reduces the abundance, diversity and community pattern of macrophytes. In such conditions certain floating macrophytes like, *E. crassipes* and *S. molesta* their occurrence and abundance were not changed. Relative abundance of these two species suppresses the growth of other species of macrophytes in this wetland. Collins and Walling, (2007); Wang et al. (2009) explain that, growth and spread of macrophytes in aquatic environment is a natural phenomenon. In recent years concern about aquatic vegetation and the water quality has been increased as a result of human activities such as agriculture, forestry operations, construction activities and urbanization programmes. Invasive species caused a strong decrease in the overall diversity and abundance of aquatic communities (Gallardo et al., 2016). The present study was in agreement with above statement; *E. crassipes* species showed higher abundance in relatively less water flow whereas *S. molesta* even present in relatively high rate of water flow. In Maranchery wetland depth of the water column was above 2m in stations 6 to 8, with an increase in floating macrophytes were observed in these stations. Winton and Edwards (2009) confirmed that, over 2 m depth floating vegetation was more prominent and it leads to decrease in submerged vegetation. Jacobs et al. (1994) have suggested that *S. molesta* is generally seen in slow moving, degraded and nutrient rich water.

In Maranchery wetland frequency of submerged vegetation of *H. verticillata* and *U. aurea* were higher in different stations. Frequency of *L. heterophylla* plant was higher in station 2 in the wetland. Stagnant nature of the water body leads to prolific growth of this delicate heterotypic plant. Unni (1971) has reported that *Hydrilla verticillata* is restricted to stagnant water. According to Scheffer (2004) healthy ecosystem of clear water lakes exhibit abundant submerged vegetation. In Maranchery wetland stagnant nature of water body and presence of moderate amount of nutrients will help to grow delicate plants like *L. heterophylla, H. verticillata* and *U. aurea*. High flow velocities can determine the growth of submerged plants through breakage or uprooting, and preventing seeds or fragments from settling and anchoring (Reeves et al., 2004). Madsen et al. (2001) reported that the accumulation of fine sediments under very low flows can cause unstable substrates that reduce plant anchoring.

In Maranchery wetland frequency of rooted floating leaved plants like *N. pubescens* and *N. indicum* was higher in stations 5 and 6. In the wetlands of Shiroda and Khandola, the maximum biomass value is reached when the broad leaved species especially *Nymphaea* sp. attains maximum growth. Amongst the different macrophytes studied *Nymphaea* plant which is a rooted floating macrophyte, has the heaviest biomass (Pradeep et al., 2016). The maximum growth of one species has been observed to reduce the biomass of other species by Lavania et al. (1990) and Nurminen et al. (2003). A thick canopy of *N. pubescens* and *N. indicum* can reduce the movement of water and create a good living space for macroinvertebrates and fishes (Cheruvelil et al., 2001).

In station wise observation, the average variations of total biomass of macrophytes was not prominent. Only station 6 shows higher variations compared to other stations. Biomass of emergent macrophytes showed high peak rate of biomass compared to other growth forms. The relatively moderate pH in this wetland could be one factor that limits the biomass of macrophytes. Biomass was highest during the month of September 2011 and October 2011 which is the flowering season of major macrophytes whereas reduction in biomass during the month of October 2010 and September 2012 was noted. This shows that in each year growth pattern of macrophytes was different in this wetland. Variations of biomass in stations 1, 2, 3 during the months of January, February and March in both years may be due to the extensive farming activities like dewatering, tillage and application of weedicides. In station 7 marginal decrease of biomass of macrophytes was noticed. The major species contributed in this station was *S. molesta*. Weight of this floating weed was comparatively less more over this station served as main out let connecting to station 4. The velocity of flow of water in this station was high; this might decrease the growth and abundance of macrophytes in same station. Similar results were observed in lake Ziway, Ethiopia by Tamire and Mengistou (2014). Maltchik et al. (2007) have noticed that the peak biomass of *E. azurea* during flood phase and *L. peruviana* during the drained or shattered phase. Several reports have documented that wide spatial variations affect biomass of macrophytes in tropical environments (Camargo and Esteves 1995; 1996). It is evident that spatial variation of biomass production in tropical regions is usually related to the seasonal variation of rainfall and water level, due to flood pulse by Camargo and Esteves (1995); Junk and Piedade (1993). Payne (1986) and West et al., (2017) opined that, temperature and photoperiod were relatively more important in affecting productivity and biomass of macrophytes than physical factors such as conductivity and temperature. But the status of nutrients like nitrite the wetlands negatively affected the biomass and production of most of the macrophyte species.

In phase wise evaluation of this wetland, in channel and paddy phases the growth pattern and biomass of macrophytes were entirely different from other wetlands this is because of change in substantial depth, soil type and strength of water flow varying during summer period compared to other wetlands. The flourishing growth of macrophytes in inundated phase of Maranchery wetland was adversely affected by water level changes or dewatering. The channel phase of this wetland exhibited a poor representation of macrophytes. The total biomass of channel phase was very low compared to other phases. Total diversity of macrophytes was also less during channel and paddy phase. Manual removal of macrophytes during the early stages of paddy cultivation period was one of the reason for decreased diversity and biomass in channels. Variation in nutrient level and substantial difference in sediment structure in relation to agricultural activities also decreased the biomass of macrophytes. Dead and decaying debris of macrophytes was higher in the channels compared to live plants. The biomass of decaying macrophytes was not accounted in this study. The canal systems were found to be dominated by *E. crassipes and S. molesta* from Kuttanad by Sylas, (2010) and highest biomass and growth rate were obtained from *Eichhornia crassipes* (3899 g/m^2). Sanyal et al. (2002) observed canal systems of Kabar lake, having higher growth rate of submerged plants. Rolon et al. (2010) observed variation in biomass along the hydrological phases occurring differentially between the wetlands of Southern Brazil. According to De Neiff et al. (1994) peak biomass of different species of hydrophytes occurs over the flooded period and reduction of biomass at low water level. Similar situation was observed in the Kole wetland. In contrary to this, the biomass of hydrophytes was lower in the flooded periods was reported by Malchik et al. (2005). Schoot et al. (2005) also recognized that, biomass was higher in the periods without the presence of water in low lying wetland. In Maranchery Kole land during wet and stable phases biomass and diversity was also higher. Decreased anthropogenic activities, increase of depth, increase of nutrients such as nitrate, phosphate increases the diversity and distribution pattern of macrophytes during inundation period. Average periphyton biomass was highest during the wet seasons of northern Everglades of Florida was accounted by Paul et al. (1998).

Low macrophyte density, such as the impact of eutrophication on water body, higher turbidity and higher concentration of suspended particles in the water body was noted by Kapitonova, (2002). The present study is in conformity with the above statement, that there is a increase in turbidity during channel phase causing decrease in density of macrophytes in channels of Maranchery Kole. Turbidity and macrophyte biomass observed a strong positive correlation significant at 1% level ($P<0.01$). According to Crow and Hellquist, (2000) the turbidity was found to be positively correlated to the density of aquatic macrophytes, because dense macrophyte cover is characterized by low concentration of suspended sediments. Negative impact of high turbidity is usually attributed to the lower accessibility of light for phototrophic macrophytes was noted by Lacoul and Freedman, (2006). Lake et al. (2002) observed some pest fishes that prevent the establishment and growth of macrophytes in de-vegetated lakes facilitate the development of monospecific stands of exotic species. In this wetland attack of some pest fishes and shredders and scrapper’s community of aquatic insects feeding on macrophytes were also noted. However, the modernization of irrigation systems in channels has altered the ecological and environmental conditions of macrophyte community in the channels and paddy fields. The moisture content and salinity of the underlying soil in the canal decreased and this altered the effects of water and salt stress on the plants, promoting weed community succession and restricting the growth of drought-susceptible plants (Lin et al., 2002). The succession of macrophytes in this wetland was absent due to continuous alteration in land use pattern. Further, change in land use pattern did not allow completing the growth of single community. In future this will severely alter the pattern and distribution of several indigenous varieties and invasion of several exotic macrophytes. Because the exotic macrophytes shows faster growth by completing their life cycle in single season.

In the paddy phase of this wetland the growth and frequency of certain species of macrophytes was increasing such as *M. quadrifolia*, *H. aristata* and *Rotala* sp. and other common varieties was decreasing. Total diversity of macrophytes was also very less compared to wet and stable phases. Continuous removal of weeds in between paddy plants also causes severe reduction in diversity of macrophytes. Limited quantity of water in agricultural fields favour the growth of *M. quadrifoliata*, *H. aristata* and *Rotala* sp. Whereas decrease of certain species like U. *aurea*, *H. verticillata*, *L. perpusilla* and *M. vaginalis* species was noted as they appeard in small patches within the paddy fields. *Sacciolepis* sp. and *Alternanthera* sp. was seen in the border of the paddy fields. Gross reduction in diversity and biomass of macrophytes attract several insect communities in the paddy fields. Moreover, the paddy plants itself support several pests, larvae of Lepidoptera, Coleoptera and Diptera. This will also change the composition and community structure of macrophytes and further reduction in yield of rice. Application of weedicides was one another reason of reduction of macrophyte growth. Paddy fields of the Kole lands shows dynamic nature which alter the community pattern of macrophytes. Varghese (1993) noted the variation in the composition of macrophytes in different seasons according to water pollution, unclean cultivation and weed growth in and around the rice fields. These circumstances are conducive for the growth of pests and ultimately cause reduction in diversity. The composition of aquatic plants in a rice field may be determined by the organisms in the field, which may be pathogens, or grazers (International Rice Research Institute (IRRI), 1993). According to Roger, (1996) some plants are antagonistic to fertilizers by releasing chemical substances that inhibit growth of weeds. Drying the rice field results in a drastic shift in the composition of floral species as reported by King and Buckne, (2000). Lehmann and Lachavanne, (1999) observed that macrophytes could change the quality of water by lowering the temperature, pH and dissolved oxygen content. Tillage results in the suppression of growth of macrophytes in agricultural fields, moreover, different agricultural activities like mixing of water and clayey soil resulted in suspension of clay particles, makes the water turbid and results in less availability of light for photosynthesis in paddy phase of this wetland. Sylas (2008) reported rice fields at Pallom recorded 48 species, out of 66 flora and a reduced species rate in Kumarakom and Thakazhy paddy fields of Kerala. *Monochoria vaginalis* and *Oryza rufipoigon* were observed as the major weeds in puncha and additional crop in Kuttanad according to the survey carried out by Abraham et al. (1990) and Sasidharan et al. (1990). Anil Kumar and Thomas (2007) explained medicinal usage of some macrophytes of the Muriyad wetland in Vembanad-Kole, Kerala. Parameshwaran and Kumar (2016) accounted of the ‘useful weeds’ associated with wetland paddy fields of Wayanad, Kerala. Further paddy associated habitats was dominated by the members of family Solanaceae, Asteraceae, Fabaceae and Moraceae. Cheng-Fang et al. (2012) analyzed the weed communities of rice fields in three areas of Central China; their results showed that weed species differed among areas. Broadleaf weeds such as *Monochoria vaginalis, Lindernia procumbens* and *Spirodela* sp. were the dominant weed species of the early and late rice stages was reported by Kufel et al. (2004). Vaheeda (2008) recorded that Poaceae family were more common in oligo/mesohaline conditions with a salinity range of 0.3 to 9.10 ppt. Abraham and Jose (2014) opined that weeds are major threat for agricultural production. Weeds compete with rice for various resources such as light, water, nutrients, space etc and reduce the yield. Li et al. (2010) and Liu et al. (2010) investigated the weeds in paddy fields in Eastern China, through comparative surveys over ten years period. Their results stated that the degree of damage due to barnyard grass declined over this period. Additionally, due to the long-term use of sulfonyl urea herbicides, many weed species that were initially malignant were reduced. Singh et al. (2010) detailed that, chemical status of water appears to be the vital factor, which influences the general distribution of vegetation in paddy fields. Abiotic factors like nature of bottom soil and fluctuation of water greatly affect the distribution of plants. According to Luo et al. (2014) aquatic plants are far more abundant in traditional flooding in wetlands, whereas aquatic plants are inhibited by rice cultivation during two consecutive drought phases.

Macrophytes have a profound influence on the nutrient budget of an ecosystem and also their hydrological balance (Mao and Gogoi, 2006). The distribution and abundance of different types of macrophytes in the extensive wetland system appear to be regulated by the environmental characteristics of the water column and substratum. Rain fall and macrophyte density was positively correlated with 5% level significant ($P<0.05$). The values of depth, pH, water temperature, turbidity and air temperature of the wetland were positively correlated with the aquatic macrophyte composition at 1% level significance ($P<0.01$); this corroborates the findings of Carr et al. (2003) in Ontario rivers, Canada. The relationship between macrophytes and water temperature was positively correlated, as during high temperature the photosynthetic activities of the macrophytes increased thus their population was increased. Carpenter and Lodge, (1986) noted submerged hydrophytes are exposed to lower oxygen concentration, light, temperature and photo respiration. Variations in environmental factors such as moderately high water temperature and high nutrient load highly influenced the macrophyte growth was reported by Horppila and Nurminen (2005). The macrophyte distribution in the Kole land was not in any way influenced by conductivity and TDS. This is in agreement with the observation of Okayi and Abe (2001) in some reservoirs of Markurdi, Nigeria. Xiao et al. (2010) examined the interplay between macrophytes and water quality variables and agreed that, there are important implications for river flow and ecological functioning. Capers, (2000) and Lambert and Davy (2010) in their study related to submerged plants and reveals that, in extreme situations, suspended sediments increase the attenuation of light with increasing water depth, and heavy loads can result in the complete loss of submerged macrophytes. Magnesium ion is an essential nutrient for plants; it shares the chlorophyll structure and is used in metabolism of plants (Antoine and Saadi, 1982). Magnesium concentration was positively correlated with the aquatic macrophyte biomass at 5% level significance ($P<0.05$). In the present study decrease in concentration of magnesium might be due to the magnesium intake of aquatic plants and share the same in chloroplast structure and metabolic processes.

The relationship between the nutrients (nitrite-nitrogen, nitrat-nitrogen, ammonia-nitrogen, phosphate-phosphorus and silicate-silica) and macrophytes growth were negatively correlated. An indication of the effect of nutrient load on macrophyte abundance and density was reported by Obot et al. (1991) in Kainji reservoir, Nigeria. Schriver et al. (1995) and Beklioglu and Moss (1996) observed that the phosphate and ammonium concentrations were unaffected by the presence or absence of macrophytes. Frankovich et al. (2011) opines that aquatic macrophyte distribution and growth are associated with nutrient rich environments particularly nitrate and phosphate which are noted to favour the growth of macrophytes. According to Sagova-Marekova et al. (2009) transformations and availability of phosphorus is largely controlled by the environmental conditions in the water, with pH and conductivity. Ratusshnyale, (2008) determines the macrophyte population and its link with ammonia and explains that, dumping of human and industrial waste in aquatic medium increases the availability of nutrient rich organic medium which can indirectly cause the increased production and growth of macrophytes. Bakker et al. (2013) concluded that macrophytes have the potential to reduce or increase nutrient levels in shallow lakes. In the present study there are two chances for relatively negatively correlations with nutrients and growth of macrophytes. Majority of macrophytes not attained or complete their life cycle due to alteration of land use patterns. Meager amount of nutrients used by plants in their flowering and fruiting period, as well as several fruits are big storage area of nutrients. Therefore plants couldn’t absorb higher amount of nutrients in growing stage this resultant to negative relation with nutrients. Second possibility was the paddy plants which absorb higher amount of nutrients in their growth period which result in decrease of availability of nutrients to other macrophytes. There was a negative correlation between the dissolved oxygen (DO) and chlorophyll *a* with macrophytes, for which Cohen (2003), reported that increase in dissolved oxygen concentration was noticed with the reduction in the macrophyte cover and vice versa.

Macrophytes diversity and richness studies about this wetland explain that station 1 is less diverse compared to station 4 and 5. The species such as *H. verticillata, U. aurea and H. aristata* appeared to be more dominant over other species in station 1. These dominant groups suppress the growth of other macrophytes, that leads to decrease in diversity and richness in station 1. The results of the present investigation corroborate with the findings of Uedeme et al. (2011), further opined that, monocular growth of species affect the community structure and diversity. According to McCann (2000) diversity can be an indication of increased stability of an ecosystem, which in turn depends on the ability of the community to contain groups that are capable of differential responses. The cluster and MDS orientations showed that paddy and channel phases were extremely different from wet and stable phases. Whereas in station wise evaluation significant differences were observed between stations 1 to 3 and stations 4 to 8. Station wise analysis of *K*-dominance curve it was shown that the cumulative dominance in the station 1 reached cumulative 100% and the most elevated curves of the dominance plot. Station 4 shows the deepest curve that reached cumulative 100%. Hence it can be concluded that station 1 has low species diversity and higher dominance and station 4 have higher species diversity of macrophytes. In phase wise evaluation diversity and richness was higher in wet phase. *K*-dominance curve shows that dominance of macrophytes were higher in wet and stable phases. This proves that there might be significant variations in plant community, composition, abundance and biomass in different phases.

Several species of macrophytes in this Kole land help the water fowl for nesting and in species like *N. pubescens* the large leaf of the plant act as place for rest and predation of small birds. When dewatering takes place, several migratory birds come to this wetland searching for their food in the macrophytes. Duck weed *L. purpusilla* itself is a food for fishes and herons. Floating weed *E. crassipes* inter phase of leaves and shoot of this plant always nestle spider web. This proves that majority of water plants interplay between different tertiary levels of communities. Venkateswarulu and Reddy (2000) and Jeppesen et al. (1998) observed that wetland vegetation provides breeding ground for different phytophagous fishes, molluscs and insects. Further, certain emergent species are known to occupy several habitat, tolerating fluctuating water level and undesirable condition and yet offering habitat for water fowls. Similar results were reported from Kole lands of Thrissur by Jayson and Sivaperuman (2005).

Ecologically speaking, rich species diversity of aquatic flora and weeds inhabiting in the Maranchery Kole wetland offers immense scope for studies on phytophysiology and taxonomy of macrophytes. The distribution pattern and diversity of aquatic vegetation is in response to temperature, depth, substratum, water quality and availability of inorganic plant nutrients. Gopal (1986), Sharma et al. (2001) have reviewed the Indian wetlands on the basis of ecology and productivity of aquatic angiosperms, based on their analysis macrophytes adaptability is greatly modified to phenophases under different ecophases or ecological conditions. A similar paradox exists so far as the distribution and diversity of aquatic vegetations in Maranchery Kole land. The negative or inhibitory influences of the species in this system also need to be investigated in detail. The maximum growth of one species which indirectly reduce the biomass of other species has been observed in different stations. In station 6 and 7 mat formation was noted by single species and this might be reduced the diversity of other species. Figure 6.14 represents mat formation by floating macrophyte *E. crassipes* in

Maranchery Kole lands. Sing (1976), Rai et al. (1995) observed similar situations in different lakes. They explained the situation, or possible reasons for reduced growth and retardation of the minor species. Due to mat formation by one species, penetration of light into deeper areas is decreased and there after the exchange of biogenic gases between air- water interface and other micro nutrients in the water column is affected. The detritus macrophytes and their role in nutrient exchange were not yet studied in this wetland. This investigation will help to assess the potential of aquatic productivity of this ecosystem.

Fig 6.14. Mat formation by floating macrophyte *E. crassipes* in Maranchery Kole wetland.

In general, the wetland exhibits an impressive array of all types of aquatic vegetations in all its major habitats. The littoral region playing host to different kinds of rooted, submerged, emergent and floating types of macrophytes in this wetland. The intense agricultural activities results in considerable fall and reduction in diversity and biomass of macrophytes in paddy phase, following the withdrawal of water for irrigation, coupled with changing water levels in the wetland. Channel phase of this wetland witness not only for reduction in the diversity and distribution of vegetation but also for the death and decay due to unfavourable conditions. Apart from offering rich and variety of food, nesting and roosting sites for vertebrates like, aquatic birds, pisces and invertebrates like aquatic and non aquatic insects, several species of macrophytes are found to be excellent fodder for cattle and also utilized in the preparation of medicines.

Table 6.7. Pearson Correlation analysis between aquatic macrophytes and environmental parameters in Maranchery Kole wetland.

	Depth																	
Plant biomass	.520**	**Plant biomass**																
Water emperature	.308**	.514**	**Water temperature**															
Air temperature	.251**	.270**	.850**	**Air temperature**														
pH	.121	.190**	-.023	-.051	**pH**													
Conductivity	.114	-.053	.244**	.278**	-.053	**Conductivity**												
TDS	-.045	-.133	.197**	.206**	-.120	.916**	**TDS**											
Turbidity	-.310**	.265**	-.116	-.145*	-.013	-.024	.061	**Turbidity**										
DO	.016	-.030	.168*	.200**	.142*	-.162*	-.145*	-.157*	**DO**									
NO$_2$-N	-.183*	-.095	-.101	-.009	-.085	.000	.105	.130	-.007	**NO$_2$-N**								
NO$_3$-N	.069	-.042	-.086	.000	.114	-.169*	-.184*	-.178*	.080	-.090	**NO$_3$-N**							
NH$_3$-N	-.278**	-.359**	.007	.084	-.413**	.221**	.242**	.151*	-.089	.125	-.080	**NH$_3$-N**						
SiO$_3$-Si	-.078	.051	-.081	-.067	.305**	.156*	.176*	.007	.075	.021	-.173*	-.034	**SiO$_3$-S**					
Po$_4$-P	-.204**	-.166*	-.019	-.093	.066	-.067	.040	.083	.225**	.262**	-.069	-.050	.076	**Po$_4$-P**				
Chl a	.035	-.047	.320**	.320**	.070	.392**	.390**	.067	.012	.136	-.141	-.029	.065	.138	***Chl a***			
Chl b	.077	-.074	.027	.052	-.127	.195**	.173*	.000	.051	-.059	-.029	.120	-.101	-.105	.103	***Chl b***		
Mg	.123	.162*	.065	.102	-.147*	.247**	.230**	.048	.019	.008	-.007	.129	-.152*	-.065	.231* *	.650**	***Mg***	
Rainfall	.245	.433*	-.013	.426	.332	-.167	.198	.231	.110	.245	.764*	-.155	1	.030	-.225	.122	.116	**Rain fall**

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

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

* * *

Chapter - 7

STANDING STOCK OF MACROINVERTEBRATES

7.1 Introduction

Wetland is a home for some of the fascinating organisms comprising an immensely complex diversity of life that thrives in aquatic macrophytes and is several times higher than that of soil, water and other substrates (Olson et al., 1999). The activities of macroinvertebrates contribute to the maintenance of the ecosystems by their influence on water, soil and food chain (Ruiz et al., 2006). There are several hundreds of species of macroinvertebrates within a square meter, especially aquatic insects, which are associated with the community of macrophytes. Many of them act as agents of nutrient cycling by regulating the retention and flux of nutrients in the wetland ecosystems through processes of decomposition, mineralization and immobilization.

Studies have indicated that different species of macrophytes typically support difference in assemblage, abundance and number of species of macroinvertebrates (Hejny, 1971). This has often been attributed to differences in the structure of macrophytes, resulting in differences in the surface area or the number of microhabitats available to invertebrates. Changes in water level and significant changes in environmental variables are suggested as factors influencing the numerical abundance of invertebrate fauna in the littoral zone of the wetland ecosystem (Horn, 1979). It is important that species of macroinvertebrates are not evenly distributed across species of macrophyte. Also hydrological regime its influence on macrophytes and the habitat of macroinvertebrates play an integral part in determining the abundance, richness and assemblage of invertebrates in a wetland ecosystem.

Several authors have worked out on the diversity and distribution of benthos and other invertebrates on soil and water column of an aquatic body. But the importance of macrophytes as a habitat for macroinvertebrates and their interaction in an ecosystem recognized very recently. Studies conducted in early forties to nineties have disclosed that, species richness, density and assemblage of macroinvertebrates associated with macrophytes, typically vary with the species of macrophytes (Berg, 1938; Mcgaha, 1952; Krull, 1970; Barry, 1974; Soszka, 1975; Gerrish and Bristow 1979; Stoner and Lewis, 1985; Schramm et al., 1987; Cyr and Downing, 1988; Chilton, 1990). Crowder and Cooper, (1982) and Minshall, (1984) studied the macrophytes and its relation with fishes as well as macroinvertebrates. Mastrantuono (1991) carried out a study regarding zoobenthos associated with submerged macrophytes at three depth intervals (0-3m, 3-6 m, 6-10 m), in cultivated lands. Cattaneo et al. (1998) reported about epiphytic algae and macroinvertebrates on submerged and floating–leaved macrophytes in an Italian lake. Cheruvelil et al. (2002) focused on the role of an exotic dissected macrophyte over macroinvertebrates. Effects of macrophytes on assemblage of epiphytic macroinvertebrate in sandy lake, Pennsylvania were studied by Baron and Ostrofsky, (2010). Edgar et al., (2004); Habib and Yousuf, (2015); Wolters et al., (2017) specified that macroinvertebrates are chiefly associated with different species of macrophytes.

The following studies were closely associated with a specific species of macrophytes and their relation with macroinvertebrates. Lillie and Budd (1992) in *Myriophyllum spicatum*; Van den Berg et al. (1997) in dense chara vegetation; Linhart (1999) in *Stratiotes aloides* vegetation; Toft et al. (2003) in water hyacinth; Strayer et al. (2003) in native species *Vallisneria americana* and an alien species *Trapa natans*; Kornijow et al. (2010) studied plant *Trapa natans*. Martin and Neely (2001) contributed response of benthic macroinvertebrate to sedimentation in a *Typha angustifolia*. Copeland et al. (2012) examined the diversity of chironomidae associated with plant *Hydrilla verticillata*.

Despite significant contribution of macrofauna to global biodiversity, our knowledge of aquatic vegetation and associated macroinvertebrates is still poor. The functional specificity of common macroinvertebrates is even not known to us. These organisms respond to different environmental variables and thus they are important indicators of aquatic health (Lalonde and Downing, 1992). Keeping in view of the role of macroinvertebrates in perennial wetlands, it is therefore, very important to study their abundance and distribution in different land use systems in relation to various aquatic macrophytes for better understanding and functioning of a wetland ecosystem.

7.2 Results

7.2.1 Numerical abundance of total macroinvertebrates

The numerical abundance of macroinvertebrates groups in eight stations are given in Fig. 7.1. The station wise comparison showed that, station 6 had the maximum mean numerical abundance (117 No./m^2) while station 4 has the lowest (66 No./m^2). In month wise analysis the average numerical abundance of the macroinvertebrates showed the maximum value in February 2012 (4240No./m^2) and the lowest numerical abundance was recorded in November 2010 (672No./m^2) (Fig. 7.2). In the month of December 2010 there was another peak variation in abundance that was noticed and after that it continues to decrease in abundance during January 2011 to June 2011 period. From October 2011 to March 2012 period there was increase and decrease of macroinvertebrates abundance recorded, after that from April 2012 to July 2012 a gradual decline of macroinvertebrates was recorded. When the mean numerical abundance was compared among the wet, paddy, channel and the stable phases, the channel phase showed the minimum numerical abundance (38 No./m^2) and wet phase showed the maximum numerical abundance (70 No./m^2) (Fig. 7.3). In paddy phase, the total abundance was (53 No./m^2) and in stable phase (39 No./m^2). ANOVA results showed that there was a significant variation in abundance at 5% level between stations ($P<0.05$) and between phases ($P<0.05$) in the wetland.

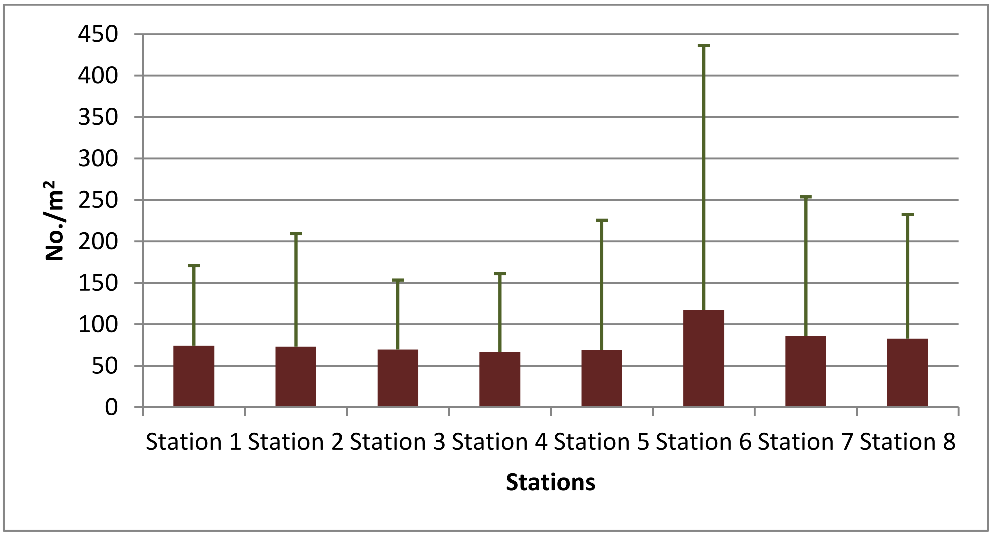


Fig. 7.1. Mean variation of macroinvertebrates in eight stations in Maranchery Kole wetland during the study period.

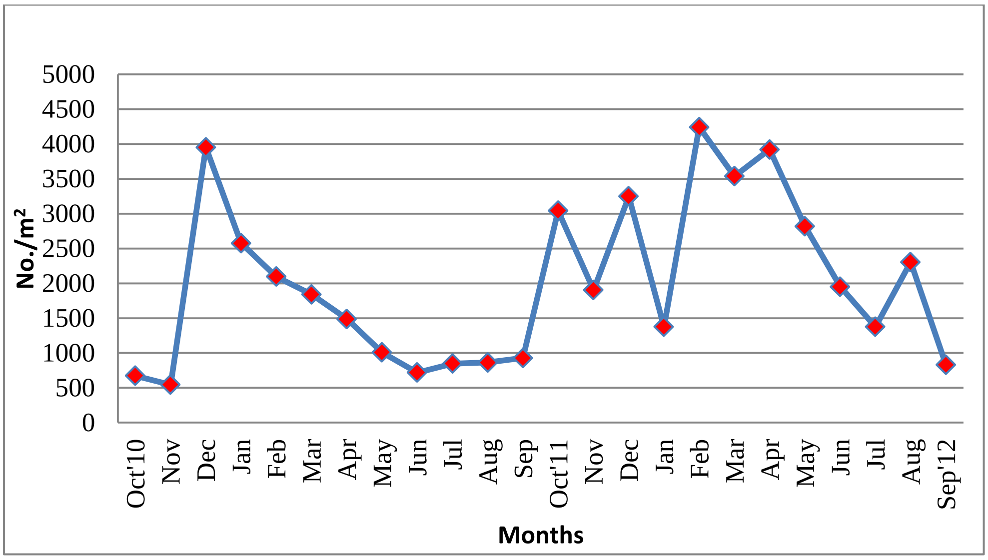


Fig. 7.2. Monthly mean variations in numerical abundance of macroinvertebrates in Maranchery Kole wetland during the study period.

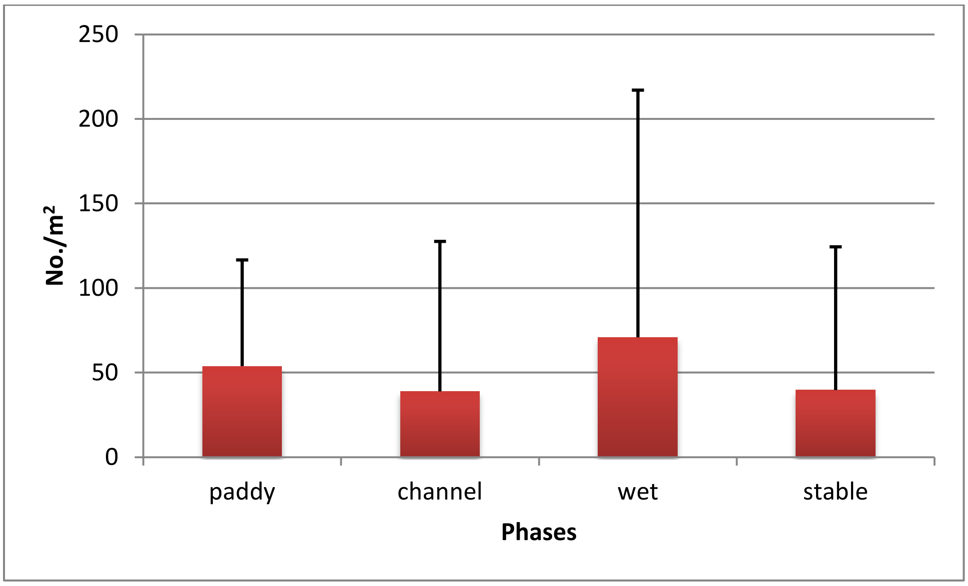


Fig. 7.3. Phase variations in numerical abundance of macroinvertebrates in Maranchery Kole wetland during the study period.

7.2.2 Numerical abundance of aquatic insects

The numerical abundance of aquatic insects in eight stations was plotted in Fig. 7.4. The station wise comparison showed that, station 6 had the maximum mean numerical abundance (175 No./m^2) and in station 1 shows the least numerical abundance (100 No./m^2). In month wise analysis the average numerical abundance of the aquatic insects showed the maximum value in February 2012 (475 No./m^2) and the lowest numerical abundance was recorded in July 2011 (48No./m^2) (Fig. 7.5). Gradual increase of numerical abundance from May 2010 to October 2011 period was noted. Mean variations in numerical abundance was compared among the wet, paddy, channel and the stable phases, the paddy phase showed the maximum numerical abundance (380.6No./m^2) followed by channel (213.3No./m^2), wet (124.17 No./m^2), and stable phase (43.69 No./m^2) (Fig.7.6). Correlation analysis between numerical abundance of aquatic insects and macrophyte biomass were plotted in eight different stations in Maranchery wetland (Figs. 7.7 to 7.14).

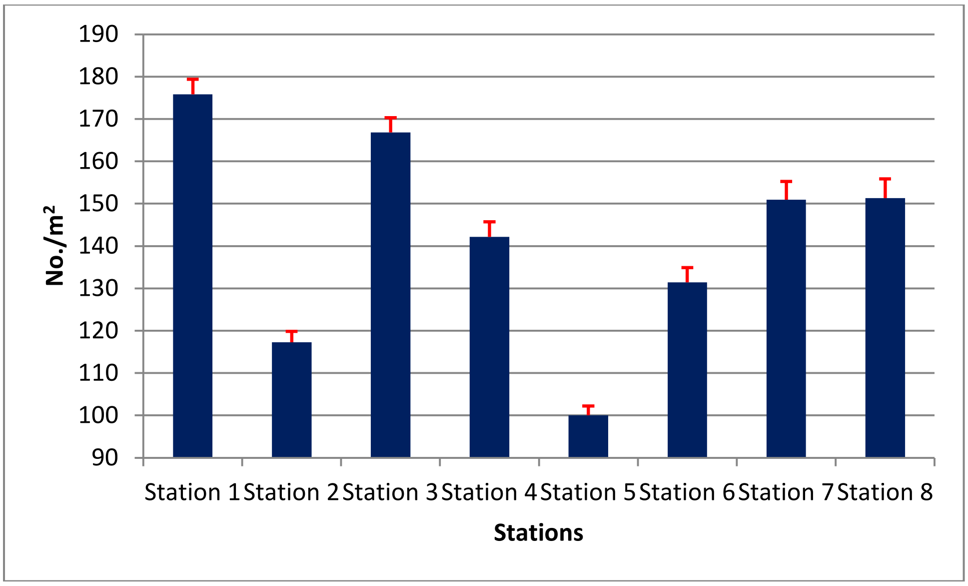


Fig. 7.4. Mean variation of aquatic insects in eight stations of Maranchery Kole wetland during the study period.

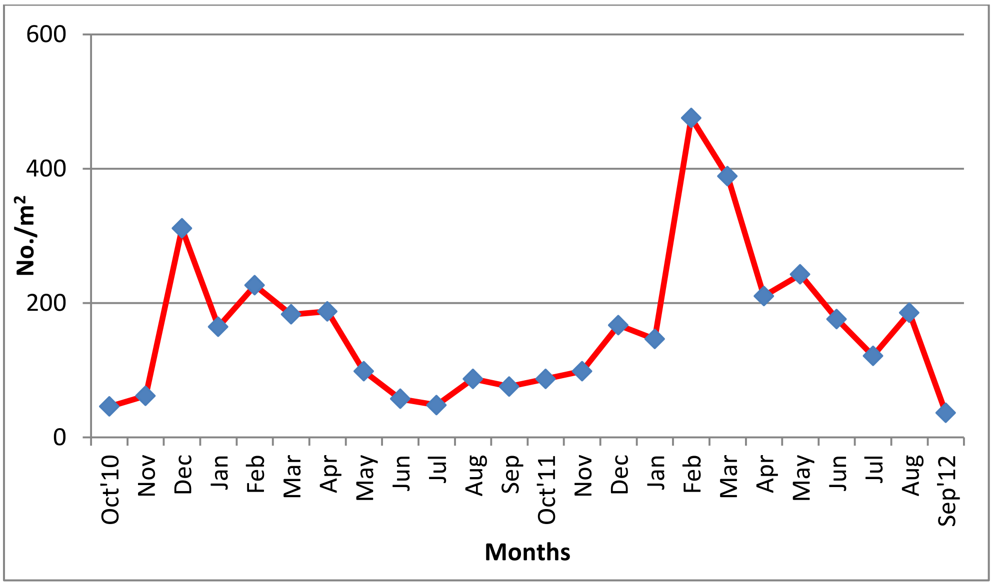


Fig. 7.5. Monthly mean variations of numerical abundance of aquatic insects in Maranchery Kole wetland during the study period.

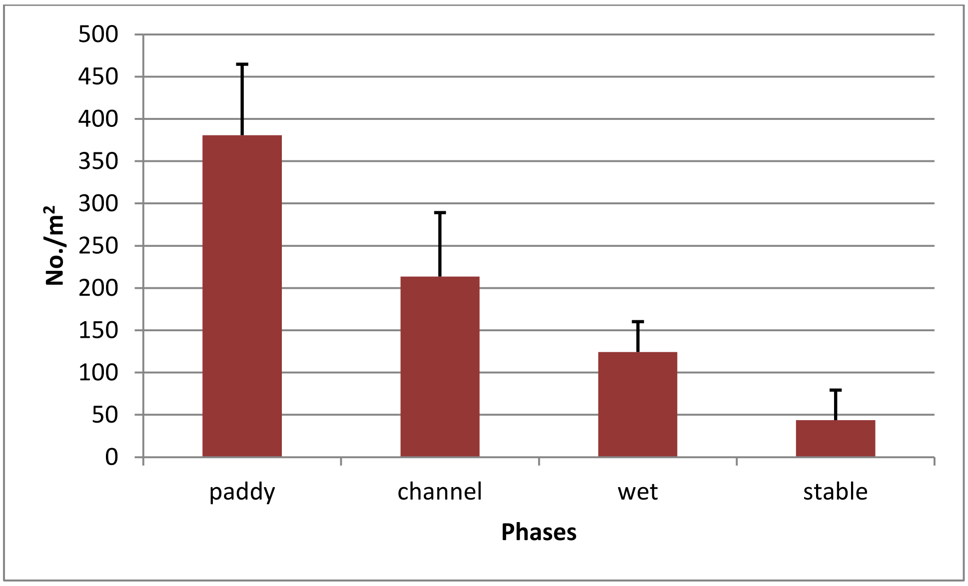


Fig. 7.6. Phase wise variations of numerical abundance of aquatic insects in Maranchery Kole wetland during the study period.

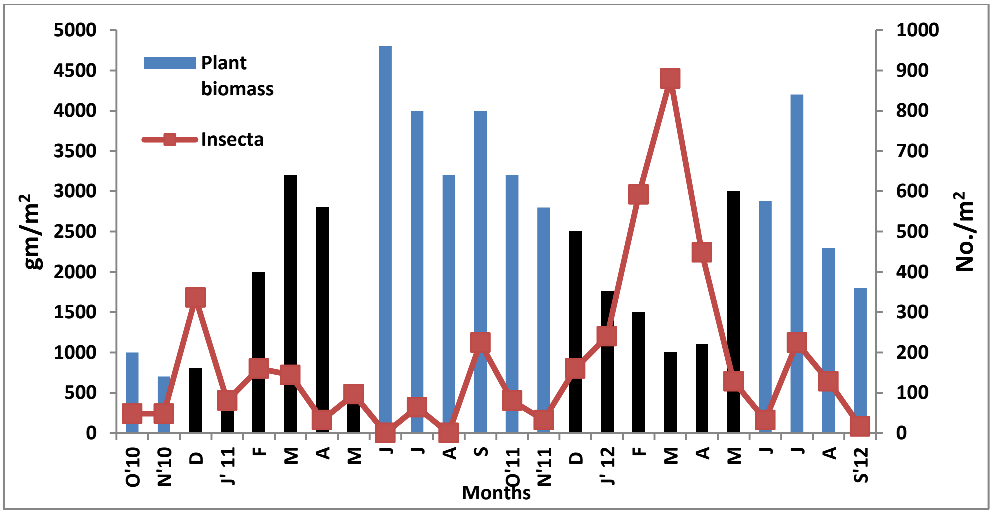


Fig. 7.7. Aquatic insects and its relation with macrophytes in station 1 in Maranchery Kole wetland during the study period.

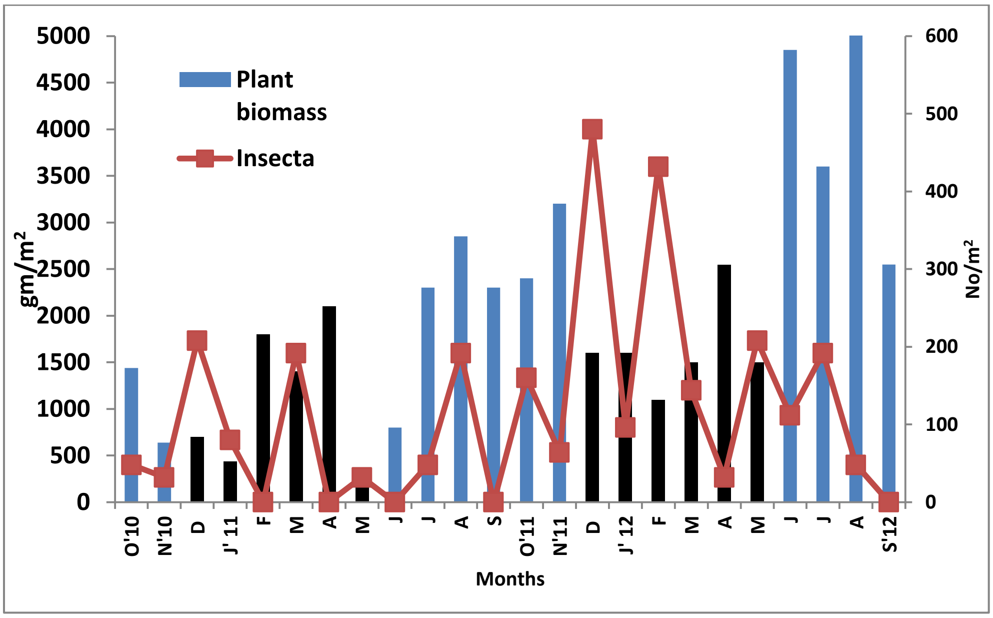


Fig. 7.8. Aquatic insects and its relation with macrophytes in station 2 in Maranchery Kole wetland during the study period.

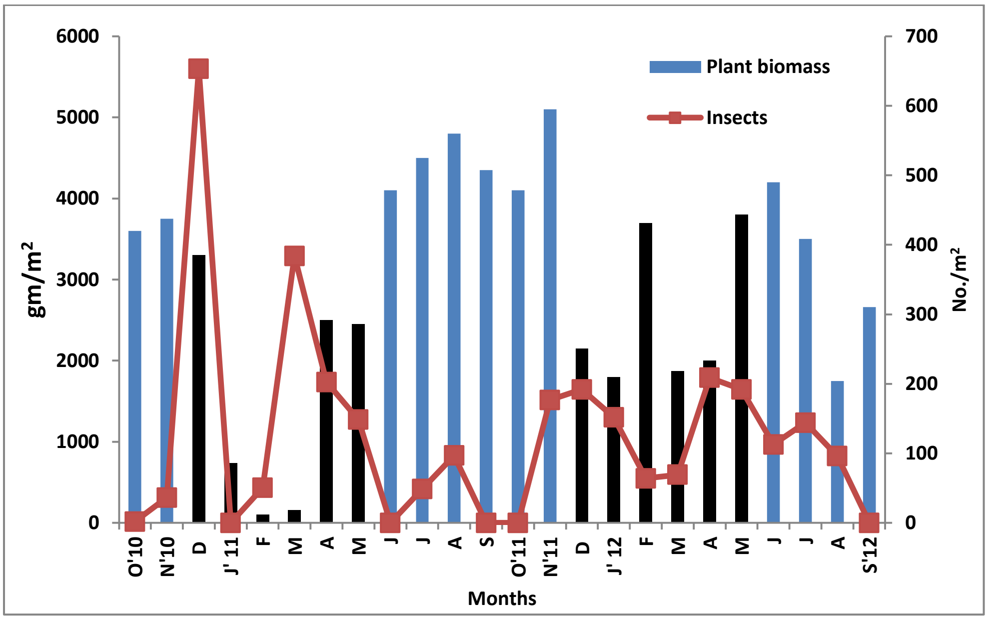


Fig. 7.9. Aquatic insects and its relation with macrophytes in station 3 in Maranchery Kole wetland during the study period.

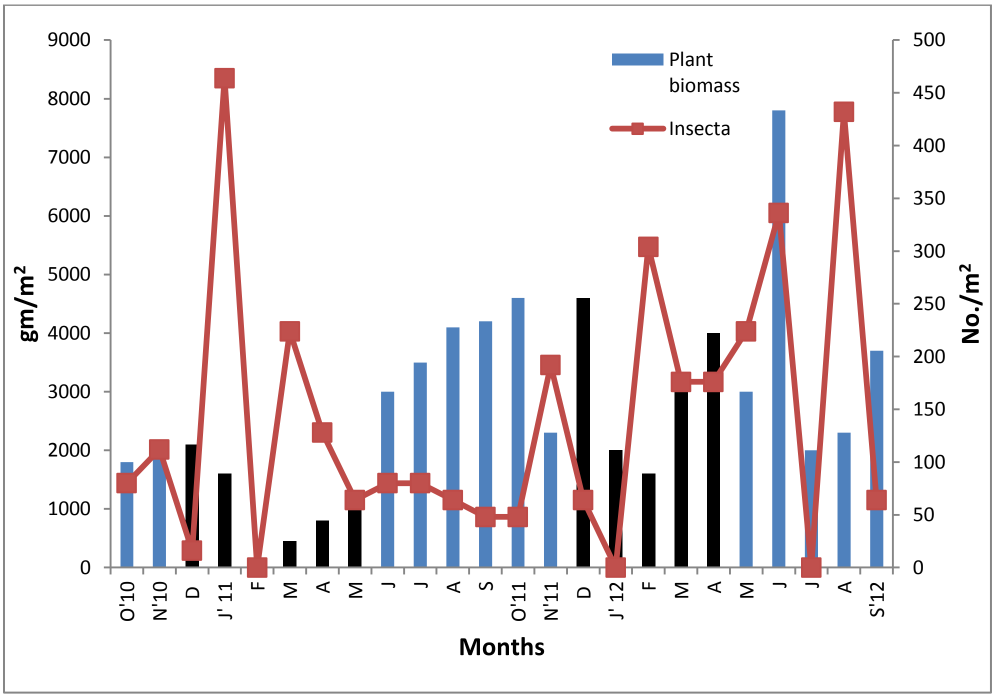


Fig. 7.10. Aquatic insects and its relation with macrophytes in station 4 in Maranchery Kole wetland during the study period.

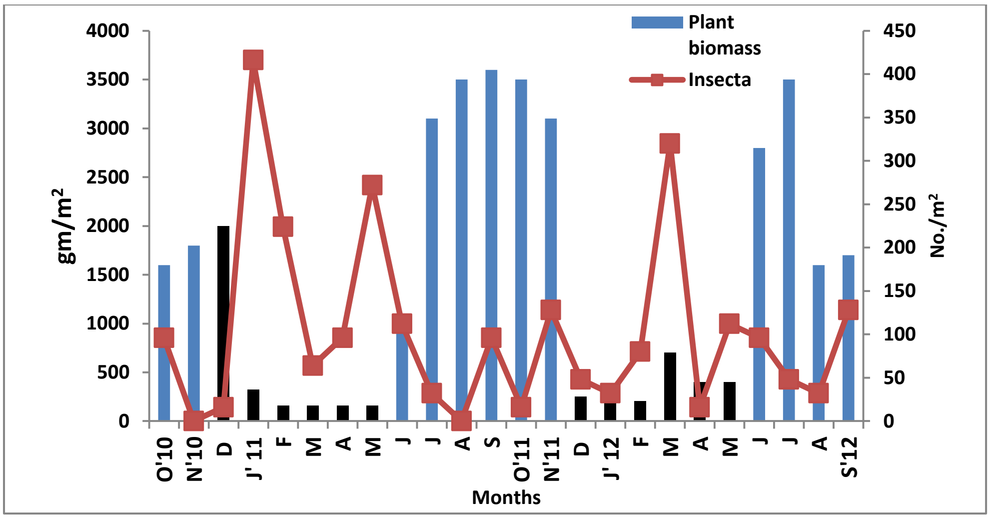


Fig. 7.11. Aquatic insects and its relation with macrophytes in station 5 in Maranchery Kole wetland during the study period.

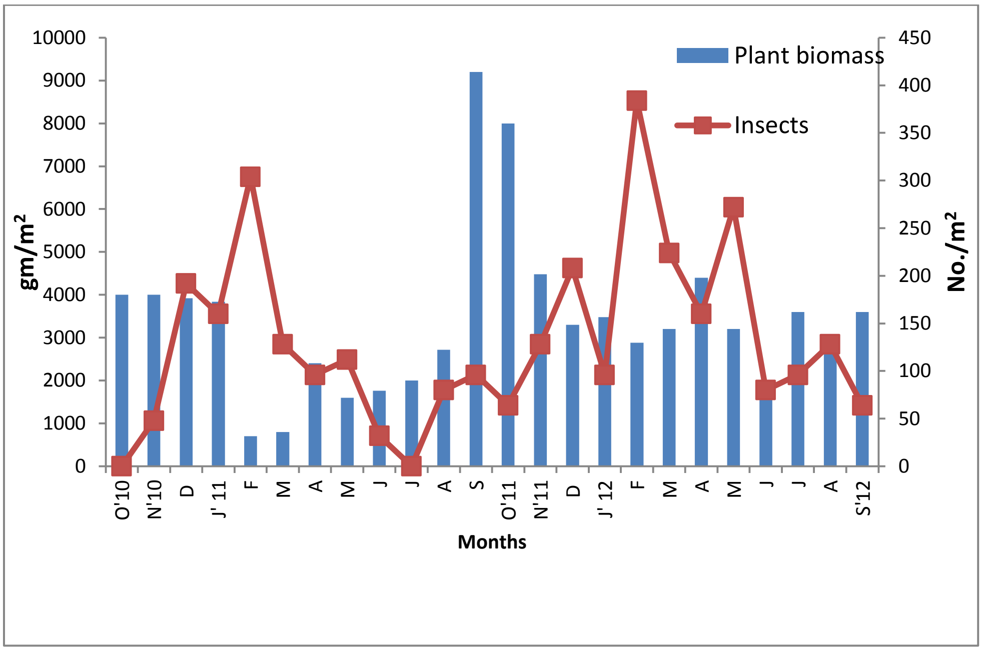


Fig. 7.12. Aquatic insects and its relation with macrophytes in station 6 in Maranchery Kole wetland during the study period.

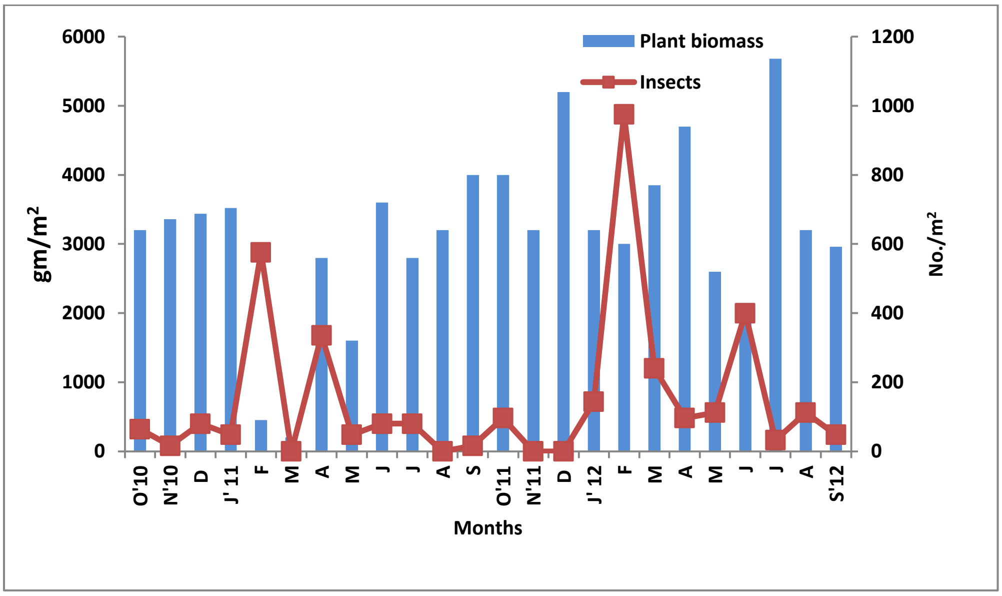


Fig. 7.13. Aquatic insects and its relation with macrophytes in station 7 in Maranchery Kole wetland during the study period.

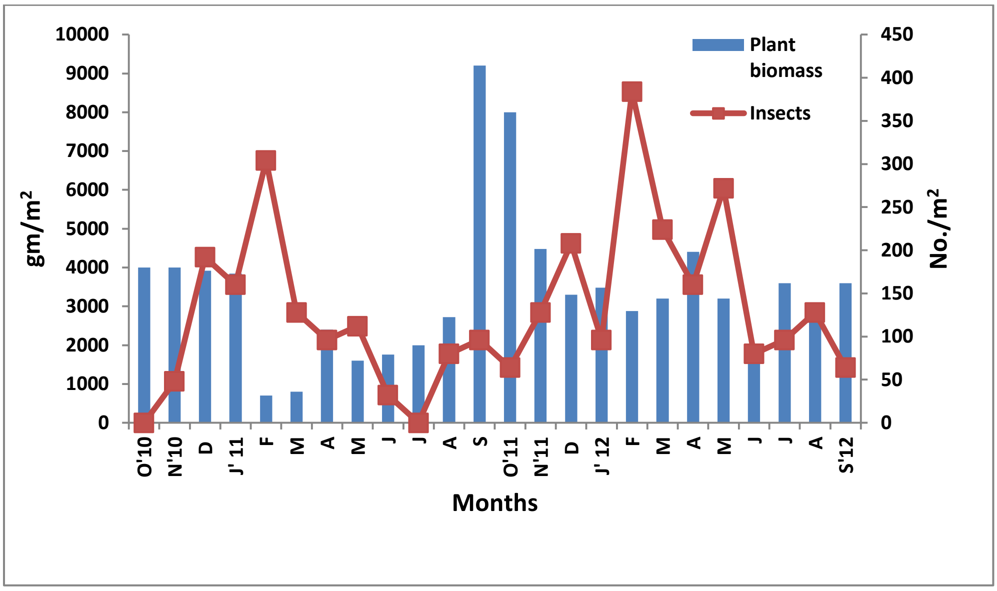


Fig. 7.14. Aquatic insects and its relation with macrophytes in station 8 in Maranchery Kole wetland during the study period.

Numerical abundance of aquatic insects in further 7 orders was represented in Figs. 7.15 to 7.28. The major orders observed in the wetland were Ephemeroptera, Odonata, Hemiptera, Trichoptera, Lepidoptera, Coleoptera, and Diptera. Different orders are dominating and associated with various macrophytes in eight study stations. In station wise analysis, the average numerical abundance of Order Ephemeroptra showed the maximum value in station 8 (39 No./m^2) and the lowest numerical abundance was recorded in stations 1 and 4 (2.7 No./m^2). Odonata showed the highest value in station 6 (28No./m^2) and the least numerical abundance was recorded in station 2 (10 No./m^2). The range of Hemiptera was from 25.3 No./m^2 to 3.3 No./m^2 and it showed the highest value in station 3 and the least abundance was in station 8 No./m^2. In the case of Trichoptera, station 2 showed the highest numerical abundance of 9.3 No./m^2 and lowest of 2.0 No./m^2 in stations 4 and 6. Lepidoptera abundance, fluctuated from a maximum of 17.3 No./m^2 in station 7 and a minimum of 4 No./m^2 in station 2. Coleoptera was widely distributed in eight stations. Abundance was maximum in station 7 (46.2 No./m^2) and minimum was in station 2 (19.9 No./m^2). Dipterans varied between 99.3 No./m^2 to 26.7No./m^2. Station 1 showed higher values whereas station 7 had lowest abundance. In phase wise comparisons of different orders, Trichoptera (8 No./m^2) and Coleoptera (85.3 No./m^2) were abundant in channels, Diptera(75.6 No./m^2) and Ephemeroptera (24 No./m^2) were abundant in paddy phase, Hemiptera(10.7 No./m^2) and Odonata(24.0 No./m^2) were comparatively higher in wet phase, and only Lepidoptera shows wider distribution patterns. ANOVA results showed that there was a significant variation in abundance at 1% level between stations (P<0.01).

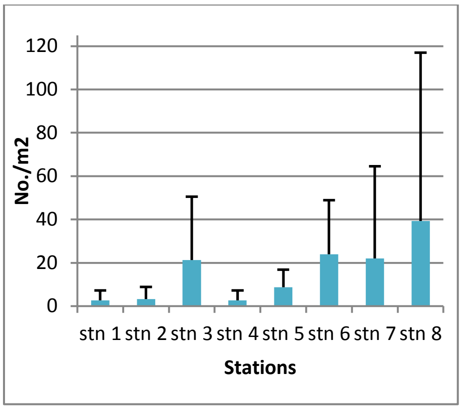


Fig. 7.15. Station wise variations in numerical abundance of order Ephemeroptera in Maranchery Kole wetland during the study period.

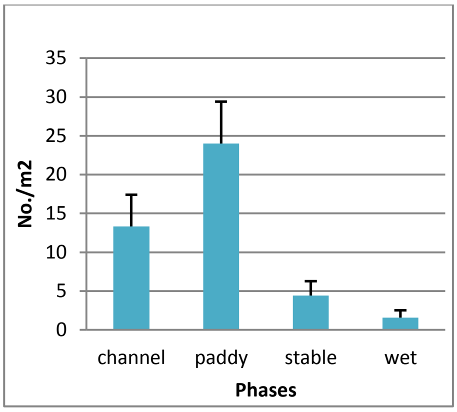


Fig. 7.16. Phase wise variations in numerical abundance of order Ephemeroptera in Maranchery Kole wetland during the study period.

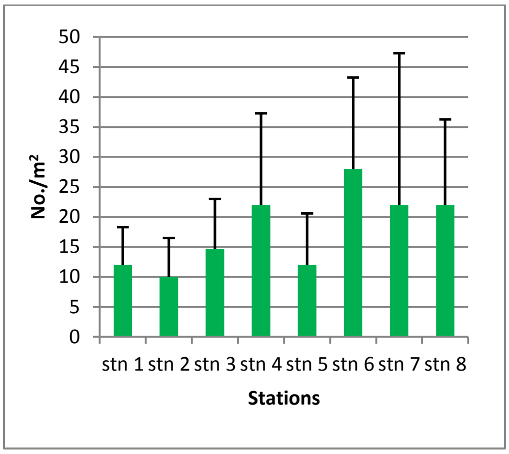


Fig. 7.17. Station wise variations in numerical abundance of order Odonata in Maranchery Kole wetland during the study period

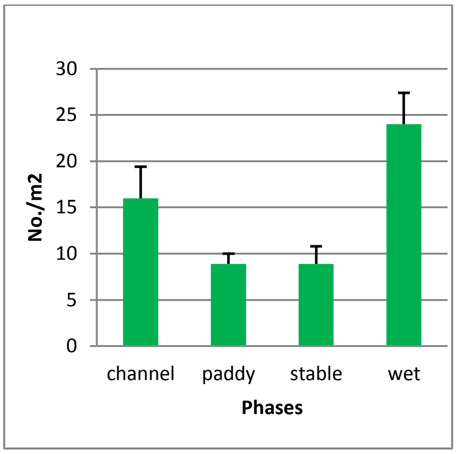


Fig. 7.18. Phase wise variations in numerical abundance of order Odonata in Maranchery Kole wetland during the study period.

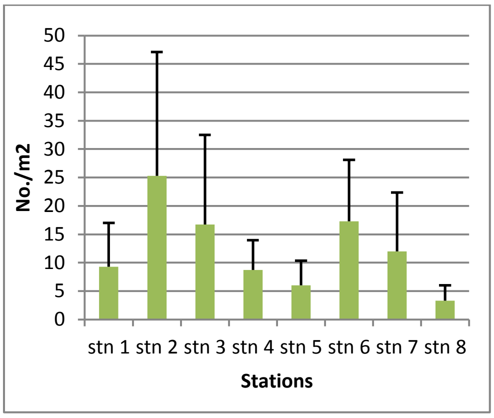


Fig. 7.19. Station wise variations in numerical abundance of order Hemiptera in Maranchery Kole wetland during the study period.

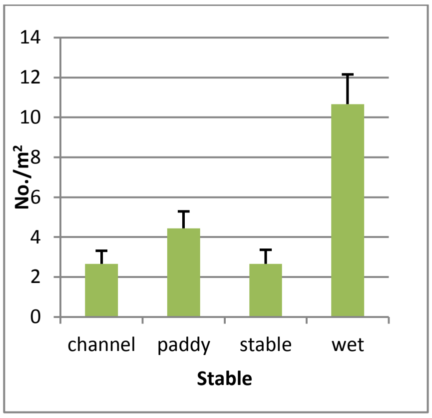


Fig. 7.20. Phase wise variations in numerical abundance of order Hemiptera in Maranchery Kole wetland during the study period.

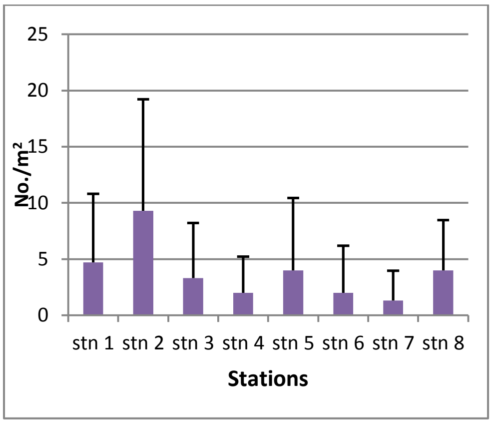


Fig. 7.21. Station wise variations in numerical abundance of order Trichoptera in Maranchery Kole wetland during the study period.

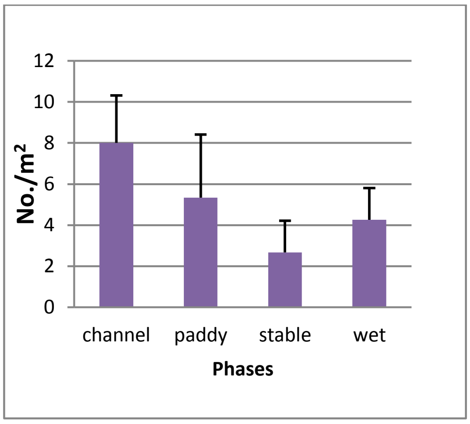


Fig. 7.22. Phase wise variations in numerical abundance of order Trichoptera in Maranchery Kole wetland during the study period.

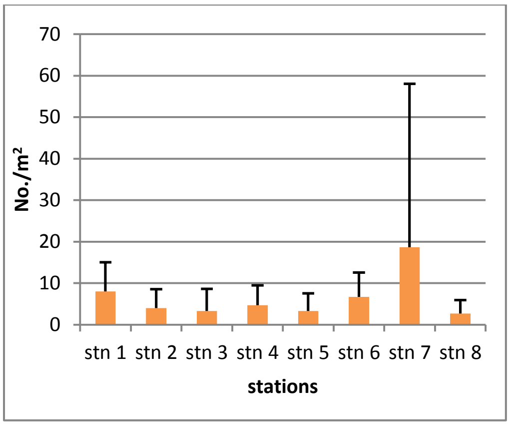


Fig. 7.23. Station wise variations in numerical abundance of order Lepidoptera in Maranchery Kole wetland during the study period.

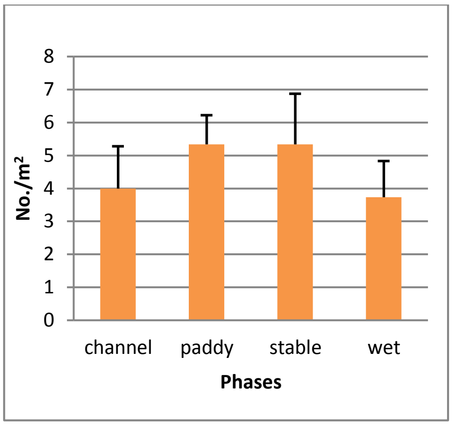


Fig. 7.24. Phase wise variations in numerical abundance of order Lepidoptera in Maranchery Kole wetland during the study period.

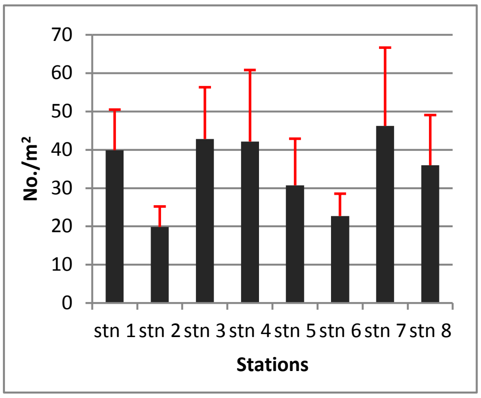


Fig. 7.25. Station wise variations in numerical abundance of order Coleoptera in Maranchery Kole wetland during the study period.

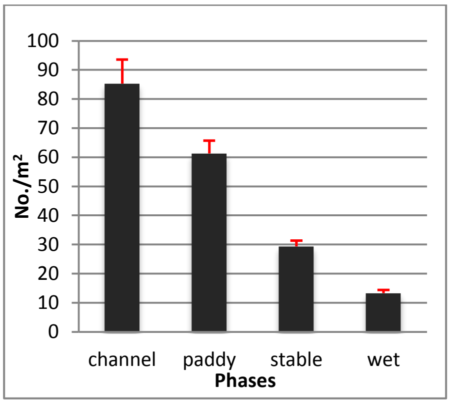


Fig. 7.26. Phase wise variations in numerical abundance of order Coleoptera in Maranchery Kole wetland during the study period.

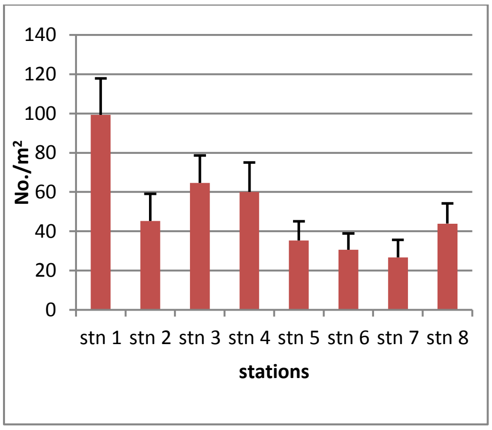


Fig. 7.27. Station wise variations in numerical abundance of order Diptera in Maranchery Kole wetland during the study period.

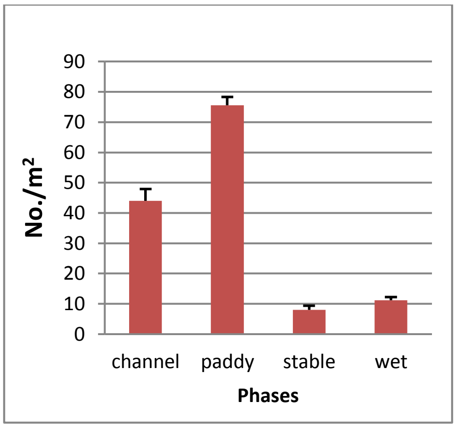


Fig. 7.28. Phase wise variations in numerical abundance of order Diptera in Maranchery Kole wetland during the study period.

7.2.3 Numerical abundance of different groups of macroinvertebrates

Station wise mean variations of different group of macroinvertebrates are given Table 7.1. The maximum numerical abundance of Euhirudinea recorded was 26.7No./m^2 in station 6 and minimum was in station 2 (6.7 No./m^2). Station 2 showed the maximum numerical abundance of molluscs (36.7No./m^2) and was least in station 7 (3.3No./m^2). Branchiopods had higher abundance in station 7(46.7No./m^2) and lowest in station 5 (2 No./m^2). In station 8 decapods was dominated (37.3No./m^2) and minimum was in station 1(1.3 No./m^2). The maximum abundance of arachnids was recorded in station 5 (47.3 No./m^2) and minimum in station 2 (13.3No./m^2). Nematodes was present in stations 1 and 7 very few in numbers (0.7No./m^2). Oligochaete abundance was maximum in station 1 (3 No./m^2) and completely absent in stations 5 and 6. Isopods contributed very few numbers in stations 6, 7 and 8. Fish fingerlings was seen in stations 2 to 6 and it was nil in stations 1, 7 and 8. Ostracods collected from all the seven study stations except from station 8. Numerical abundance of Ostracods was maximum in station 7(12.67 No./m^2) and minimum in stations 3 and 5 (2 No./m^2).

In phase wise comparison of different groups of macroinvertebrates in Maranchery wetland showed lower abundance in channel phase (Table 7.2). Nematodes was present only in paddy phase (0.89 No./m^2) and it was absent in other three phases. Molluscs and arachnids were present in all the four phases whereas oligochaetes, euhirudinea, ostracods, branchiopods and isopods were absent in channel phase. In paddy phase, the abundance was comparatively higher in the case of oligochaetes (1.78 No./m^2) followed by stable (0.89 No./m^2) and wet phases(0.53 No./m^2). Euhirudinea (13.33 No./m^2), arachnids(21.30 No./m^2) and ostracods (2.22 No./m^2) had the highest abundance in stable phase. Branchiopods showed a declining pattern of abundance among wet, stable followed by paddy phases. In wet phase it was 16 No./m^2, stable (12.44 No./m^2) and paddy phase (3.56 No./m^2) respectively. Pisces (fish fingerlings) were collected during channel and paddy phases, and the abundance was higher during channels of the Kole wetland (1.33 No./m^2).

Table 7.1. Mean variation of macroinvertebrates in eight stations in Maranchery Kole wetland during the study period(No./m^2).

Stations / Group	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
	Mean±S.D	**Mean±S.D**	**Mean±S.D**	**Mean±S.D**	**Mean±S.D**	**Mean±S.D**	**Mean±S.D**	**Mean±S.D**
Insecta	175.9±3.5	117.2±2.6	166.8±3.5	142.1±3.6	100.0±2.2	131.4±3.5	150.9±4.3	151.3±4.5
Nematoda	0.7±3.3	0	0	0	0	0	0.7±0.3	0
Oligochaeta	1.3±4.5	0	0.7±3.0	0.7±3.0	0	0	0.7±3.0	0.7±3.0
Euhirudinea	8.7±14.9	6.71±6.3	7.3±14.1	15.3±25.6	14.0±53.2	26.7±51.0	21.3±37.1	13.3±24.8
Mollusca	8.0±6.7	36.7±160.4	9.3±27.5	12.0±36.8	8.0±20.3	11.3±32.2	3.3±11.9	12.0±27.5
Ostracoda	0.67±0.0	6.0±18.4	2.0±9.8	4.0±19.6	2.0±7.2	8.0±31.1	12.67±41.6	0
Branchiopoda	21.3±42.4	25.3±69.5	7.3±17.6	14.7±29.8	2.0±7.2	83.3±273.1	46.7±141.2	24.7±50.8
Isopoda	0.7±3.3	0	0	0	0	2.0±5.4	0.7±3.3	2.7±13.1
Decapoda	1.3±3.2	23.3±0.3	9.3±3.3	4.7±6.5	38.0±0.5	79.3±8.9	18.0±302.2	37.3±0.5
Arachnida	15.3±17.0	13.3±30.3	16.0±40.4	14.7±37.3	47.3±116.9	25.3±80.3	15.3±31.3	19.3±41.9
Pisces	0	0.7±3.0	0.7±3.0	0.7±3.1	0.6±3.5	0.7±3.0	0	0

Table 7.2. Phase wise variation of macroinvertebrates in Maranchery Kole wetland during the study period(No./m^2).

Phases / Group	Paddy	Channel	Wet	Stable
	Mean±S.D	**Mean±S.D**	**Mean±S.D**	**Mean±S.D**
Insecta	380.6±83.85	213.3±75.89	124.17±35.87	43.69±35.52
Nematoda	0.89±3.77	0	0	0
Oligochaeta	1.78±5.17	0	0.53±0	0.89±3.77
Euhirudinea	5.33±12.27	0	17.6±2.92	13.33±24.08
Mollusca	3.56±10.15	32.00±11.15	12.98±78.67	5.63±12.87
Ostracoda	0.44±3.77	0	1.33±0.00	2.22±8.19
Branchiopoda	3.56±8.77	0	16.0±58.68	12.44±37.85
Isopoda	0	0	0	3.56±15.08
Decapoda	0	25.33±107.58	3.20±12.77	2.67±9.75
Arachnida	7.11±21.79	8.67±16.33	10.67±22.75	21.30±55.69
Pisces	0.89±3.77	1.33±4.62	0	0

7.2.4 Multivariate analysis

7.2.4.1 *k*-dominance curve

In this graphical representation, macroinvertebrate species are ranked in the cumulative contribution of each of these to the total density of this wetlands. The *k*-dominance curve determines the inherent diversity, and in this graph the lower lines represent samples with higher diversity. Present investigation, multiple *k*-dominance plots were constructed for aquatic insects on the basis of station wise and phase wise abundance. Fig. 7.29 and 7.30 represents the station wise and phase wise cumulative dominance curve of Maranchery Kole wetlands. The station wise plots implied that, station 7 would have a low species density index compared to other stations. In phase wise comparisons, paddy phase shows higher abundance of insects and channel phase indicates lower abundance of insect population.

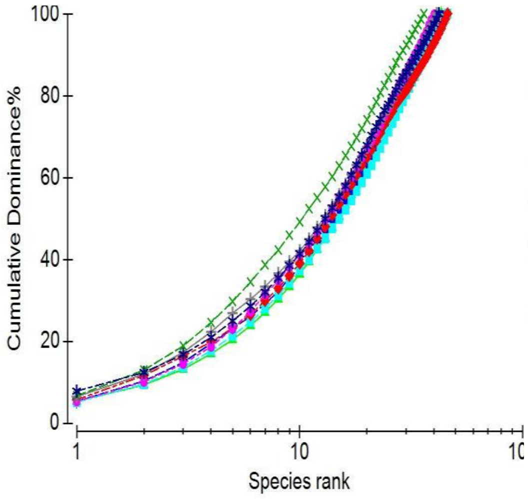


Fig. 7.29. Station wise *K*-dominance curve in Maranchery Kole wetland during the study period.

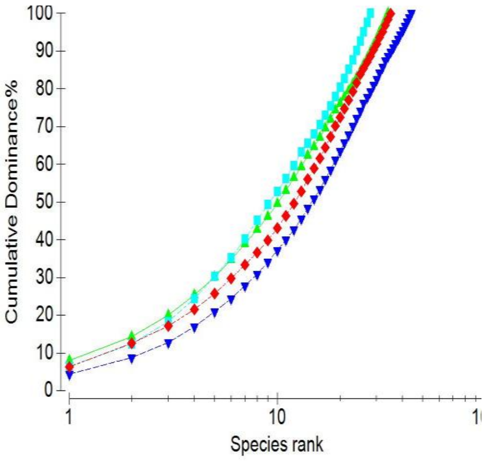


Fig. 7.30. Phase wise *K*-dominance curve in Maranchery Kole wetland during the study period.

7.3 Discussion

From the literature survey, very little information is known about the macroinvertebrate faunal community associated with macrophytes inhabiting in Indian wetlands. A few limnological studies have been done on macrobenthos in different types of wetlands but they have not mentioned the importance of macrophytes and its role in invertebrate assemblages. Maranchery wetlands offer dynamic system with diverse group of macrophytes and this leads to a complex food chain. Community of macrophytes offers suitable surface area for shelter, a spot for oviposition, development and resting and nesting ground for macroinvertebrates. Apart from a good ambient weather, it offers hiding places for pisces and other aquatic life. Needham (1929) opined that macroinvertebrates living on macrophytes were more abundant than those living in base sediments. According to Kirby and Ringler (2015), during daylight, the aquatic vegetation contributes to enrich the dissolved oxygen content of water and harbours a wide variety of macroinvertebrates.

Macroinvertebrate species are adapted to live in a particular “niche” in the community. In short, the environmental factors which govern the distribution, abundance and density of aquatic insects especially the dipterans are climate, physical and chemical condition of habitat, hosts and enemies and completion in some cases (Parsons and Matthews, 1995). Jayson and Sivaperuman (2005) explained that migratory birds in Trichur Kole lands grab international importance and this wetland in Kerala comes under Central Asian- Indian flyway. Wissinger (1999), Batzer et al., (2004); Rodríguez-Pérez and Green, (2012) reported that benthic macroinvertebrates form an important source of food for water birds. Therefore, the standing stock of macroinvertebrates in this wetland is closely associated with avian fauna.

For studying the aquatic invertebrates, the aquatic macrophytes were selected from different stations of this wetland were dominated by *Hydrilla verticillata* in station 1, *Limnophyla heterophylla* in Station 2, *Utricularia aurea* in station 3, *Nymphaea pubescens* in station 4, *Nymphoides indicum* in station 5, *Eichhornia crassipes* in station 6, *Salvinia molesta* in station 7 and *Ludwigia adscendens* in station 8. From the present investigations it is found that the standing stock of macroinvertebrates was varied largely due to the presence or absence of insect fauna. The dominant macrophytes present were *H. verticillata* and *U. aurea*, the percentage coverage and height of each macrophyte species in each enclosure was varied. Therefore, the assemblages of macroinvertebrates were totally varied according to the macrophyte bed. The presence or absence of submerged macrophytes also has a major impact on the structure of the phyto and zooplankton community observed by Per Schriver et al. (1995). According to Eadie and Keast, (1984) and Nohner (2107) macrophytes are termed as keystone structure in fresh water habitat and small scale changes of macrophytes inevitably lead to tremendous changes in the biodiversity.

In Maranchery wetland, station 6 shows higher abundance of macroinvertebrates compared to other stations. The plant *E. crassipes* has highly favoured the growth of branchipods, arachnids, euhirudinea and decapods in this station. Station 7 also contributed larger number of macro invertebrates like decapods and branchiopods apart from aquatic insects in the biocenosis of *S. molesta*. Majority of these crustaceans are filter feeders or detritus feeders. The root system of these plants has created a good niche for these organisms as well as plants absorb organic compounds and stored in their fruiting bodies offering a source of food. The vegetation supported relatively more gastropods, water mites, oligochaetes, euhirudinea, branchiopods, damselfly and dragonfly larvae, true bugs, aquatic moths, caddisfly larvae, and beetles. The highly variable abiotic environment like temperature, pH, dissolved oxygen, ionic content and other dissolved organic matter together with biotic factors, fishes, amphibians, various species of waterfowls influences in particular abundance and distribution of macroinvertebrates in the wetland. Moreover, aquatic plants with complex vegetative structure support the greater abundance of epiphytes and they offer a large variety of microhabitats for colonization. According to Skinner and Gardner, (1930) and Arora et al. (2003) the profusely branched floating mats of *Salvinia* and *Eichhornia* species trap the suspended sediments and detritus which may also provide as an excellent source of organic nutrients to invertebrates. Varshney and Rzóska, (1976); Zutshi and Gopal (1990); Samuel (2003) concluded that majority of fauna associated with *Salvinia* are algal feeders or detritus feeders. Sobhana and Balakrishnan(1983) explained the ecological aspects of floating weeds, which prevents the sunlight to the deeper part of lake, resulting anoxic conditions in bottom of the lake. This may lead to the migration of bottom animals towards the surface and cause an increase in macroinvertebrate abundance in these types of hydrophytes. Welcome (1992) and Hamilton et al. (1997) supported the above statement; they observed that the degree of deoxygenation of water below the floating macrophytes depends on the water movements. During their studies in Paraguay river, South America, increasing anoxic conditions was observed during the first contacts of the rising water with the previously dry floodplain.

Oligochaetes were represented in stations 1 to 4, and 7 to 8 of the Maranchery wetland. They presented comparatively higher abundance of *H. verticillata* species of plant. Oligochaetes were more abundant in wetlands having higher pH and limited lower in decreasing pH was reported by Schell and Kerekes, (1980). They are also influenced by substrate type and water depth (Moore et al, 2006). The highest average abundance of oligochaetes, *Naididae* species was found in association with aquatic flora of *Cabomba*, *Ipomoea* and *Najas* sp. in two reservoirs of Brazil (Alves and Gorni 2007). Sobhana and Balakrishnan (1983) reported twelve species of oligochaetes belonging to family Naididae in association with *S. molesta* in the Veli lake, Kerala. Earlier studies of Gopalan and Nair (1975) in Kuttanad area revealed that relatively large number of aquatic insect larvae, annelids and ostracods that shows biocenosis with *S. molesta* in the brackish water. Further, several species of macroinvertebrates were attached to the roots of *S. molesta* which in turn form a food for variety of planktonic organisms.

Numerical abundance of isopods was higher in association with *L. adscendens* in station 8. Euhirudinea was abundant in association with *E. crassipes* in station 6, *S. molesta* in station 7 and *L. adscendens* in station 8, and these stations are under the stable phase. Isopods and Euhirudinea are less mobile therefore, stable conditions of water column help for abundant growth of hirudinea and isopods in these stations. According to Jerry et al. (2006) isopods were chiefly abundant in wetlands of southeastern Maine, and the pH of this wetland was nearly or less than 5. Mishra et al. (2013) noted that, Central sector of Chilika lake was covered with *P. pectinatus, Naja* sp. and *Halophila ovalis* creating a condition for growth of macrobenthic fauna like gastropods, bivalves and isopods. Balci and Kennedy (2003) observed that the greater complexity and surface area of the submerged macrophyte habitat favours taxa that feed on periphyton as well as provide greater refuge from predators for less mobile taxa. In contrast to this, in Maranchery Kole lands, flat worms were highly associated with floating weeds.

Molluscs were abundant in station 2 that is *L. heterophylla* plant was highly associated with this group and it was dominated during wet phase. The decrease of molluscs during paddy and channel phase is due to frequent application of burnt ashes in the agricultural fields. It will prevent the attack of bivalves and gastropods which inhibit the growth rate of molluscs in these phases. Olson et al. (1999) observed typha vegetation produced the greatest number of molluscs. Engel (1988) assessed the interactions of submerged macrophytes and found that the species composition was higher in submerged vegetation compared with sediment biota.

In phase wise evaluation there is a drastic decrease of macroinvertebrates except that the insect fauna was noticed in shifting period i.e., from wet to paddy phases. During the fluctuation they could not show any migration from one plant to another. Some of the invertebrates showed diapauses like hirudinea creates waxy coating to protect dry environment, several of them creates cocoons and deposit eggs in mud. Fragmentation of wetlands and death and decay of macrophytes suppress the growth and abundance of macroinvertebrates. After a short period of fluctuation of water they would again come in contact with macrophytes. In the case of insect fauna they are having wide range of tolerance so as to remain unaffected in this fluctuation of water level. McLachalan and McLachalan (1975) studied a tropical lake after a dry phase, and explained that pronounced horizontal and vertical variations affect the density of macro-fauna inhabiting the aquatic vegetations further, the dead and live plants also causes variations in the average faunal values. Nalepa et al.

(2007) observed the oligochaetes, ostracods and chironomids were dominating in tropical lagoons and showed a tendency with plants having greater area contributed higher diversity. Olson et al. (1995) and Dvorak and Best, (1982) also supported the above statements.

Numerical abundance of aquatic insects in Maranchery Kole land is detailed in Figures 7.23 to 7.30 and plotted its association with macrophytes. There was a striking contrast between the insect population in the stations with dense macrophyte growth and those with sparse macrophyte growth. The numerical abundance of insect density was maximum in station 1 and minimum in station 5. Among the aquatic insects the highest number was associated with *H. verticillata* and followed by *U. aurea*, which were completely below the water surface or submerged during the sampling period. This plant is having long dissected leaves and highly complex in structure. The floating, undissected leaves, *N. indicum* plant contributed least number of aquatic insect followed by *N. pubescens. E. crassipes* harbouring the second highest numbers of aquatic insects. Large number of macroinvertebrates on the submerged species *H. verticillata* and *U. aurea* may be due to the fact that submerged species represent a suitable well-illuminated substrate in the water column unlike the floating vegetation (*N. pubescens and N. indicum*) that is less inhabitable for epiphytic organisms because of the emergence of upper sides of leaves and the shading caused by floating leaves. More over these two plant species are simple in structure. Similar studies showed that, the architecture of hydrophytes itself may significantly affect the colonization by phytophilous invertebrates, the abundance of which is often greater on plants with dissected leaves than on plants with un dissected leaves by Jackson (1997); Cattaneo et al. (1998) and Cheruvelil et al, (2002). *E. crassipes* and *S.*

molesta were one other important habitat for insect fauna in this wetland. Flourished growth and fibrous root system inhabited by several minor taxa of invertebrates and soft spongy bulbous shoot system for inhabitance was one of the reasons for attracting insects into this plant. The invertebrate abundance is similar than that found in *E. crassipes* floating meadows growing in the Parana river, South America, floodplain lakes was observed by De Neiff and Carignan, (1997). De Neiff (2003) assessed the abundance of macroinvertebrates in *E. azurea* sps. in fringing floodplain of the Paraguay river, South America, and found inhabited by a rich fauna showed a similar taxonomic composition in different stations of the floodplain and also doubted that senescent macrophytes and macrophyte detritus are important in food webs.

The abundance of seven orders of insect fauna in eight stations was significantly different between stations and attributed to fluctuating water levels. Seven orders showed a significant difference in distribution between vegetation types. Submerged plant *H. verticillat*a was closely associated with dipterans and the abundance was higher during paddy phase. Stubbington et al. (2009) examined and found high number of diptera in open waters that is closely associated with filamentous algae. The highly dissected structure of this plant might support comfort niche to the smallest dipteran larvae for eg. chironomids. Moreover the chironomids are generally filter feeders, the complex nature of this plant trap suspended particulate matter from water, and that would represent an important food resource for filter feeders or filtering collectors. Jaynes and Carpenter, (1986); De Neiff et al. (2009) agree with the above statements. However vegetated areas play a double role as inorganic sediment trap as well as invertebrate retention during flooded conditions (Carvalho et al., 2017). Among chironomid larvae, *Glyptotendipes* and *Lauterborniella* species were more common on plants than at the bottom (De Neiff et al., 1994). Hemiptera was less abundant in station 8 whereas higher in station 2 with plant *L. heterophylla.* The fast swimming habit of this order prefers less complex plants. Density of this emergent plant was comparatively low in this station also support the above declaration. Olson et al, (2009) supported the above statement in their study. They usually observed hemipterans were quit prevalent in open water, this is because they live close to the surface for diving to feed and for aeration. Lepidoptera and odonates were higher in association with *S. molesta* in station 7 and *L. adscendens* in station 8. Chiltton (1990) suggested that factors other than plant type and surface area may also affect the pattern of invertebrate abundance. Aquatic hemipterans of Corixidae family were abundant in low pH wetlands was noted by Jerry et al. (2006). Lepidopterans were equally abundant in paddy and stable phases of this wetland.

Odonates shows higher abundance during wet phase. The nymph stage of odonates prefer highly pure water for habitat (Subramanian and Babu, 2017). Odonate nymphs are generally categorized as shredders and scrappers, these can often eat plant leaf for diet. Variability of population in different phases could be attributed to several factors like mortality, hatching of eggs, emergence, predation and availability of food. Predominance of family Libellulidae in both the wet and stable phases may be due to the fact that it is the largest family of Odonata, tolerant to several anthropogenic impacts and armed with long mid dorsal and lateral spines for avoiding predators, moreover, moderate amount of nutrients and flourished growth of macrophytes also attracts odonates into this wetland.

Order Trichoptera and Ephemeroptera were usually minimal in abundance compared with other groups. And these insects were abundant during channel and paddy phases of this wetland. Coleoptera was widely distributed at different stations in this wetland whereas there is higher abundance during channels and followed by paddy phases. The availability of food those of paddy leaves may attract beetles into agricultural fields and associated channels might be one of the reasons for increase in population in these phases. Different invertebrates can use the structural components of their habitat selectively (Difonzo and Cambell, 1988; Hann, 1995). On the other hand, hydrophyte gives refuge for predators too, and they can change the diversity, density, and size spectra of aquatic insects associated with the macrophytes (Heck et al., 1981). From the study it is clear that the changes in abundance of different insect orders are closely associated with plants architecture, so they should be 'species specific'. From the correlation studies carried out between plant biomass and different macroinvertebrates showed that macrophyte biomass is positively correlated with 1% level, significance ($p<0.01$) with insect fauna, branchiopods and decapods and that off strong negative correlation with isopods and oligochaetes. A weak positive correlation observed between plant biomass with pisces, molluscs, ostracods and euhirudinea (Table 7.6).

In phase wise evaluation the increase in abundance of total aquatic insects in paddy and channel phases were noticed in the Kole land, and at the same time, the abundance of macroinvertebrates like, decapods, arachnids, branchiopods, etc decreased. Water level fluctuation altered the abundance of macroinvertebrates especially insect community. *K*-dominance curve also stated that there is an increase of abundance during paddy and channel phases compared to wet and stable phases. Seasonal life cycle and changes in the morphology of macrophytes during the growing season adversely affect invertebrate growth (Lillie and Budd, 1992; Beckett et al. 1992). Humphries (1996) studied the Tasmanian river ecosystem, Australia, with varying water level and they discussed that, they may be at particular water level, beyond which an invertebrate may find it untenable to remain faithful to a specific macrophyte. Usha Balaraman (2008) assessed the dry phase of the soils and noted numerous number of forms of resting eggs, especially the crustaceans in ephemeral wetlands of Southern Kerala. The composition of micro crustaceans in vegetated water of the southern Pantanal wetlands, Brazil is similar both in the rainy and dry seasons (Rocha and Por, 1998). Heino and Toivonen (2008) observed land use pattern in agricultural areas and found that human disturbance was strongly related to the species richness of the macrophytes and the abundance of fin fishes. Many fin fishes preferred for oligotrophic conditions. In Maranchery wetland abundance of pisces (fish fingerlings) was higher in stations 3 to 6 and in the spatial variations paddy and channel phases of this wetlands showed higher abundance of fish fingerlings compared to other phases. Sand-Jensen et al. (2000) explained that eutrophication likely leads to increase in diversity of macrophytes. Later hypereutrophic conditions are known for decreased macrophyte diversity in lakes. According to Rhoads and Klein (1993) the oligotrophic freshwater ecosystems evidenced by a considerable number of species. In Maranchery Kole land wet and stable phases had decreasing abundance of fish fingerlings that might be due to increased spatial area and rich in floristic composition, however increase in abundance during paddy and channel phases might be due to patchy habitat and decreased vegetations. More over change in soil structure affect the invertebrate abundance (Vineetha et al., 2015). Relationships of total abundance and taxonomic richness of invertebrates with depth were mostly negative (Humphries, 1996). Opadam and Wascher, (2004); Mantyka-Pringle et al. (2014) in their study concluded that, the population and community persistence at various scales is not thus far well-developed for fresh water macrophyte diversity. Sandy Engel (1985) made a detailed study of submerged macrophytes - functioned as a screen to select and restrict fish movements. Macrophyte beds exceeding 300 g/m^2 (dry weight) were usually devoid of fishes. Monotypic stands of curly-leaf pond weed, over 200 g/m^2, were difficult for fishes to penetrate. Such dense islands of vegetation, contributing nearly 15% of all plant samples in June-August, acted as refuges for macroinvertebrates escaping from fish predation. Fishes under 120 mm (ages 0-l) readily penetrated the remaining plant beds by distributing their foliage throughout the water column, even dense stands of pond weed appeared loose under water and allowed small fishes to access the foliage. In this wetland, presence and absence of fish fingerlings was agreeing with the above statement.

The agricultural practices adopted in a rice cultivation cycle in the paddy fields have influenced the macrophytes richness and associated invertebrate assemblages in Maranchery wetland. The biomass of macrophytes in the tillage phase was lower than that of the paddy growing phases and the end of the paddy growing phases same time there was a steady increase of aquatic insects during tillage phase. With respect to the gradual increase in the biomass of macrophytes as decrease of aquatic insect community was recorded in this wetland. The decrease of richness and biomass of macrophyte at the tillage phase was due to the use of herbicides, consequence of soil drainage, and also use of machinery. The absence of water during tillage phase suppressed the growth of hydrophytes which are less tolerant to drought and the use of machinery causes spinning of soil and serious mechanical damage to the macrophytes. These lead to migration of aquatic insects to the available local patches of hydrophytes in paddy phase and another possibility for the increase in abundance of insects is the luxurious paddy growth, which offers a good source of food to these kinds of organisms. Rolon et al, (2010) is of the opinion that, the habitat provided by rice fields could contribute to increase in the connectivity in fragmented landscapes.

In the study between macrophytes associated macroinvertebrates and their abundance it is concluded that, the close proximity of different plant communities could allow the emigration and immigration of invertebrates between samples. Sampling of macroinvertebrates in heavily vegetated areas can be difficult to do because of the close association of the invertebrates with the vegetation. Newman, (1991) also agrees with this observation. Species of macrophyte which differ in the structure and pattern of stems and leaves often support abundance of invertebrates (Stoner and Lewis, 1985). Numerical abundance of the population of macroinvertebrates was varied with stations and hydrological phases in Maranchery Kole land. This high variability of macroinvertebrate populations can be explained, in terms of normal die off, hatching off eggs, pupation, emergence, pattern of predation, local movements and uneven distribution.

Table 7.3. Pearson correlation analysis between macroinvertebrates and macrophyte biomass in Maranchery Kole wetland during the study period.

Groups	Insects											
Nematodes	-0.462	Nematodes										
Oligochaetes	0.061	0.655	Oligochaetes									
Euhirudinea	-0.298	0.073	-0.298	Euhirudinea								
Molluscs	0.419*	-0.361	-0.079	0.196	Molluscs							
Ostracods	0.089	-0.145	-0.537	0.845**	0.110	Ostracods						
Branchiopods	-0.538	0.138	-0.256	0.795*	-0.096	0.522	Branchiopods					
Isopods	-0.152	-0.050	0.033	0.471	0.018	0.094	0.576	Isopods				
Decapods	-0.303	-0.419	-0.708*	0.663	-0.449	0.090	0.690	0.583	Decapods			
Arachnids	-0.130	-0.371	-0.480	0.059	-0.308	0.194	-0.288	-0.140	0.526*	Arachnids		
Pisces	0.207	-0.745*	-0.683	-0.033	0.269	0.367	-0.087	-0.467	0.274	0.396	Pisces	
Macrophyte biomass	0.788*	-0.012	-0.011	0.018	0.121	0.139	0.231*	-0.002	0.312*	0.296	0.155	Macrophyte biomass

*Correlation is significant at the 5% level, ** Correlation is significant at the 1% level.

* * *

Chapter - 8

COMPOSITION AND COMMUNITY STRUCTURE OF MACROINVERTEBRATES

8.1 Introduction

“Biological diversity” means the variability among living organisms from all sources including, *inter alia,* terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; it includes diversity within species between species, and of ecosystems (Article II, Convention on Biological Diversity, 1992). Literal meaning of biodiversity is the diversity of all life forms on earth. This includes the various races and species of all microbes, plants and animals that live on earth, including their genetic differences, i.e., the gene pool of each species (Armsworth et al., 2004).

Habitat complexity has long been considered as one of the determinants of biological diversity (MacArthur et al., 1966) and is used as a predictor of species richness over a wide range of spatial scales, from individual aquatic plants (Jeffries, 1993; Taniguchi et al., 2003) to continental scales (Gaston, 2000). Theoretically, more complex habitat higher will be the number of species (Heywood and Watson, 1995). Wetlands are significant sites for biological conservation because they support rich biodiversity and present high production potential (Mitsch and Gosselink, 2000). However, biodiversity in wetlands has been reduced worldwide (Shine and Klemm, 1999). The impact of loss of wetland on biodiversity was verified by the decline of populations of several wetland-dependent species (Millennium Ecosystem Assessment, 2005). Several exotic macrophyte species significantly alter the distribution pattern of macro invertebrates. Freshwater insects have important roles in the ecology of wetlands. They are vital for riparian and flood plain food webs, processing organic matter and transporting energy along channels, laterally to the flood plains and vertically down into the edaphic zones. Many aquatic inhabit insects fauna, break down the leaf litter and supply nutrients, carbon and energy to the wetlands and associated ecosystems (Pintar and Resetarits, 2017).

The change in the landscape has caused a reduction in the area and connectivity of natural habitats. The fragmentation of wetlands is one of the main problem related to the diversity and distribution of entomofauna. Agricultural activities cause physical loss, shrinkage and modification of aquatic habitats especially flora and minor crustaceans. It ultimately lead to extinction of tertiary level organisms especially variety of fishes. By assuming wetlands be the ecological islands surrounded by terrestrial habitats, the relationship among species richness and wetland size was extensively used for wetland management (Hall et al., 2004). Agriculture is one of the main human activities responsible for the decline of natural wetlands throughout the world, the distribution of the species was impacted by irrigated agriculture expansion (Millennium Ecosystem Assessment, 2005). Rice is the most important cereal crop in a developing country (Juliano, 1993). In 2003, approximately 151 million ha of land were cultivated with rice, worldwide (FAOSTAT, 2008). Biodiversity in agricultural landscape is an ecological challenge (Ormerod et al., 2003). Number of studies have demonstrated the contribution of managed ecosystems, like rice fields and irrigation channels, providing habitats for establishment of aquatic organisms (Elphick, 2000; Bambardeniya and Amerasinghe, 2004; Goulder, 2008; Herzon and Helenius, 2008; Lupi et al., 2013; Desta et al., 2014).

Information on the composition and relative abundance of the macroinvertebrates in any aquatic ecosystem is a prelude to the understanding of the nature of the secondary production and pattern of energy flow. Its role in a wetland ecosystem is directly related to fishery potential and biological structure. Diversity and distribution of faunal community of Kole wetlands were often fragmentary. Bijoy Nandan (2008) reported dominant benthic group in the backwaters of Kerala. Invertebrate diversity of Vembanad lake was surveyed by Dev et al. (2009). Latha and Thanga (2010) identified 24 families of benthic invertebrates in Veli and Kadinamkulam lakes. Martin et al. (2011) reported macrobenthos of Cochin backwaters. Balachandran et al. (2012) on distribution pattern of aquatic insects in Central Western Ghats, Abhijna et al. (2012) documented insect fauna of Vellayani lake. Kripa et al. (2013) assessed the status of macroinvertebrates in Koratty chal, Thrissur. Raj et al. (2014) studied the invertebrates of Ashtamudi estuary Vineetha et al. (2015) documented the oligochaete diversity of Maranchery Kole lands. From the literature it is clear that the diversity and species structure of macroinvertebrates from northern part of Kole wetlands of Kerala is less studied.

8.2 Results

8.2.1 Faunal Composition

8.2.1.1 Macroinvertebrate groups

The macrophyte associated macroinvertebrates in Maranchery wetland belonged to 5 Phyla (nematodes, annelids, molluscs arthropods, and chordates), and 11 classes (nematodes, oligochaetes, euhirudineans, molluscs, ostracods, branchiopods, isopods, decapods, arachnids, insects, and pisces. The insects fauna were found dominating during the study period (64.2%). The percentage contribution of Branchiopoda, Arachnida, Euhirudinea, Mollusca, Decapoda and Ostracoda were in the order 9.8%, 6.8%, 6.5%, 5.8%, 3.3% and 2% respectively. Nematoda, Oligochaeta, Isopoda, Pisces contributed on an average less than 1% in the study stations (Fig. 8.1). In station wise analysis, 55% and above was contributed by insect fauna in all the eight study stations (Figs. 8.2 to 8.9). In station 1 where insect fauna contributed 75.3%, branchiopods 9.2% and euhirudinea 4.3%; that in station 2 insects contributed 55.8% of the total fauna, the other major macroinvertebrates were molluscs contributed(17.4%), branchiopods (10.1%) and arachnids (7.7%). In station 3 insects distributed 57.2% followed by molluscs (17.9%), branchiopods (10.4%) and arachnids (7.5%) contributed major percentage ; that in station 4 insects formed 66.1%, branchiopods contributed 9.9 %, arachnids contributed 7.2% followed by euhirudiea and molluscs (5.6% and 5.9%) contributed major percentage of distribution. In station 5 insects formed 61.3%, followed by branchiopods contributing 13.1%, arachnids 9.4%, euhirudinea 8.9% whereas molluscs contributed 4.9%; that in station 6 insects contributed 60.5% of the total macroinvertebrate fauna, euhirudinea 12.8%, branchiopods 9.8%, arachnids 7.0% molluscs 5.2% and ostracods 3.7%. In station 7 macroinvertebrates composition comprised of, insects contributing 61.5%, followed by euhirudinea (9.1%), branchiopods (8.7%), decapods 7.1%, arachnids (6.3%) and ostracods (5%); that in station 8, 59.6 % were contributed by insects, decapods contributing 13.6%, arachnids 7.6% , branchiopods 8.4%, euhirudiea 5.5%, and molluscs 4.7% of the invertebrate fauna. The comparison among the phases showed that insects were contributing maximum percentage in four phases (Figs. 8.10 to 8.13). Its maximum percentage was contributed in paddy phase (80%), followed by channels (62.1%) wet (38.7 %) and stable phase (32.6%). In paddy and channel phases the other macroinvertebrate distribution were shown that in paddy phase decapods and arachnids contributes 16.2% and 11.2% respectively, branchiopods (3.8%) and molluscs (3%) whereas other groups contributes less than 1%. ; that in channel phase arachnids contributes 6% followed by molluscs 5%, isopods, decapods and euhirudinea contributed 2% each, and others are less than 3%. In wet and stable phases other groups were equally distributed compared to insect fauna. In wet phase composition of macroinvertebrates were molluscs 22.8%, followed by arachnids (12.6%), euhirudinea (9.9%), decapods (3.6%), ostracods (3.0%) and oligochaetes (0.3%). In stable phase it was arachnids (22.7%) ,branchiopods and isopods (10.4%), molluscs (9.0%), euhirudinea (7.1%), ostacods (4.7%), decapods (2.8%) and oligochaetes (0.5%). The list of macroinvertebrate species recorded from Maranchery Kole wetland is given in annexure II.

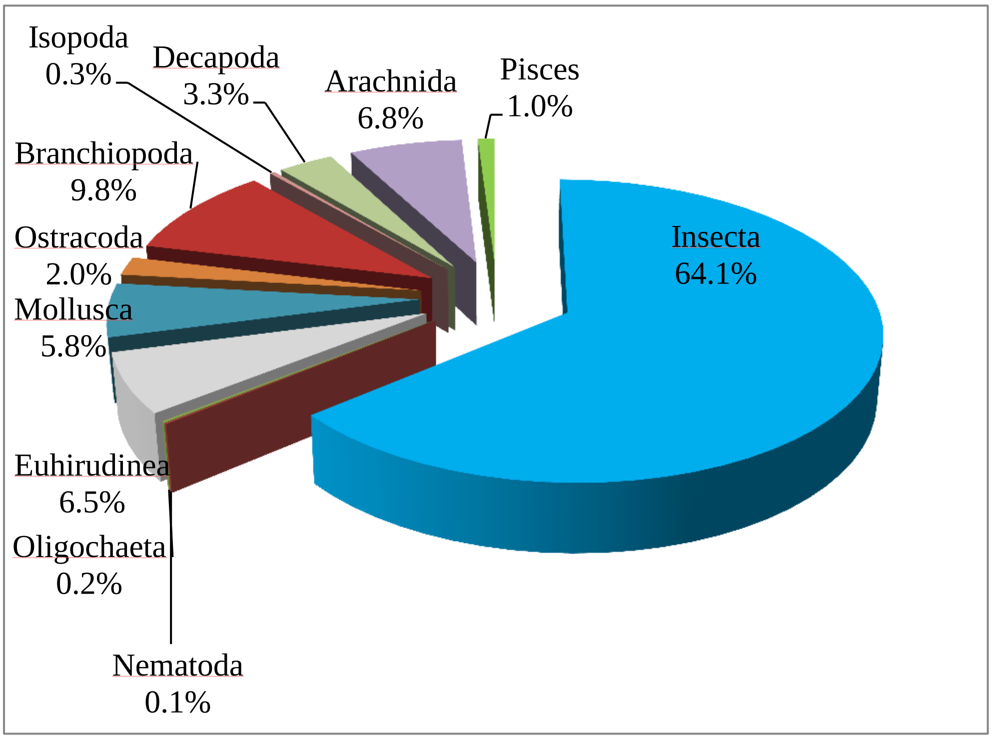


Fig. 8.1. Mean percentage composition of macroinvertebrates groups in Maranchery Kole wetland during the study period.

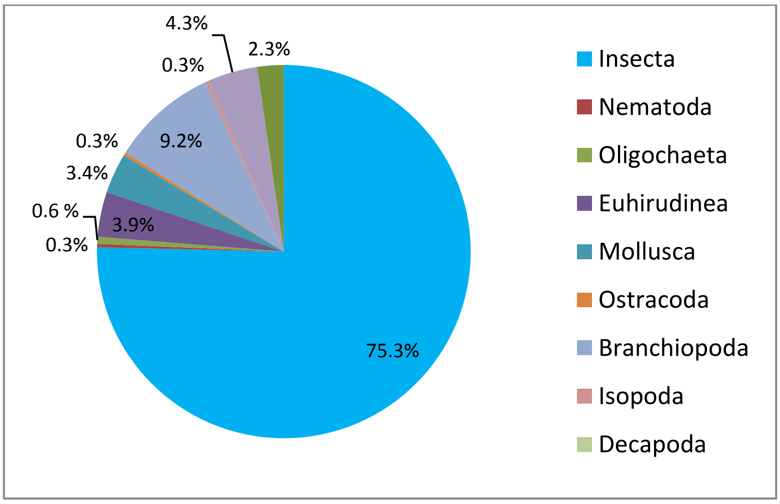


Fig. 8.2. Mean percentage composition of macroinvertebrates groups in station 1 in Maranchery Kole wetland during the study period

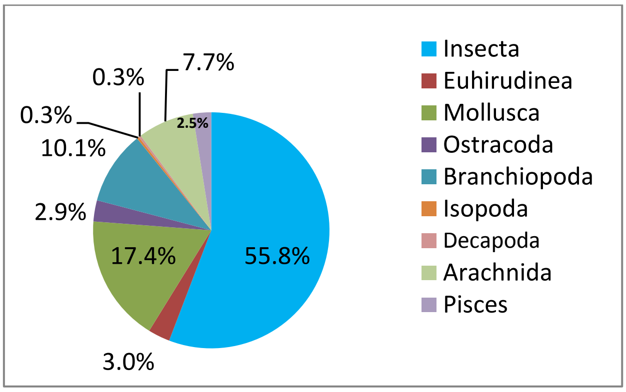


Fig. 8.3. Mean percentage composition of macroinvertebrates groups in station 2 in Maranchery Kole wetland during the study period.

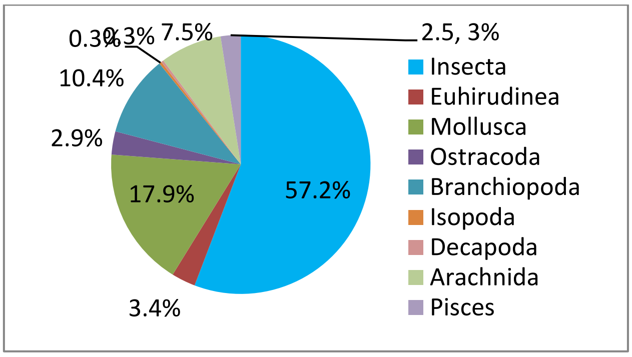


Fig. 8.4. Mean percentage composition of macroinvertebrates groups in station 3 in Maranchery Kole wetland during the study period.

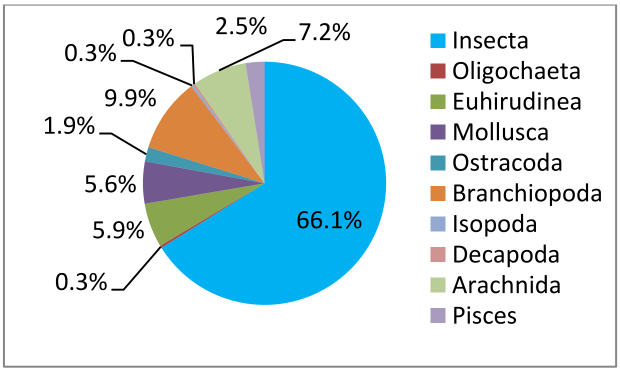


Fig. 8.5. Mean percentage composition of macroinvertebrates groups in station 4 in Maranchery Kole wetland during the study period.

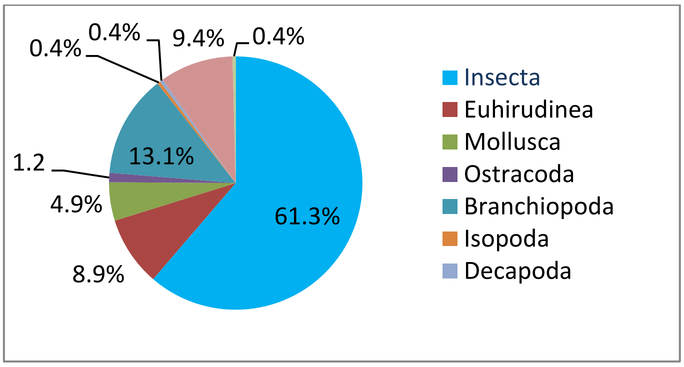


Fig. 8.6. Mean percentage composition of macroinvertebrates groups in station 5 in Maranchery Kole wetland during the study period.

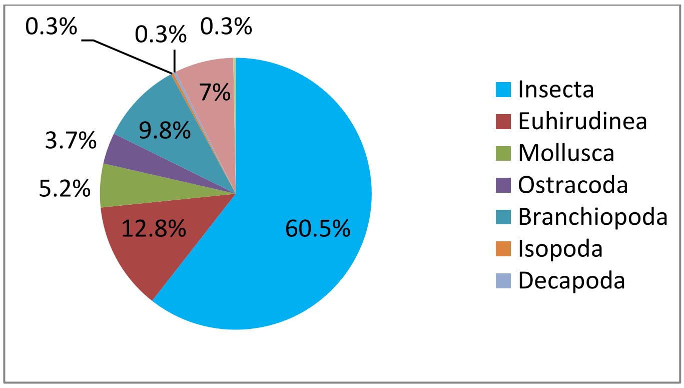


Fig. 8.7. Mean percentage composition of macroinvertebrates groups in station 6 in Maranchery Kole wetland during the study period.

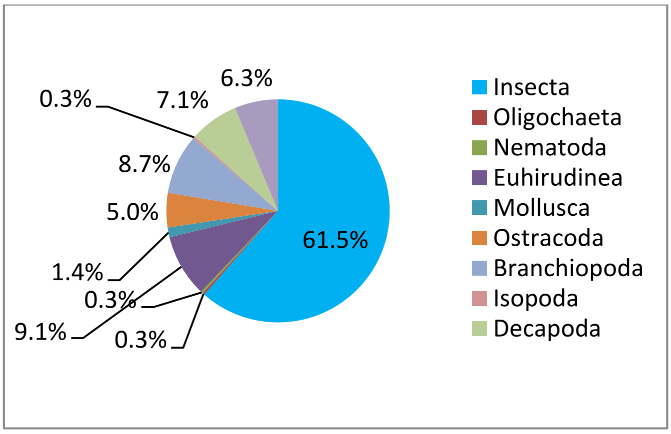


Fig. 8.8. Mean percentage composition of macroinvertebrates groups in station 7 in Maranchery Kole wetland during the study period.

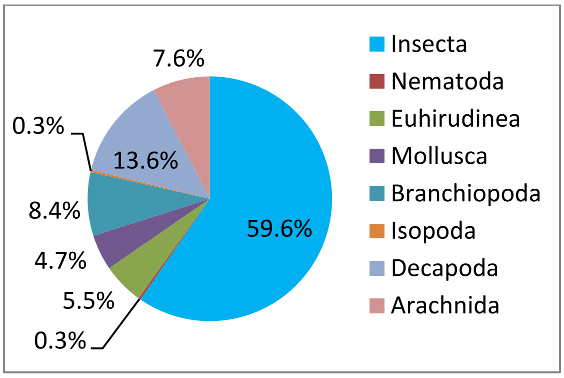


Fig. 8.9. Mean percentage composition of macroinvertebrates groups in station 8 in Maranchery Kole wetland during the study period.

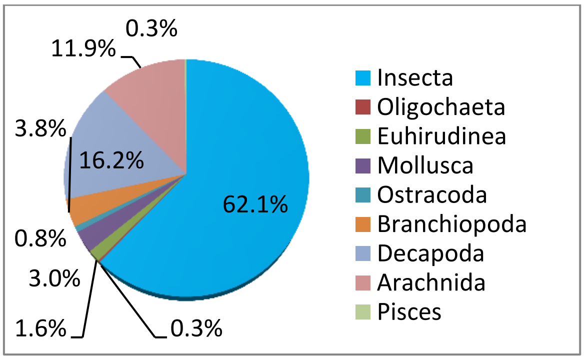


Fig. 8.10. Mean percentage composition of macroinvertebrates groups in channel phase in Maranchery Kole wetland during the study period.

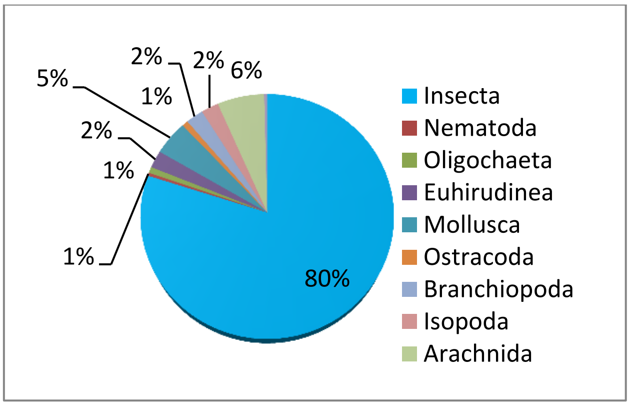


Fig. 8.11. Mean percentage composition of macroinvertebrates groups in paddy phase in Maranchery Kole wetland during the study period.

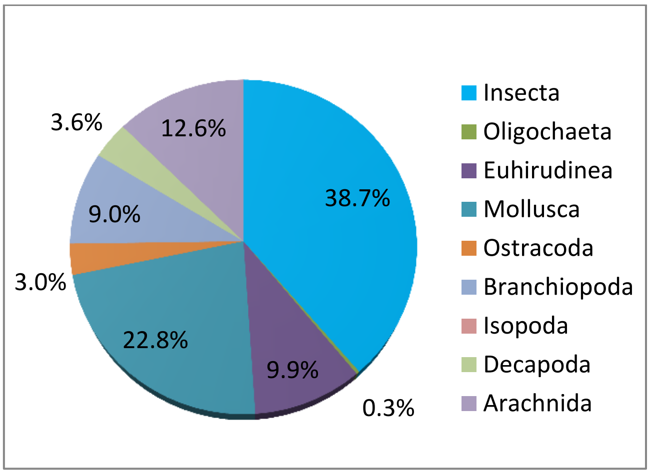


Fig. 8.12. Mean percentage composition of macroinvertebrates groups in wet phase in Maranchery Kole wetland during the study period.

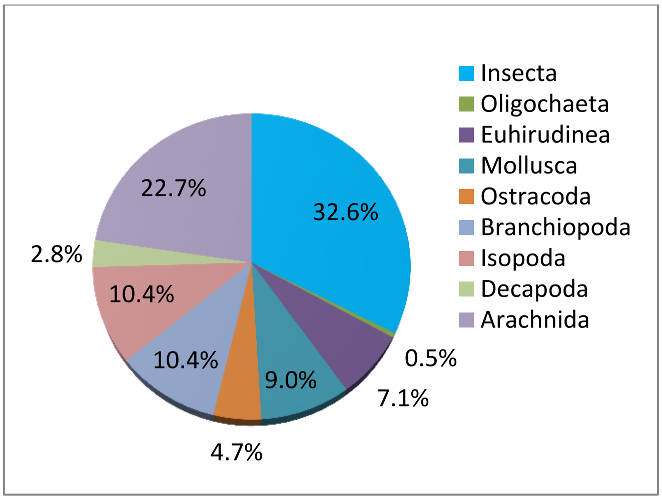


Fig. 8.13. Mean percentage composition of macroinvertebrates groups in stable phase in Maranchery Kole wetland during the study period.

8.2.1.2 Distribution and diversity of aquatic insects

Detailed investigations of insect fauna of Maranchery wetlands were carried in station wise and phase wise. The percentage composition of various insect orders collected from Maranchery wetland is shown in Figure. 8.14. From the identified insect fauna, insect larvae contributed major percentage than adult insects. The Class Insecta was represented by Ephemeroptera (May flies) Odonata (Dragon flies and Damselflies), Hemiptera (Semi aquatic bugs), Trichoptera (Caddisflies), Lepidoptera (Butter flies), Coleoptera (Beetles) and Diptera (True flies). The major percentage of insects was contributed by Dipterans in eight stations except station 7 that was represented by Coleoptera. The station wise and phase wise distribution of aquatic insects fauna is represented in Figures 8.15 and 8.16. Station 1 constituted 56.4% of Diptera followed by 22.7% of Coleoptera, 6.8% Odonata, 5.3% Hemiptera, 4.5% Lepidoptera, Trichoptera(2.7%) and remaining 1.5% was Ephemeroptera; whereas in station 2 Diptera contributed 38.7%, Hemiptera contributed the second large percentage of 21.6%, Coleoptera 17.0%, Odonata 8.5%, Trichoptera 7.9%, Lepidoptera 3.4% and Ephemeroptera 2.8%. In Station 3 the insects recorded were Diptera 38.7%, Coleoptera 25.6%, Ephemeroptera 12.8%, Hemiptera 10.0%, Odonata 8.8%, Trichoptera and Lepidoptera 2.0% each. The insects recorded from station 4 was Diptera 42.3%, followed by Coleoptera contributed 29.6%, Odonata 15.5%, Hemiptera 6.1%, Lepidoptera 3.3% and less contributed by Trichoptera 1.4% and Ephemeroptera 1.9%. In station 5 Diptera contributed 35.3%, Coleoptera distributed 30.7%, Odonata 12.0%, Ephemeroptera 8.7%, Hemiptera 6.0%, Trichoptera 4.0% and less contributed by Lepidoptera 3.3%. In station 6 % contribution of dipteral was only 23.4%, Odonata 21.3%, Ephemeroptera 18.3%, Coleoptera 17.3%, Hemiptera 13.2%, Lepidoptera 5.1% and

Trichoptera 1.5%; whereas in station 7 percentage of Coleoptera was higher (31.0%), followed by Diptera 17.9%, Odonata and Ephemeroptera by 14.8% each, Lepidoptera 12.6%, Hemiptera 8.1%, and Trichoptera 0.9%. In station 8 the distribution pattern of insects fauna was dominated by Diptera 29.1% followed by Coleoptera contributing 23.8%, Ephemeroptera by 26.0%, Odonata 14.5%, Hemiptera 2.2%, Trichoptera 2.6% and less contributed by Lepidoptera by 1.8%. In phase wise analysis Paddy phase recorded Diptera that was contributed by 40.9%, Coleoptera by 33.2%, Ephemeroptera 13.0%, Odonata 4.8%, Trichoptera and Lepidoptera by 2.9% and Hemiptera 2.4%. In channels major percentage was constituted by Coleoptera by 49.2%, Diptera 25.4%, Ephemeroptera 13.0%, Odonata 9.2%, Trichoptera by 4.6% and Lepidoptera by 2.3% and only 1.5% was Hemiptera. In wet phase of this wetland Odonata 34.9%, Coleoptera by 19.4%, Diptera 16.3%, Hemiptera 15.5%, Trichoptera by 6.2% and Lepidoptera by 5.4% and Ephemeroptera 2.3%. In stable phase it was chiefly contributed by Coleoptera by 47.8%, Odonata 14.5%, Diptera 13.0%, Lepidoptera by 8.7%, Ephemeroptera 7.2%, and Hemiptera and Trichoptera together contributed by 8.6%.

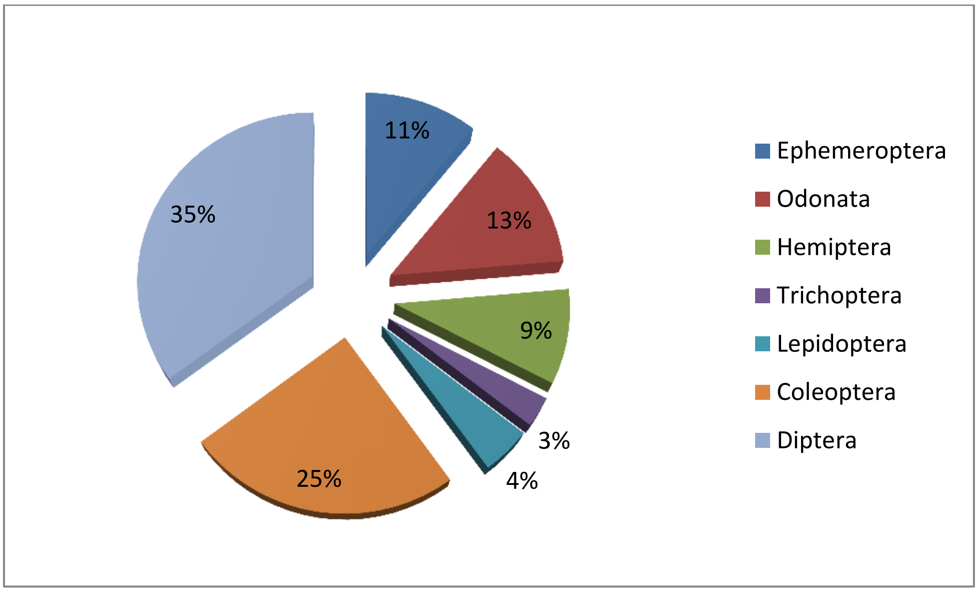


Fig. 8.14. Mean percentage composition of insect orders in Maranchery Kole wetland during the study period.

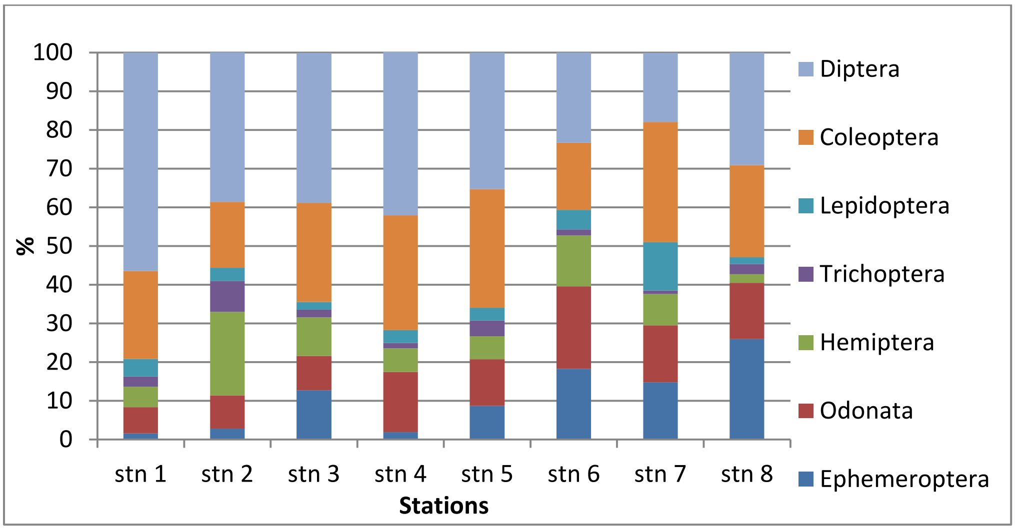


Fig. 8.15. Mean percentage composition of insect orders in the eight stations in Maranchery Kole wetland during the study period.

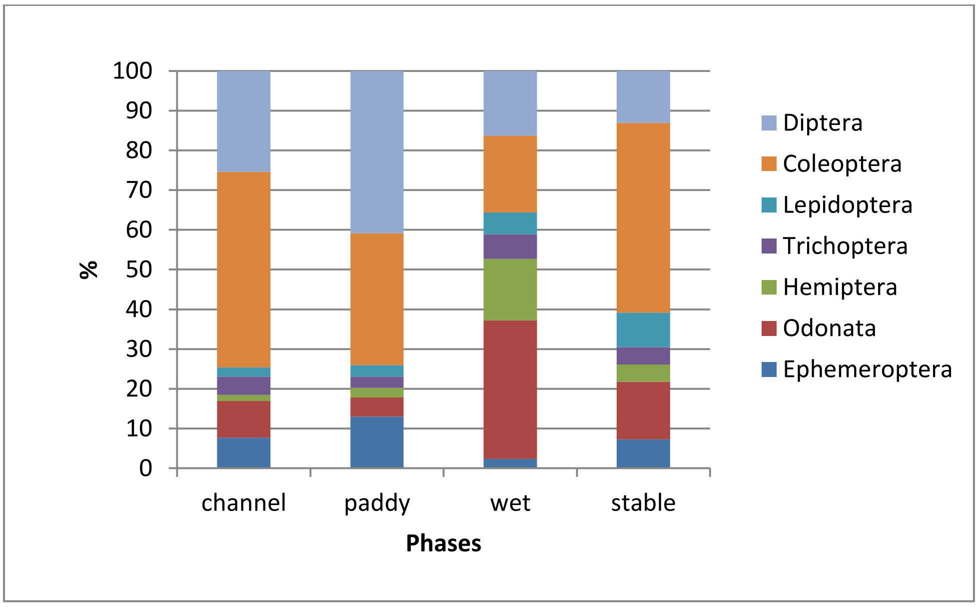


Fig. 8.16. Mean percentage composition of insect orders in the four phases in Maranchery Kole wetland during the study period.

In diversity analysis the aquatic insect fauna representing 58 genera/species categorised under 30 families and 7 orders were collected in association with macrophytes of the eight study stations. Station wise variations in community structure and percentage distribution of aquatic insects are represented in Annexure III. These include adults, pupae and larval stages of insects belonging to the Orders Ephemeroptera (3 species), Odonata (7 species), Hemiptera (7 species), Trichoptera (3 species), Lepidoptera (4 species), Coleoptera (adult 13 species and larvae 5 species) and Diptera (16 species). Station 1 contributed 43 genera, 20 families and 7 orders, while 43 genera, 21 families, and 7 orders were recorded form station 2. The aquatic insect faunal diversity in station 3 was represented by 46 genera, 23 families and 7 orders; whereas in station 4, 46 genera, 22 families, and 7 orders were recorded. Forty genera, 20 families, and 7 orders were recorded from station 5. The insects recorded from station 6 were included under 41 genera, 22 families, and 7 orders; while station 7 only 36 genera, 18 families, and 7 orders were recorded. Station 8 was represented by 42 genera, 23 families and 7 orders. Phase wise variations in community structure and percentage distribution of aquatic insects are represented in Annexure IV. In phase wise evaluation paddy phase belonged to 45 genera, 21 families and 7 orders, while in channels it belongs to 34 genera, 19 families and 7 orders. Wet phase represented 35 genera, 17 families and 7 orders whereas stable phase recorded 28 genera, 16 families and 7 orders.

The Mayflies or Ephemeroptera was represented in Maranchery Kole lands by the three families Ephemerellidae, Caenidae and Baetidae. The family Ephemerellidae was contributed by *Ephemerella* species that was absent in station 2 and present in all other stations. It was recorded during paddy and channel phases of these ecosystems. The family Caenidae and Baetidae similarly contributed one species each. *Caenis nigropunctata* was common in all stations, and phases. *Centroptilum* sp. of family Baetidae was having higher percentage in station 3(1.5%) whereas it was absent in stations 2, 4, 5 and 7. This species was present in paddy and stable phases.

The Odonata was represented by the families Libellulidae, Gomphidae and Coenagrionidae. The important members of family Libellulidae was *Nannophya pygmaea*, and the other nymph species were mainly found in association with macrophytes were *Crocothemis servilia* and *Hydrobasileus croceus. Crocothemis servilia* was recorded from all the eight stations and it was recorded during channels and paddy phases of Kole lands. Whereas *Nannophya pygmea* was absent in station 2 and present in four phases. *Hydrobasileus croceus* was recorded from stations 2 (2.3%), 6 (0.5%) and 8 (0.4%). This species was seen in stable and wet phases. The species *Ictinogomphus rapax* of family Gomphidae was seen in stations 3 (0.4%), 5 (1.3%), 6 (0.5%) and 7(0.4%), and it was absent during wet and stable phases. The family Coenagrionidae was chiefly represented by 3 species of nymphs *Agriocnemis lacteola, Ischnura senegalensis* and *Pseudagrion* sp. among this *Pseudagrion* sp. was common and in all the study stations and phases. Compared to other stations, station 3 shows higher percentage (1.5%) of *Agriocnemis lacteola* whereas *Ischnura senegalensis* was higher percentage in station 8(4.4%).

The order Hemiptera or semi aquatic water bugs was one of the diverse species comprising 9% of the total insect fauna collected from macrophytes. Adult species were recorded from this wetland. It was categorized under 6 families viz., Nepidae, Belostomatidae, Pleidae, Corixidae, Hebridae and Gerridae. Of these Belostomatidae was the most common family among Hemiptera in eight stations constituted by two species *Diplonychus rusticus* (3.1%) and *Diplonychus annulatum* (3.6%). In phase wise analysis both species were present in four phases. Pleidae and Corixidae were represented by two genus *Paraplea* sp. and *Micronecta* sp. *Paraplea* sp. had higher percentage in station 6 (2.0%) and it was absent in stations 1, 4 and 7. This genus was absent in paddy and channels and found in stable (1.7%) and wet phases (1.5%). *Micronecta* sp. was only present in wet phase. Family Hebridae, Nepidae and Gerridae contributed minor percentage to the wetland. In station wise analysis, 0.2% was contributed by each species of this family it was *Ranatra brevicollis* by family Nepidae, *Hebrus* sp. by family Hebridae and *Gerris* sp. by Gerridae.

Trichoptera or caddisflies were contributed by three species *Neureclipsis* sp., *Hydropsyche* sp., and *Himalopsyche phryganea*. Among the Trichoptera taxa, *Neureclipsis* sp. of family Polycentropodidae was common throughout the study period in all the stations. These species was having higher percentage in station 8(2.2%) and very less percentage in station 6 (1.0%). In phase wise it was represented in four phases and in comparison with *Hydropsyche* sp. of family Hydropsychidae and *Himalopsyche phryganea* of family Rhyacophilidae was present in channels and stable phases. This two species has contributed higher percentage in station 8. The order Lepidoptera was represented by Pyralidae larvae constituting a total of 4% insect fauna in this wetland. Five species mainly contributed in this family *Elophila interruptalis, Parapoynx diminutalis, Potamomusa* sp., and *Eoophyla* sp. *Elophila interruptalis* was most common among the four species and it was present in total eight stations.

Among the entomofauna collected the order Coleoptera was the most common group and diverse in number of species (18) which includes adult and larval stages. The order Coleoptera comprised 25% of the total insect fauna in Maranchery wetland. It was represented of 10 families viz., Dytiscidae, Noteridae, Hydrophilidae, Curculionidae, Chrysomelidae, Dryopidae, Hydraenidae, Carabidae, Staphylinidae and Histeridae. Among this Dytiscidae, Noteridae and Hydrophilidae were represented by two species each and others were represented by single species each. Coleopteran larvae were found in two major families of Dytiscidae and Hydrophilidae. From the family Dytiscidae the most predominant species was *Hydrovatus confertus* and wide spread in eight stations whereas family Noteridae species of *Canthydrus luctuosus* was contributed 4.3% in total coleopterans. Hydrophilidae family was mainly represented by *Enochrus esuriens* and *Berosus indicus.* These two species were found in most of the stations while in station 7 *Berosus indicus* was absent. *Bagous* sp. of family

Curculionidae was represented by total of 1.2%. Chrysomelidae family of genus *Cassida* sp. contributed only 0.1%. The other species mainly found in association with hydrophytes were *Helichus* sp. (0.4%), *Henicocerus* sp.(0.3%), *Chlaenius* sp.(0.9%), *Paederus* sp.(0.8%), *Platylomalus* sp.(0.2%) among the aquatic coleopterans. The species of coleopterans showed higher percentage in channels and paddy phases compared to wet and stable phases. Compared to wet phase larval instars were also higher in paddy, channel and stable phases. Among the larval instars identified *Hydrovatus* sp. was represented in most of the stations.

The order Diptera or Midges were rich in number of species. This family represented both biting and non biting midges in almost all the stations. The dipterans were contributed by major four families representing Chironomidae, Ceratopogonidae, Chaoboridae and Culicidae. Among family represented by Chaoboridae and Culicidae pupae stage was identified. There were no adult insects was found in association with macrophytes. Among the Chironomidae family *Chironomous major* had higher percentage (5.4%) and it was found in all eight stations followed by *Ablabesmyia annulata* (2.8%), *Polypedilum nubifer* (2.7%), *Paratanytarsus* sp. (2.5%), *Polypedilum leei* (2.3%), *Tanypus* sp. (2.1%), *Cladotanytarsus* sp. (1.9%), *Monopalopia tillandsia* (1.7%), *Lueterboniella* sp. (1.5%), *Einefeldia synchrona* (1%), *Dichrotendipes* sp.(0.8%) and *Chono chironomus* sp. (0.4%). From the biting midges family Ceratopogonidae had higher percentage and the genus *Bezzia* sp. contributed 7% of the total dipterans and it was cosmopolitan in distribution. In phase wise evaluations, it was having higher percentage during channel and paddy phases. Photographs of major aquatic insects identified in Maranchery wetland are given in Figure 8.17.

Caenis nigropunctata

***Ephemerella* sp.**

***Centroptilum* sp.**

Agriocnemis lacteola

Ephemerella sp.

Centroptilum sp

***Paraplea* sp.**

Diplonychus rusticus

Diplonychus annulatum

***Micronecta* sp.**

Ranatra brevicollis

***Hebrus* sp.**

***Neureclipsis* sp.**

Laccophilus parvulus

***Cassida* sp.**

Enochrus esuriens

Hydrovatus confertus

***Bagous* sp.**

***Helichus* sp.**

***Henicocerus* sp.**

***Noterus* sp.**

Canthydrus luctuosus

Berosus indicus

***Chlaenius* sp.**

***Paederus* sp.**

***Platylomalus* sp.**

***Hydrovatus* sp. (Larva)**

***Sternolophus* sp. (Larva)**

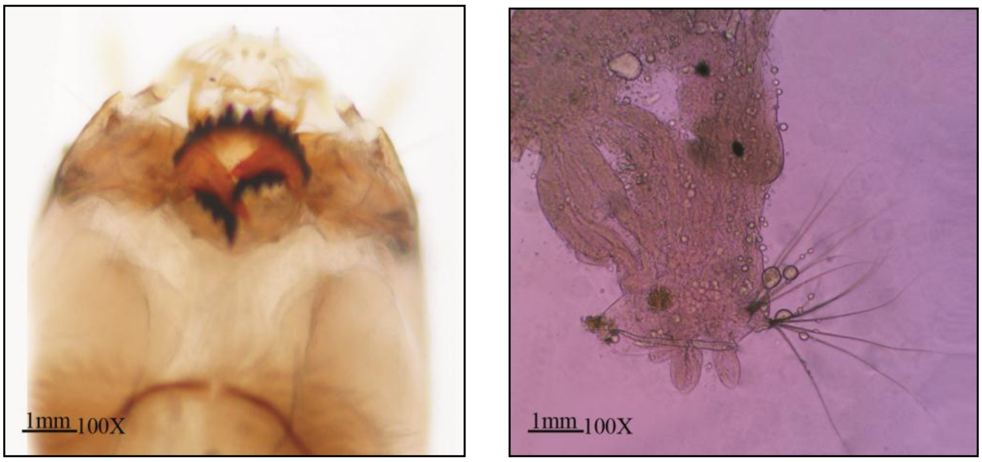
***Bezzia* sp .**

***Anopheles* sp. (Pupa)**

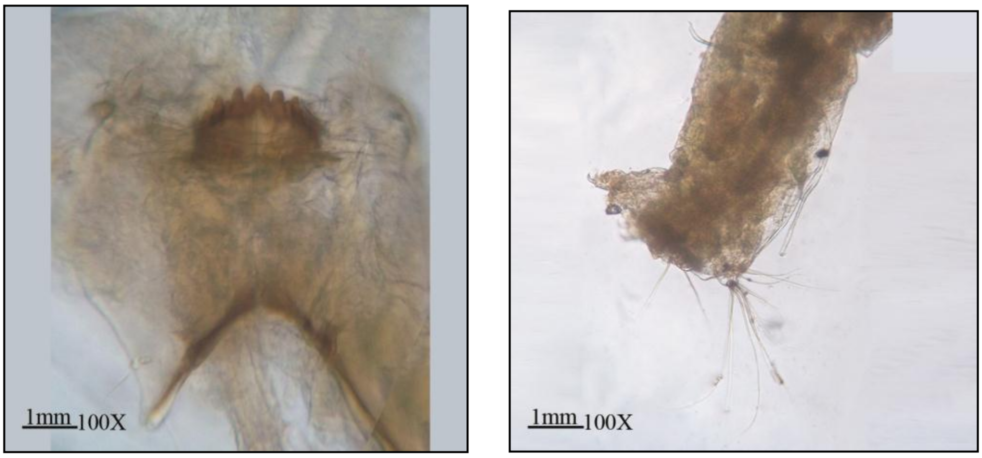
***Anopheles* sp. (Larva)**

***Chironomid* sp. (larva)**

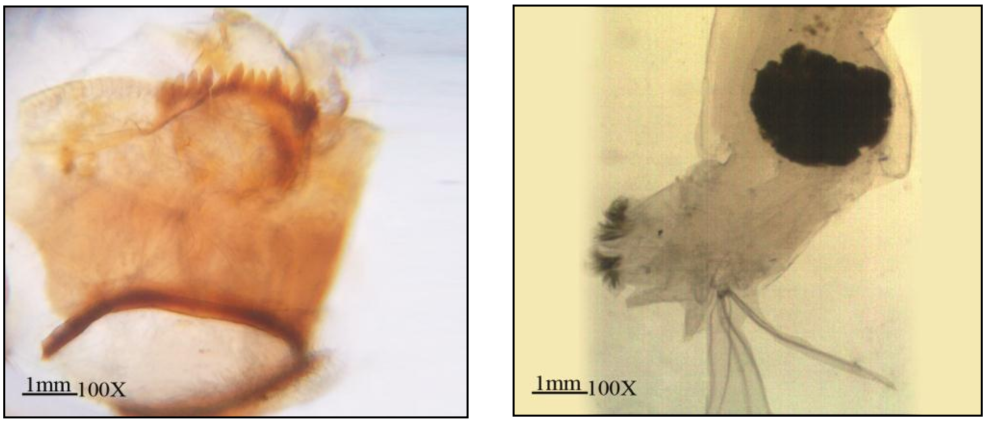
Ventral head capsule and Posterior part of *Ablabesmyia annulata*



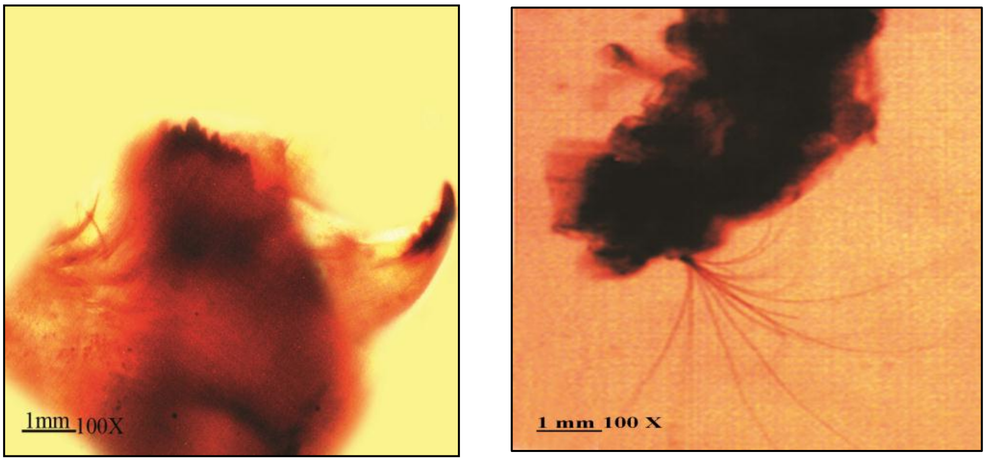
Ventral head capsule and Posterior part of *Chironomus major*



Ventral head capsule and Posterior part of of *Cladotanytarsus* sp.

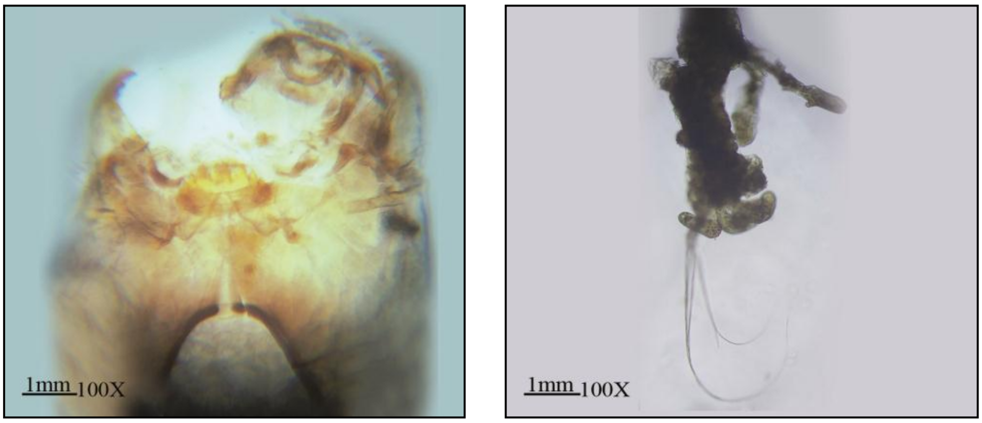


Ventral head capsule and Posterior part of of *Conochironomus* sp.



Ventral head capsule and Posterior part of of *Dichrotendipus* sp.

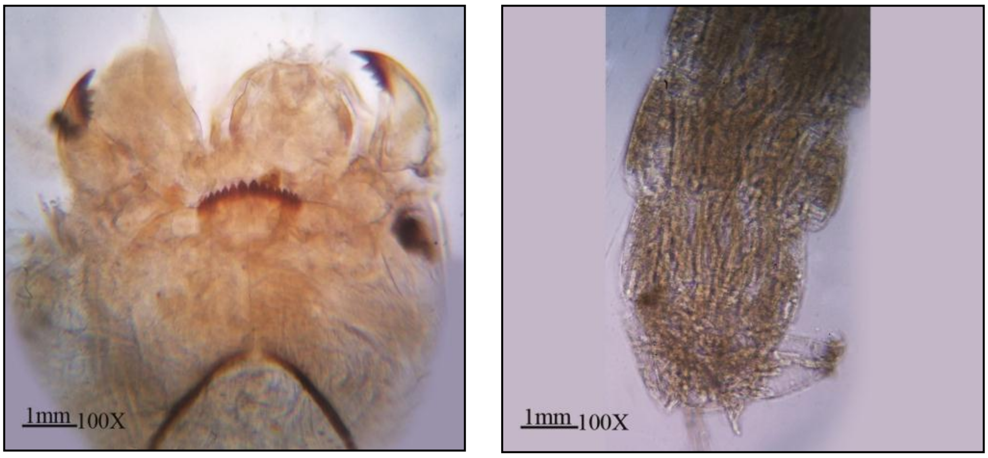
Ventral head capsule and Posterior part of *Einfeldia synchrona*



Ventral head capsule and Posterior part of *Lueterboniella* sp.

Ventral head capsule and Posterior part of *Monopalopia tillandsia*

Ventral head capsule and Posterior part of *Paratanytarsus sp.*



Ventral head capsule and Posterior part of *Polypedilum leei*

Ventral head capsule and Posterior part of *Polypedilum nubifer*

Ventral head capsule and Posterior part of *Rheotanytarsus pellucidus*

Ventral head capsule and Posterior part of *Tanypus carinatus*

Fig.8.17. Major aquatic insects identified in Maranchery Kole wetlands during the study period

Apart from aquatic insects the other major groups observed were Euhirudinea, Mollusca, Ostracoda, Branchiopoda, Decapoda, and Arachnida. Molluscs were further identified and representing three families which includes Viviparidae, Bullinidae and Ampullaridae. Viviparidae contributed one species, *Bellamya bengalensis* (4.6%), followed by family Bullinidae by *Indoplanorbis exustus* (43.1%) and family Ampullaridae by *Pila globosa* (52.3%) of the total molluscs. Ostracods was represented by one family Cyprididae which includes four species, *Stenocypris derputa* (33.9%), *Stenocypris hislopi*(22.6%) and *Chrissia* sp. (22.6%), *Strandesia elongate* (20.7%). About 9.8% of Branchiopoda was further classified to single Cyclestheriidae family of species *Cyclestheria hislopi*. Decapoda comprised of two families, Penaeidae by *Metapenaeus* sp. (97.5%) and Palaemonidae by *Macrobrachium rosenbergii* (2.5%). Arachnida was chiefly contributed by water mites (4.3%) and spiders (2.3%).

8.2.2 Univariate analyses and community structure of macroinvertebrates

The station wise species diversity indices of macroinvertebrates is presented in Table 8.1. The maximum richness was recorded in stations 1, 3 and 4 (d=1.954) closely followed by station 7 (d=1.953) and minimum in station 8 (d=1.520). Evenness based on macroinvertebrate groups showed the maximum evenness in station 8 (j'=0.635) and minimum in station 1 (j'=0.425). Shannon index was the highest in station 2 (H'=2.010) and lowest in station 1 (H'=1.413). Simpson dominance based on macroinvertebrates was calculated. Compared among the stations, the maximum dominance was observed in station 1 (1-λ'=0.577) and minimum in station 2 (1-λ'=0.353). In phase wise, species diversity indices comparison of macroinvertebrates is given in Table 8.2. When the richness was compared among different phases, the maximum richness was observed in the stable phase (d=1.716) followed by wet and paddy phase (d=1.338 and1.332) and minimum richness was observed in the channel phase (d=0.709). When the phases were compared, evenness index ranged from j'=0.767 in stable phase to j'=0.565 in wet phase. Higher diversity was shown in stable phase (H'=2.431) decreased during wet (H'=1.695) channel (H'=1.162) and paddy phases (H'=0.470). The maximum dominance was recorded in paddy phase (1-λ'=0.887) and minimum was in wet phase (1-λ'=0.238).

Table 8.1. Mean diversity indices of macroinvertebrate faunal groups in the eight stations in Maranchery Kole wetland during the study period.

Stations	Richness (d)	Evenness (J’)	Diversity (H’)	Dominance (1- λ’)
Station 1	1.954	0.425	1.413	0.577
Station 2	1.737	0.634	2.010	0.353
Station 3	1.954	0.459	1.527	0.538
Station 4	1.954	0.538	1.789	0.454
Station 5	1.737	0.578	1.833	0.406
Station 6	1.737	0.595	1.888	0.395
Station 7	1.953	0.589	1.957	0.398
Station 8	1.520	0.635	1.906	0.385

Table 8.2. Mean diversity indices of macroinvertebrate faunal groups in the different phases in Maranchery Kole wetland during the study period.

Phases	Richness (d)	Evenness (J’)	Diversity (H’)	Dominance (1- λ’)
Paddy	1.333	0.149	0.471	0.887
Channel	0.710	0.501	1.163	0.598
Stable	1.716	0.767	2.432	0.239
Wet	1.339	0.565	1.695	0.465

8.2.3 Univariate analyses and community structure of aquatic insects

Variation in diversity and richness of insect fauna among the stations in Maranchery Kole wetlands is given in Table 8.3. The maximum richness was observed in stations 1, 2 and 3 (d=1.303), closely followed by stations 4 to 8 (d=1.302). Evenness based on insect families showed the maximum evenness in station 6 (j'=0.906) and showed a minimum in station 1 (j'=0.667). The maximum diversity was in station 6 (H'=2.546) and minimum diversity was in station 1 (H'=1.873). When the dominance based on insect families was compared, among which station 4 showed the highest dominance (1-λ'=0.288) and the lowest in station 6 (1-λ'=0.175).

When the richness of aquatic insect was compared among different phases in this wetland is given in Table 8.4. The maximum richness was observed in paddy phase (d=9.737) followed by wet phase (d=8.924), channel (d=7.830) and in stable phase (d=7.395). Compared among phases, evenness index ranged from j'=0.977 in stable phase closely followed by j'= 0.976 in wet phase, j'=0.975 in paddy phase and j'=0.964 in channel phase. The maximum diversity was in wet phase (H'=5.327) and the lowest diversity was observed in the paddy phase (H'=4.700). The maximum dominance value was observed in channel phase (1-λ'=0.023), whereas the paddy and stable phase showed a dominance (1-λ'=0.015) and in the wet phase showed a minimum dominance (1-λ'=0.011).

Table 8.3. Mean diversity indices of aquatic insect fauna in the eight stations in Maranchery Kole wetland during the study period.

Stations	**Richness (d)**	**Evenness (J')**	**Diversity (H')**	**Dominance (1- λ')**
Station 1	1.303	0.667	1.873	0.374
Station 2	1.303	0.835	2.344	0.233
Station 3	1.303	0.812	2.280	0.243
Station 4	1.302	0.735	2.064	0.288
Station 5	1.302	0.825	2.318	0.239
Station 6	1.302	0.906	2.546	0.175
Station 7	1.302	0.895	2.514	0.185
Station 8	1.302	0.813	2.282	0.223

Table 8.4. Mean diversity indices of aquatic insect fauna in the different phases in Maranchery Kole wetland during the study period.

Phases	**Richness (d)**	**Evenness (J')**	**Diversity (H')**	**Dominance (1- λ')**
Channel	7.830	0.964	4.907	0.023
Paddy	9.737	0.975	4.700	0.015
Stable	7.395	0.977	5.010	0.015
Wet	8.924	0.976	5.327	0.011

8.2.4 Multivariate analyses of macroinvertebrates and aquatic insect community

8.2.4.1 Cluster analysis of macroinvertebrates community

The similarity between the stations and phases of total macroinvertebrates community was analysed (Figs. 8.18 and 8.19). The similarity between stations showed that station 1 was significantly varied (Pi=1.26) and standing apart from the other stations with 67% similarity whereas the other stations were clustered together with more than 71% similarity. The similarity study between the phases showed that wet phase and stable phase were clubbed together at 63% similarity, channel and paddy phases were clubbed at 61% similarity and these four phases were significantly altered with a similarity at 51% (Pi=3.18).

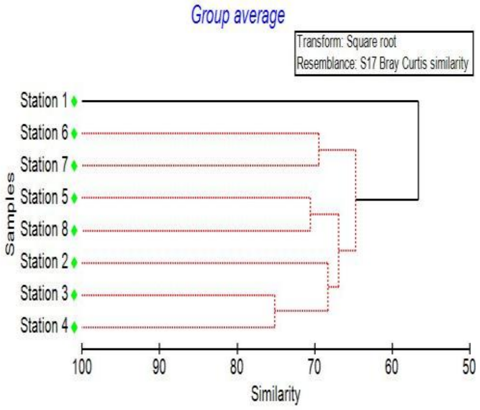


Fig. 8.18. Dendrogram of macro invertebrates groups of showing similarity in eight stations in Maranchery wetland during the study period (Solid lines represent significant delineation of groupings by SIMPROF test).

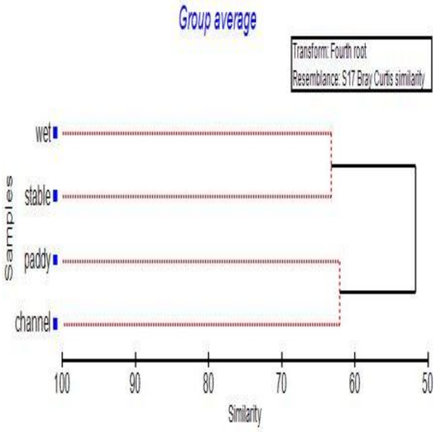


Fig. 8.19. Dendrogram of macroin vertebrates groups of showing similarity in four phases in Maranchery wetland during the study period (Solid lines represent significant delineation of groupings by SIMPROF test).

8.2.4.2 Cluster analysis of aquatic insect community

Similarity between insect community in station wise and phase wise was also analysed and plotted in Figures. 8.20 and 8.21. In station wise analysis, 3 major clusters were observed. Stations 6 and 7 clustered with a similarity 66%. Stations 1,2,3 and 4 clustered together with a similarity 67% and third cluster formed between stations 5and 8 with 66% similarity. In phase wise analysis showed that, two major clusters among which wet and stable phase clubbed together with a similarity 49% and paddy and channel phase clubbed together and showed a 63% similarity. Cluster 1 and cluster 2 were combined and showed a overall similarity 43% (Pi=3.5).

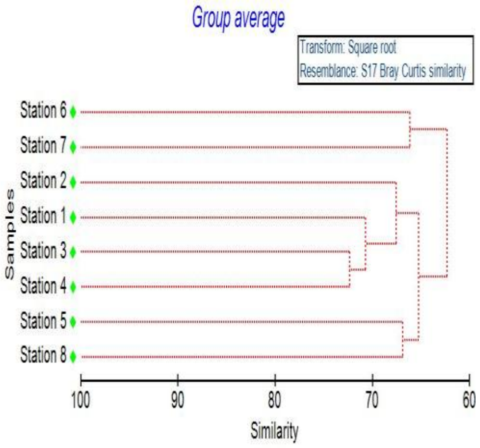


Fig. 8.20. Dendrogram of aquatic insects of showing similarity in eight stations in Maranchery wetland during the study period.

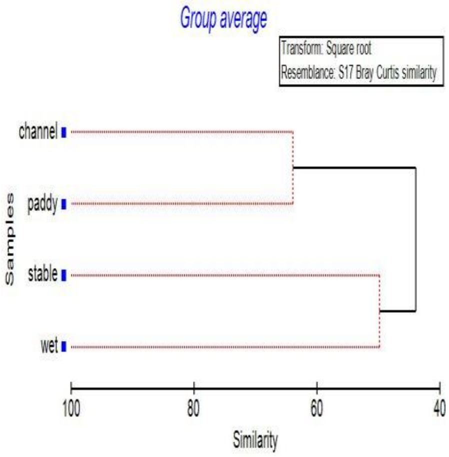


Fig. 8.21. Dendrogram of aquatic insects of showing similarity in four phases in Maranchery wetland during the study period (Solid lines represent significant delineation of groupings by SIMPROF test).

8.2.4.3 MDS plots (Non metric multi dimensional scaling) of macroinvertebrates community

To investigate macroinvertebrate community structure MDS plots were constructed between stations and phases (Figs. 8.22 and 8.23). In station wise analysis the stress value of MDS plots was 0.07. The MDS plots showed an average of 40% similarity for all stations. Stations 2,3,4,5,6,7 and 8 were clustered together at 60% similarity but station 1 was standing at a distance from the other stations. MDS plots between phases showed a good ordination having a stress value of 0.0. The wet phase and stable phase were clubbed together at 60% similarity. Similarly channel and paddy phase were clubbed together at 60% similarity. Within the two clusters four phases together formed and showed overall similarity of 40%.

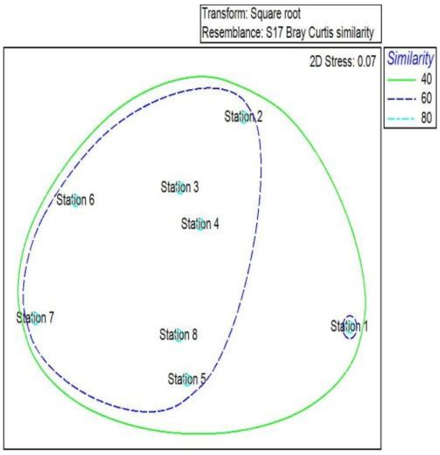


Fig. 8.22. Non-metric Multi Dimensional Scaling (MDS) ordination plots in the eight stations of macroinvertebrates groups in Maranchery Kole wetland during the study period.

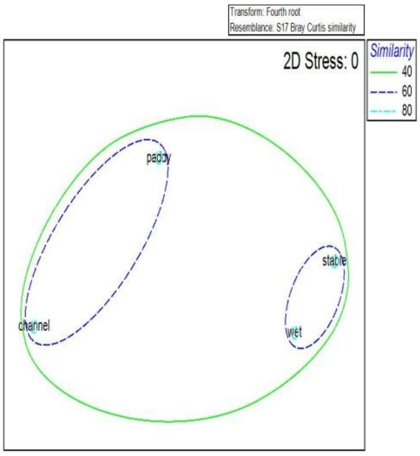


Fig. 8.23. Non-metric Multi Dimensional Scaling (MDS) ordination plots in the four phases of macro invertebrates groups in Maranchery Kole wetland during the study period.

8.2.4.4 MDS plots (Non metric multi dimensional scaling) of aquatic insect community

Similar to macroinvertebrates, MDS plots were constructed to analyze the similarity between stations and phases with respect to aquatic insect distribution. Eight stations were clustered together and showed an average of 60% similarity for all stations. The stress value of MDS plots was 0.11 (Fig. 8.24). MDS plots between phases showed that the paddy and channel phase were clustered together at 60% similarity. Wet and stable phase was standing apart with overall similarity of 40% with the other phases. The stress value of MDS plots was 0.0 (Fig. 8.25).

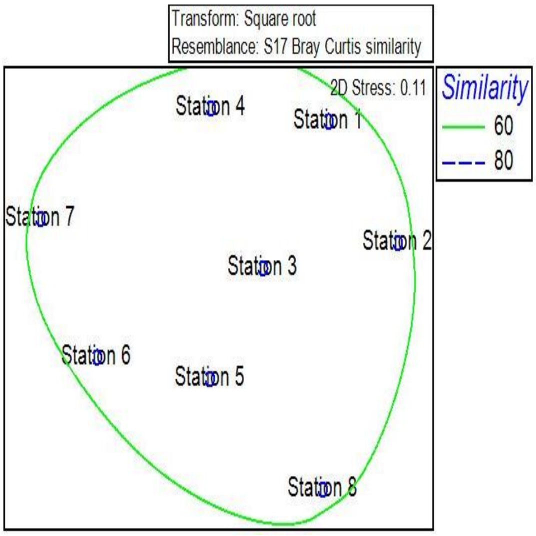


Fig. 8.24. Non-metric Multi Dimensional Scaling (MDS) ordination plots in the eight stations of aquatic insects in Maranchery Kole wetland during the study period.

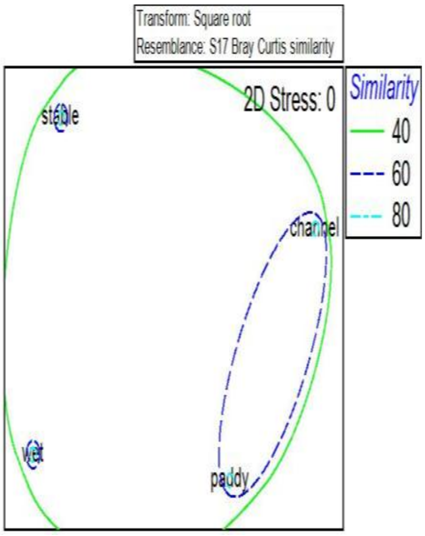
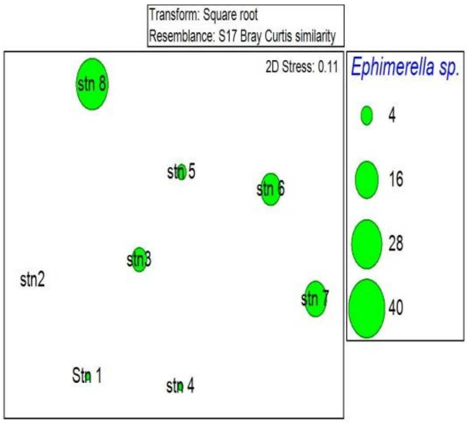


Fig. 8.25. Non-metric Multi Dimensional Scaling (MDS) ordination plots in the four phases of aquatic insects in Maranchery Kole wetland during the study period.

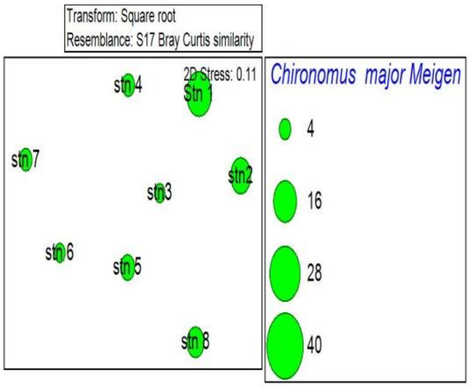
8.2.4.5 Bubble plots of major aquatic insect community

Bubble plots were also depicted that contributed to above 10% of major aquatic insects in station wise and phase wise as given in Figures 8.26 (a to f) and 8.27 (a to e). Station wise bubble plot analysis showed that

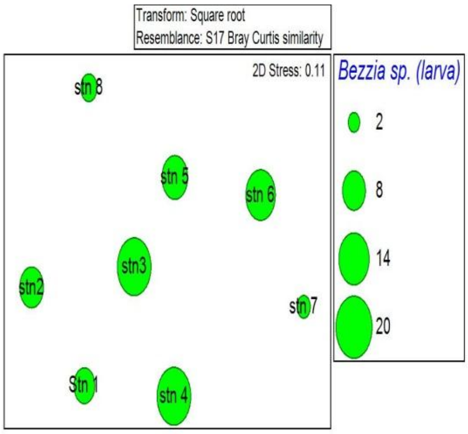
Ephemerella sp., depicted higher abundance in station 8; *Nannophya* sp. in station 7; *Chironomus major* in station1; *Bezzia* sp. with stations 3 and 4; *Canthydrus luctuosus* in station 4; whereas *Parapoynx diminutalis* in station 7. In phase wise analysis of insect fauna above 10% contributed to the ecosystem where *Nannophya* sp. and *Canthydrus luctuosus* contributed to channels; *Ischnura senegalensis* to the wet phase; *Berosus indicus* to both paddy and channel phases; whereas *Paederus* sp. to stable phase.



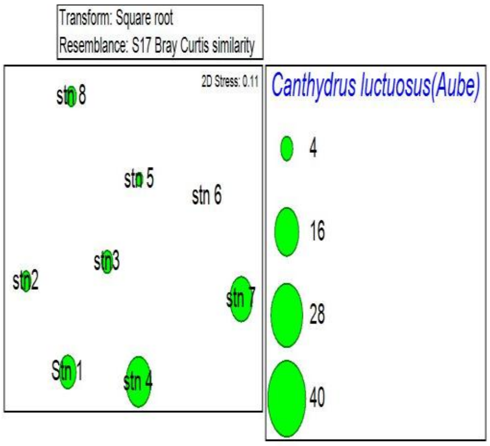
(a)



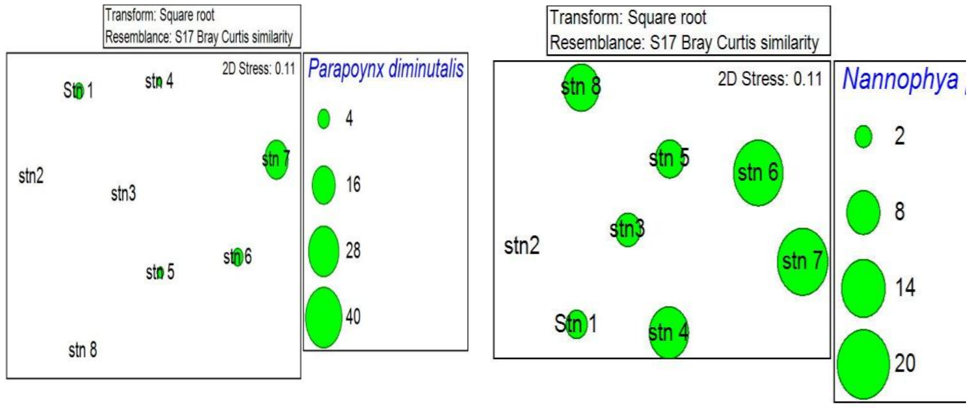
(b)



(c)

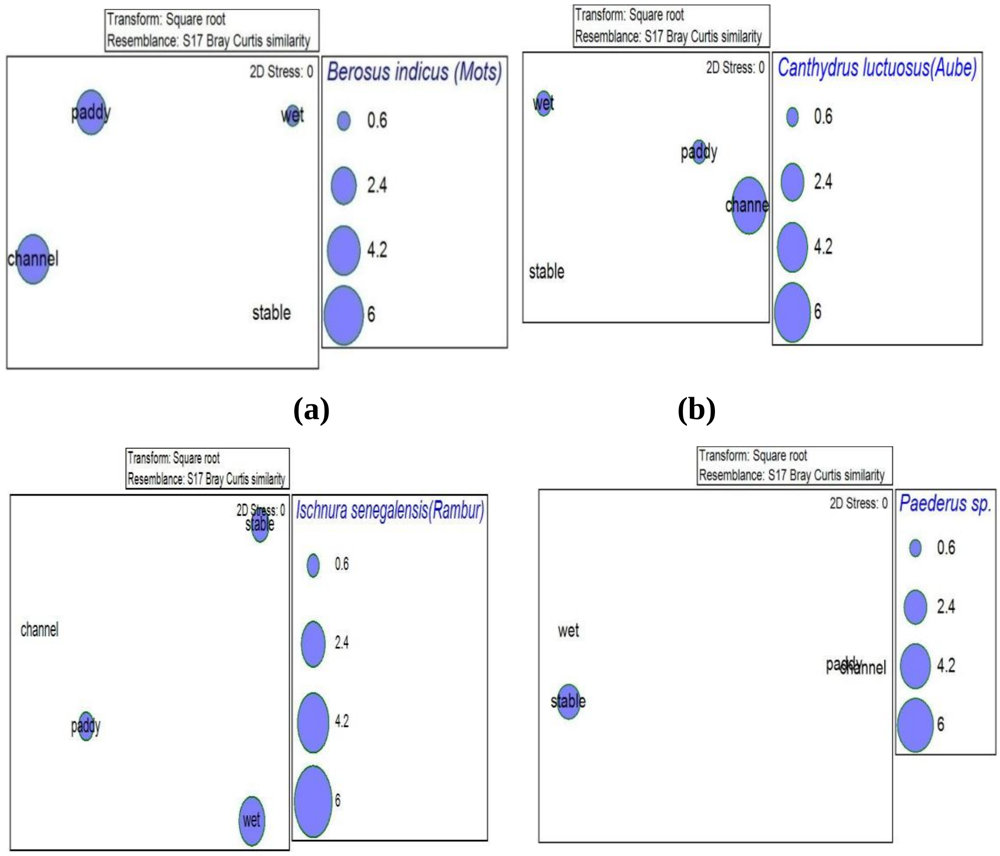


(d)



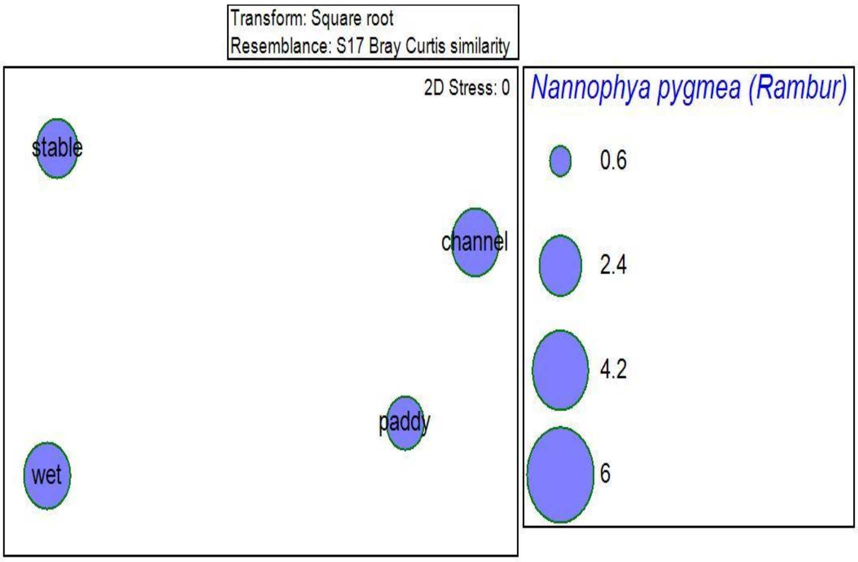
(e) (f)

Fig. 8.26 (a to f). Bubble plots of major aquatic insect observed in different stations in Maranchery Kole wetland during the study period.



(a) (b)

(c) (d)



(e)

Fig. 8.27 (a to e). Bubble plots of major aquatic insect observed in different phases in Maranchery Kole wetland during the study period.

8.2.4.6 Funnel plots of aquatic insect community

In funnel plots, both taxonomic distinctness and variation in taxonomic diversity of aquatic insects values of each study stations were compared on the basis of different phases. Average taxonomic distinctness during paddy phase for three stations (Stations 1, 2 and 3), except for station 3 was on the lower part of the 95% confidence funnel (Fig. 8.28). Stations 1 (63.03) and 2 (62.63) showed higher values and it reflects the higher diversity compared to station 3 (60.56). In channels of wetlands station 5 (61.67) has fallen within the 95% confidence funnel. However, the station 4 (58.52) fell extremely below the confidence funnel due to the less diverse community (Fig. 8.29). Again the wetlands were inundated, during wet phase in stations 1, 2, 3 and 4, have fallen within the 95% confidence funnel. Station 5 (62.04) fell extremely below the 95% confidence funnel (Fig. 8.30). During stable phase of Maranchery Kole land station 6 (60.44) showed higher deviation from the distributed path length (Fig. 8.31).

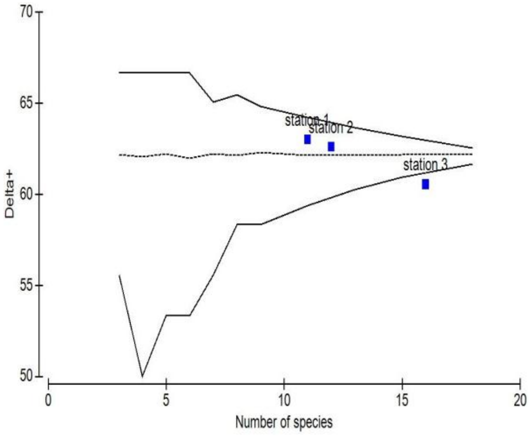


Fig. 8.28. Funnel plots of aquatic insects in the paddy phase in Maranchery Kole wetland during the study period.

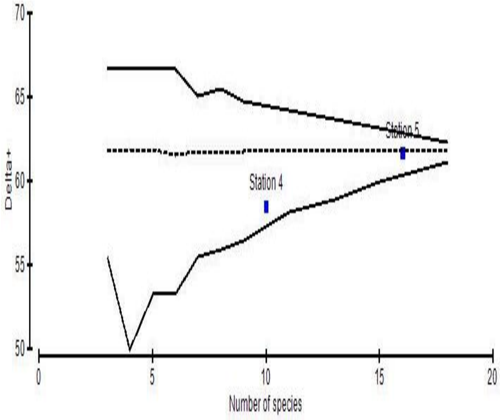


Fig. 8.29. Funnel plots of aquatic insects in the channel phase in Maranchery Kole wetland during the study period.

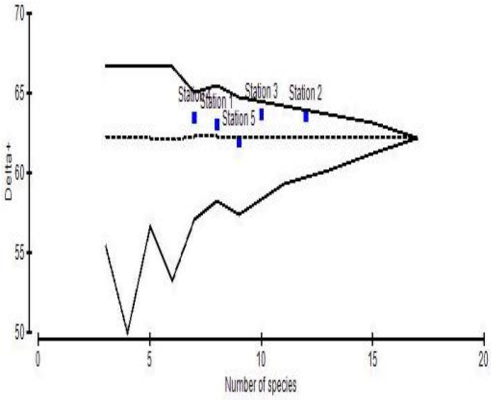


Fig. 8.30. Funnel plots of aquatic insects in the wet phase in Maranchery Kole wetland during the study period.

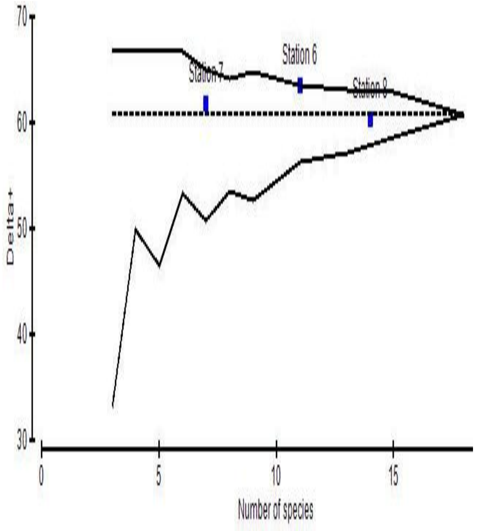


Fig. 8.31. Funnel plots of aquatic insects in the stable phase in Maranchery Kole wetland during the study period.

8.2.4.7 Species accumulation plot of aquatic insect community

Station wise and phase wise aquatic insects species accumulation plot was depicted in Figure 8.32 and 8.33, which helps to determine if the species collected during the sampling and adequately describe the actual species composition of the study area. In station wise examination the total number of species estimated by the species estimators varied from 42 to 61species. While the minimum estimate was specified by Sobs and UGE the maximum estimate was given by Jacknife 2. The number of insect fauna projected by Sobs, Chao1, Chao2, Jacknife1, Bootstrap MM and UGE were 58, 61, 59, 61, 59, 58 and 58 respectively. In phase wise evaluation total number of species varied from 35 to 65 species. The minimum estimate was given by UGE the maximum estimate was given by Jacknife 2. The number of insect fauna projected by Sobs was (56), Chao 1(64), Chao2 (66), Jacknife 1(64), Bootstrap (59), MM (57) and UGE (56).

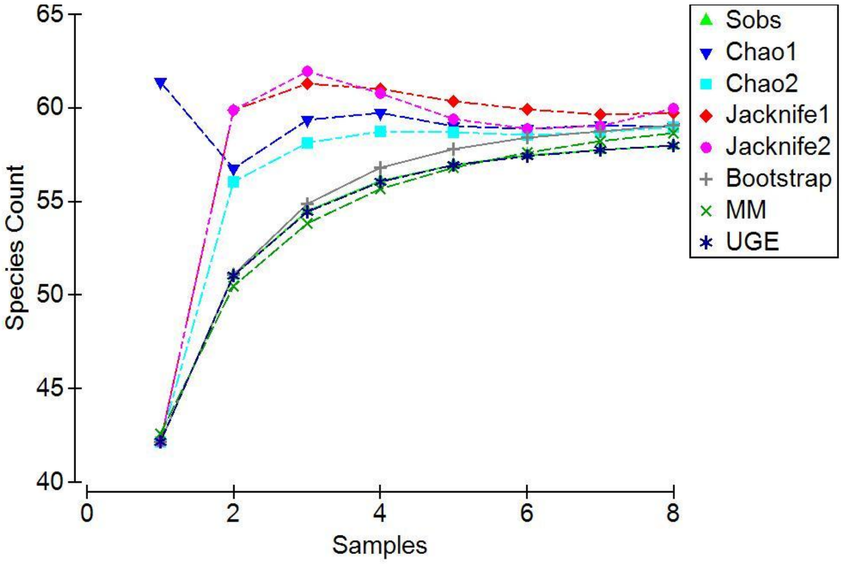


Fig. 8.32. Station wise species accumulation plots of aquatic insects in Maranchery Kole wetland during the study period.

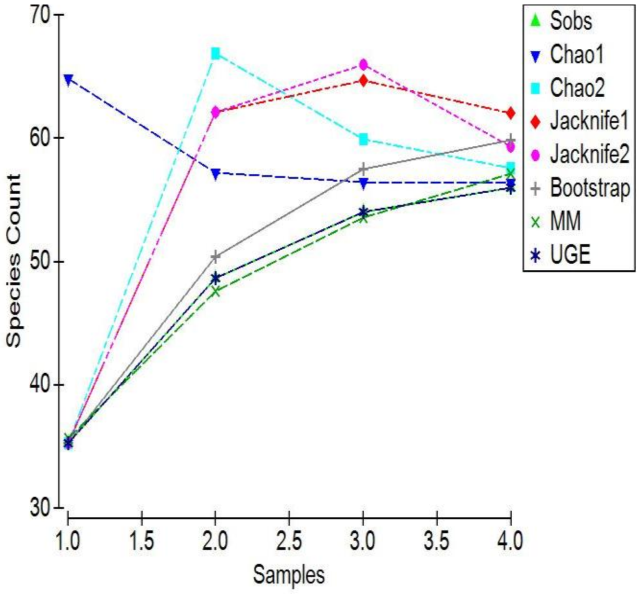


Fig. 8.33. Phase wise species accumulation plots of aquatic insects in Maranchery Kole wetland during the study period.

8.3 Discussion

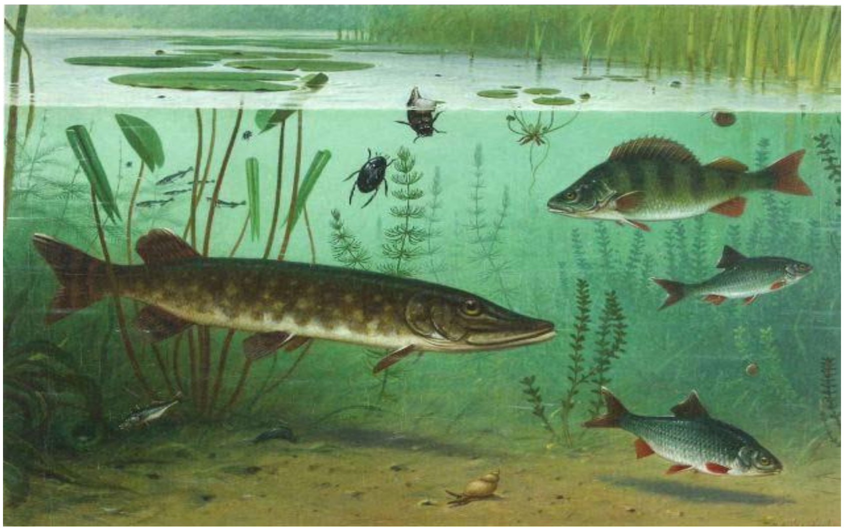
Bespyatova (2009) examined that, diverse and complex arthropods showed special microbiotope inhabited by a complex and peculiar microbiocenosis. In Maranchery wetland, there is a complex microbiocenosis, because each genus/species was associated with different macrophyte species. The present study identified 75 species/genus of macroinvertebrates, it comprised of 11 classes belonging to Insecta, Nematoda, Oligochaeta, Euhirudinea, Mollusca, Ostracoda, Branchiopoda, Isopoda, Decapoda, Arachnida and Pisces (Annexure II). The insect fauna were found dominating during the study period (64.2%) in all the stations and also during phase wise evaluations. The leaves of hydrophytes are providing substrate for epiphytic communities. These macrophytes use light energy, carbon dioxide and water to synthesize carbohydrates and release oxygen into aquatic environment during photosynthesis, which is utilised by aquatic biota. Further, this plant can alter water temperature and availability of oxygen in the aquatic habitat, indirectly influencing the growth and survival of juvenile fishes. Dense surface canopies also radically change the habitat quality for macroinvertebrates. Macrophyte vegetations stabilize sediments, and it helps to improve water quality, and add diversity to the littoral regions of the wetland. Ahmad, (2016) studied the crustaceans and its microhabitat. Opined that water temperature and macrophyte density significantly altered the fish diversity also noticed that free floating and submerged plants obstruct the fish population. The diversity and distribution of macroinvertebrates in this wetlands varied widely, which was chiefly dependent on the availability of macrophytes and environmental quality of water. The dense vegetation and diversity of floral community was found to be responsible for greater faunal assemblage and help to establish stable insect communities. The significance of macrophytes in the distribution and abundance of freshwater insects has been well established by earlier researchers. Ghosh and Ponniah (2001) studied the floodplain wetlands, and catogorised wetlands into intermediate conditions between lentic and lotic ecosystems, they further analysed 31 species of common macrophytes which served as abundant and diverse number of aquatic entomofauna. Maranchery Kole land also is considered as intermediate in condition, because the land use pattern highly varied in a seasonal basis. They support diverse floral community and associated insects comprise of 7 orders, 30 families and 58 genera/species of aquatic insects and instars. Among insect fauna collected, Coleoptera was diverse in number of genera (18sp.) comprising 20% of insect fauna which includes adults and larval forms. The other orders represented were by Ephemeroptera (3 species), Odonata (7 species), Hemiptera (7 species), Trichoptera(3 species), Lepidoptera (4 species) and Diptera(16 species). The major percentage of insects was contributed by Dipterans in eight stations except station 7 that was represented by Coleoptera. Sehgal (1991) recorded 57genera of insects from 11 rivers of the North-Western Himalaya. Balachandran et al. (2012) studied the insect fauna from river of Central Western Ghats and identified 38 genera under 28 families and 8 Orders. Joydeb Majumder et al. (2013) identified 31 species belonging to 23 genera, 15 families and 4 orders were recorded from freshwater lakes of Tripura; Sarma and Baruah. (2013) recorded 15 genera and 14 families of aquatic insects from lotic ecosystem of Guwahati City. Kripa et al (2013) identified 44 families of macroinvertebrates from Koratti chaal; Abhijna et al. (2013) identified 60 species under 37 families and 8 orders of entomofauna from Vellayani Lake; 74 genera of invertebrates identified from ephemeral wetlands of Southern Kerala by Usha Balaraman, (2008). Singh and Mishra (2013) noted 30 taxa of macro-invertebrates dominated by Ephemeroptera and followed by Diptera, Tricoptera and Plecoptera in the Ken river, central India. Joshi (2013) recorded 50 genera of insects from Sherkhad stream in Himachal Pradesh. Mohan (2005) reported 68 genera of insects from various rivers of Kumaon region. Compared to above studies Maranchery Kole lands also showed a good diversity of entomofauna.

The percentage contribution of Branchiopoda, Arachnida, Euhirudinea, Mollusca, Decapoda and Ostracoda were in the order 9.8%, 6.8%, 6.5%, 5.8%, 3.3% and 2% respectively. Nematoda, Oligochaeta, Isopoda and Pisces contributed on an average less than 1% in the study stations. Ostracods are represented by four species only but are the most subdominant in number as comparing with other groups. Ostracods feed the parts of plants or associated periphyton (Lodge, 1991**)**. The abundant ostracods may prevent algal blooms, thereby allowing submerged macrophytes to persist. Harkal et al. (2011) identified three species of ostracods from Kagzipura lake. In the case of branchiopods this wetland also supported only one species during the entire study period. The species identified was *Cyclestheria hislopi* of family Cyclestheriidae was common throughout the study period. Subhash Babu and Bijoy Nandan (2010) distinguished a new record of male and Ephippial female of *Cyclestheria hislopi* from a irrigated paddy field (60 ha.) at Thommana, Trichur in Kerala. Usha Balaraman, (2008) elaborated branchiopods were essential invertebrates from temporal pools, represented by only one species of Conchostraca. Euhirudinea was chiefly found in association with plants *E. crassipes* in station 6 and *S. molesta* in station 7.

Molluscs was one another important phylum identified from Maranchery Kole, which belongs to gastropods. Species *Indoplanorbis* *exustus* and *Pila globosa* are the common species observed throughout the study period. *Bellamya bengalensis* was one another species identified which was rarely seen in this wetland. Nine species of gastropods and forty five species of bivalves were identified from Vembanad lake (Dev et al., 2009). Previously Unnithan et al. (2001) and Suja and Mohamed, (2010) studied the growth rate of clam species. Arachnids were contributed mainly by water mites and spiders which were chiefly associated with plant *E. crassipes*. Arachnids were covered with more than 90% of the natural enemies in Korean paddy fields reported by Bang et al. (2006). In contrary to this arachnids are found less in percentage in paddy phase whereas higher percentage in wet and stable phases of this wetland. Compared to spiders, water mites were having higher percentage in the wetland.

Association of oligochaetes and macrophytes was rare, only 0.2% was identified from this Kole land, which are collected from paddy fields. Mastrantuono (1991) noted decrease of chironomids and nematodes in accordance with the increase of oligochaetes and gastropods in Lake Vico, Italy, and opined that, the intensification of agricultural activities in the last decade pointed to the necessity of analysing the littoral biocenosis in order to identify possible negative effects on littoral fauna. Twenty seven species of oligochaetes were reported from Maranchery wetlands by Vineetha, (2015). Eighty two species of oligochaetes were found from freshwater bodies of Montenegro, Albania by Danijela and Branko, (2012).

Lakes and other stagnant water are homes for different groups of aquatic insects i.e. for the surface hunters and divers (Yule and Yung, 2012). In this Kole lands compared to adult insects larval and nymph stages are observed frequently. Presence or absence of littoral vegetation and depth of the wetland found to be important factors and that is affecting in the distribution of aquatic insects in this wetland. Diversity and distribution of aquatic insects were higher in paddy phase of this wetland. The habitat fragmentation in paddy phase favoured insect taxa more due to their active/flight mode of dispersal also shallow water in paddy phase favours insects compared to other macroinvertebrate groups. Tonapi (1959) gave information about the aquatic fauna and their adaptations. Many of the adult, nymph and larval stages of mayfly, stone fly, dragon fly, cadis fly and mosquitoes and as well as numerous other species which are aquatic throughout their life cycle. The macroinvertebrate species was responsible for the differences observed between natural and artificial wetlands, however are ubiquitous and do not find natural wetlands having better water quality. As a result of an extended drought period, the natural wetland sites were in a drying phase and water levels were low at the time of sampling which influenced the macroinvertebrate diversity (Devi, 2013; Papas, 2007). Zoetwatervisschen and Koekkoek (1873 – 1944) given a clear sketch which shows how macrophytes turns as habitat for macroinvertebrates.



Source: Zoetwatervisschen Koekkoek, 1873 – 1944

The family Ephemerellidae contributed by *Ephemerella* species was absent in station 2 and was present in all other stations of the present study. The family Caenidae, *Caenis nigropunctata* are also wide spread in this wetland. The caenids are poor swimmers and they usually crawl among vegetations and feed on microorganisms in association with submerged hydrophytes. This species is generally considered as an indicator organism (Morse et al, 2007). Nymphal stages of Caenidae are common in standing water and are quite tolerant of organic pollution Dudgeon et al. (2006). Burton and Sivaramakrishnan (1993) observed higher numbers of Ephmerellidae from the streams of the Silent Valley National Park, Kerala. Baetidae family members of *Centroptilum* sp. larvae was mainly seen in the lower surface of plants and it was absent in stations 2, 4, 5 and 7 in the wetland. Baetidae family adult are seen in water surface but some species crawl along the water surface and lays rows of eggs beneath the water, they swim rapidly and for short distances. This is one reason for increase in percentage of *Centroptilum* sp. larvae in this wetland. Chiangthong (2005) found that the most abundant family found during the study period was Baetidae in Mae Kham watershed, Chiang Rai Province, Thailand. Species of Ephemeroptera taxa only was recorded in upper stretch of Assam river (Sarma and Baruah, 2013). Number of aquatic insects and their diversity were low during monsoon season primarily because of the dynamics of water which did not allow the entomofauna to grow and propagate in spite of nutrient input to the river from catchment areas (Amezaga et al., 2002). In Maranchery wetland, similar situations were observed in the case of Ephemeroptera assemblage. Diversity of Ephemeroptera was comparatively higher in paddy phase and decreased during wet phase. The increase in abundance and diversity of Ephemeroptera in paddy phase might be vegetative and reproducing growth stages of the rice plant such as tillering, booting and flowering stages attract many of the groups whereas decrease in diversity that may be due to higher nutrient input and heavy flow rate in wet phase.

Dragon flies and Damsel flies are the commonly observed aquatic insects during sampling time. In early morning they fly across the wetlands and near shore habitats, unfortunately no adult species was found in association with macrophytes; only larval stages were collected during sampling period. Most of the odonates deposit eggs on leaves of the hydrophytes. Larval and nymph stage of odonates inhabit in water. According to Tachamo (2010) the adult and larvae undoubtedly prey extensively on mosquitoes. Odonata distribution can also be indicative of the richness of other invertebrates and macrophytes. In Maranchery Kole field, 13% was contributed by odonates, and are chiefly found in association with free floating hydrophytes of *Eichhornia crassipes*. The Odonata was represented by the families Libellulidae, Gomphidae and Coenagrionidae. The family Libellulidae was represented by *Nannophya pygmaea*, and the other nymph species were mainly found in association with macrophytes are *Crocothemis servillia* and *Hydrobasileus croceus. Crocothemis servillia* was recorded from all the eight stations. Whereas, *Nannophya pygmaea* was absent in station 2. *Hydrobasileus croceus* was recorded from stations 2, 6 and 8. This species was seen in stable and wet phases. The species *Ictinogomphus rapax* of family Gomphidae was observed in stations 3, 5, 6 and 7. *Ictinogomphus rapax* species of family Gomphidae are generally mud dwellers. It was collected during paddy phase and channels of Kole lands during the study period. In these phases plants were usually sampled very near to the soil substrata. These results were agreeing with Yule and Yong (2004) and Gomphidae species was represented generally in harsher environments of highly acidic water in peat swamps or oligohaline pools of landward margins. Respiratory adaptations of long snorkel in the posterior segments of Gomphidae allow them to burrow into a depth of at least 5 cm or probably deeper and taking clean water into its rectal basket (Silsby, 2001). Gong et al. (2000) also stated that, species of Gomphidae are burrowers, clingers or simply live concealed with in bottom detritus or aquatic vegetations. Gullan and Cranston (2008) collected odonates from spider webs in the vegetation around ponds and drains. This study is in tune with the present observed results. In Maranchery wetland, higher number of arachnids webs were found in association with *E. crassipes*, it might trap the larvae of Odonates. Contrary to this, another possibility of increase in odonates in association with *E. crassipes* plants might be higher number of branchipods, midges, ostracods and water mites found in association with these plants. The higher availability of food is attracted to odonates to these vegetations. Corbett (1999) was agreeing with the above statement, and they mentioned that odonates larvae are voracious carnivores, using vision or mechanoreceptors to detect their prey. The family Coenagrionidae is chiefly represented by 3 species of nymphs of *Agriocnemis lacteola, Ischnura senegalensis* and *Pseudagrion* sp. In this study *Pseudogrion* sp. was in higher abundance with *L. heterophylla* and *Ischnura* sp., that showed biocenosis with *L. adscendens*. Typically, the labial palp shoot out very rapidly to capture the target organism. The increase in abundance of these two species might be the diverse growth of macrophytes and this will offer a good niche and will also be helpful for their predation. *Pseudogrion* sp. and *Ischnura* sp., are common in Brahmaputra Valley, Assam (Gupta and Narzary, 2013).

Das and Gupta (2010) observed that density of hemipterans in the agricultural field was less compared to the density in the rain pools. Similar results were observed from Maranchery Kole land, the diversity of Hemiptera was very less in paddy phase of this wetland. In wet phase 15.5% was contributed by Hemiptera. Six families and 7 species was presently recorded from this wetland. Adult species were common in this wetland. Major six families recorded were Nepidae, Belostomatidae, Pleidae, Corixidae, Hebridae and Gerridae. Of these Belostomatidae was most common family among Hemiptera in eight stations constituted by two species, *Diplonychus rusticus* and *Diplonychus annulatum*. In phase wise analysis both the species were present in four phases. Pleidae and Corixidae were represented by two genus *Paraplea* sp. and *Micronecta* sp. *Paraplea* sp. was having higher percentage in station 6 and it was absent in stations 1, 4 and 7. *Micronecta* sp. contributed only in wet phase. Tirumalai (2002) identified 80 genera of Hemiptera from different wetlands of India. Deepa and Rao (2010) and Deepa Jaiswal (2010) gave the information of water bugs of Andhra Pradesh. Sharma and Chowdhary (2011) recorded total 13 species belonging to 4 different orders in Central Himalayan River, Tawi (Jammu and Kashmir). Indiscriminate application of pesticides like Malathion, an organophosphorus compound in agricultural fields may hamper the diversity of Hemiptera (McKnight et al., 2015). They reported single species of Hemiptera. Schowalter (2016); Sites et al. (1997) in rain fed ecosystems the Hemiptera was successfully colonized in highly vegetated areas to avoid the risk of competition. In Maranchery Kole land higher diversity of Hemiptera was found in association with *L. heterophylla* in station 2. Hebridae, Nepidae and Gerridae contributed minor percentage to the wetland. In station wise analysis, 0.2% was contributed by each species. Family Nepidae was represented by *Ranatra brevicollis*; family

Hebridae was represented by *Hebrus* sp. and family Gerridae was represented by *Gerris* sp.. Hemiptera are generally hemimetabolous in nature, this feeding habitat might be attracting the bugs into the particular hydrophytes of this Kole land. Shah and Walling (2017) noted hemipterans generally stake over the water surface and most of the species are wide spread in variety of habitats. Gogola (1996) observed ripple communication for prey location and courtship has been demonstrated in certain species of water bugs. The *Ranatra* sp. (water stick insect) are most abundant and wide spread in Southeast Asia (Lansbury, 1972). Nepidae and Belostomatidae family is generally found in association with trash and mud or remains entangled with aquatic flora in the shallow littoral regions of the wetlands (Zettel and Yang, 2002; Deepa Jaiswal, 2010). The above study was in consonance with our results. Belostomatidae family was the most common species found in association with littoral vegetation of the wetland.

In Maranchery wetland, Trichoptera was contributed by only 3%. Trichoptera or caddis flies are generally tube dwellers or case dwellers. In this study free living trichopterans like *Neureclipsis* sp. of Polycentropodidae family was most common and wide spread in all stations. Family Hydropsychidae and Rhyacophilidae are not common and occasionally observed in some stations. Yadav (2006) identified Hydropsychidae from Palung valley from Kathmandu, Nepal. *Polycentropus* species of family Polycentropodidae was most common in Vellayani lake reported by Abhijna and Biju (2015). Ríos-Touma et al. (2017) reported species of Polycentropodidae family that is found usually in fine sand in slowly moving streams. The family Hydropsychidae is the most commonly encountered family of Trichoptera in Asian streams reported by Wells and Huisman (1992). Trichoptera larvae are usually fully submerged in the water and depend on oxygenated water for respiration (Kjer et al., 2002). Similarly in wet phase increase in density of Trichopera was mainly due to increase in abundance of macrophytes and increase of depth of water column in this phase. In Maranchery wetland, Trichoptera taxa were less abundant during paddy phase, this might be due to less availability of water in this phase. The immature stages of Trichoptera and life history of majority of species are unknown, especially in Southeast Asia (Merritt and Cummins, 1996). This could be one limitation in further identification of Tricoptera upto the species level.

Order Lepidoptera belonging to moths and butterflies was contributed by 4% of the collection in the wetland. Only larvae were identified in association with macrophytes. In Maranchery Kole land, Lepidoptera showed higher biocenosis with *S. molesta* vegetations and was abundant during stable phase. Major species observed were *Elophila interruptalis*, *Parapoynx diminutalis,* and *Potamomusa* sp. The decrease in diversity and density of Lepidoptera in paddy and channel phases might be due to predation of migratory birds more over these larvae have very slow locomotors for movements, therefore the birds are very easy for predation. There are above hundreds of species of Lepidoptera whose early stages are associated with aquatic vegetation (Munroe and Solis, 1998). In general *Elophila* sp. and *Parapoynx* sp. was usually laid egg under the floating leaves (Vallenduuk and Cuppen, 2004). *Parapoynx* sp. usually makes tunnels under aquatic vascular plants (Buckingham and Bennett, 1996). The larvae of *Potamomusa* is habitually located near the water surface and part of the body is extend to upper portion of aquatic vegetation. Murphy (1989) concluded that, large number of aquatic vascular plants and water ferns (Salviniaceae, Pteridaceae, Marsiliaceae, Menyanthaceae, Scorphulariaceae and Onagraceae) are utilized by the moth groups. Genus *Parapoynx* and *Eoophyla* was also reported from Vellayani lake by Abhijna (2009). Jacobsen (1993) reported that about 95% of aquatic macrophyte exploitation is due to larval lepidopterans, mainly family Pyralidae. Difference in the density and diversity of aquatic insects may also be attributed to some of the anthropogenic influences and grazing near stream bank as reported by Nusrat and Tahir (2014).

From the aquatic beetles of Maranchery wetland the results have shown that diversity were higher compared to other groups of insects. About 25% of Coleoptera was inhabited in this wetland. They were semi aquatic, aquatic and adult as well as larvae in forms. They are found in association with submerged or partially submerged macrophyte communities. Odegaard (2000) reviewed that beetles are not only rich in species but also, in size and ecological strategies. True beetles are diverse and inhabit a great variety of niches (Crowson, 1981). From the identified species several beetles are terrestrial in origin, during their evolution they invade the aquatic environment many times. Of the 10 families of aquatic Coleoptera - Dytiscidae, Hydrophilidae, and Noteridae are chiefly represented members in the wetland. Major species observed in Dytiscidae family was *Hydrovatus confertus* species that showed biocenosis with emergent and free floating plant *S. molesta* and submerged species of *U. aurea.* Among the Hydrophilidae family *Berosus indicus* showed higher in association with *S. molesta* and *U. aurea*, and *Laccophilus parvulus* was abundant in station 8. They were usually seen crawling among the vegetation. The surface hunters are the common water striders, water skaters and beetles which rarely, dive below. They walk and run with great speed on surface of water. Most surface hunters are gregarious and decided partially for open water particularly some shady plants on the shore (Vasantkumar and Roopa, 2014). The major studies of aquatic beetles in India were conducted by members of Vazirani, (1970, 1984); Jach and Balke (2008); Ghosh and Nilsson (2012). Khan and Ghosh (2001) and Johri et al. (2010) noted Coleoptera was the most common species recorded from their regional studies. In Maranchery wetlands dense vegetation of *U. aurea* and *S. molesta* gives immense space for live family Dytiscidae water beetles. Family Dytiscidae species might be eating detritus and decaying macrophytes. The family Dytiscidae generally occupied the clean and fresh vegetative portion of leaves near the bottom along the littoral region, that was reported by Deepa and Rao (2007). Larson et al. (2000) in conformity with above statement, in general reported that most of the species of diving beetles community was observed with abundant aquatic vegetation and also characterized by meso and eutrophic water bodies. Khan and Ghosh, (2001) accounted water scavenger beetles are generally found in shallower regions of water bodies with abundant hydrophytes particularly emergent ones and feeding detritus and decaying vegetative matter. These species are always in contact with surface water films and are good swimmers or crawling among water plants. The larvae of Hydrophilidae and Dytiscidae are also present in this wetlands. *Canthydrus luctuosus* of Noteridae family was one of the most abundant species in this wetland. Family Noteridae species inhabit in stagnant or slowly flowing water, rich in emergent and floating vegetation (Freitag et al., 2016). Biswas and Mukhopadhyaya (1995) identified the aquatic insects of West Bengal and stated that Hydrophilids are least accounted species. The dense networks of roots are favourable for growth of these kind of entomofauna in this wetland. The species of this family generally prefer semi exposed areas in water or fully sunny habitats. Larvae of Noteridae are usually collected from roots of aquatic plants, the larvae cannot swim, but crawl rapidly on the substrate or among water plants (Wood and Sites, 2002). The differences between the wet and dry periods for Coleoptera genera composition was determined by seasonal and diet variation. In Maranchery wetland species like, *Canthydrus luctuosus, Hydrovatus confertus* are higher in channels due to sunny habitat, shallow nature of water and availability of food resources. Therefore it may be categorized into marginal invaders. Arthropods such as beetles and spiders, are marginal invaders, and the channels associated with paddy fields are an important habitat of the same. Their populations in paddy fields rapidly recover after irrigation and tillage, because they escape to the margin and readily reinvade the paddy fields (Kawahara 1976; Hidaka, 1998). Some species of Coleoptera beetles are carnivorous in the wet and detritivores in the dry period (Motta and Uieda, 2004).

The other major species found in the wetland were ground beetles of families Curculionidae, Chrisomelidae, Dryopidae, Hydraenidae, Carabidae, Staphylinidae and Histeridae. The semi aquatic ground beetles, Carabidae, are usually nocturnal predators which are found on the shores of aquatic habitats. The genus *Bagous* of Curculionidae family live in stagnant water where they sprawl or cling to plants. Family Dryopidae, *Helichus* sp. are commonly known as long-toed beetles having bases of the antennae which are widely separated. First and second segments of antenna are enlarged and hardened, forming a shield beneath which remaining segments may be retracted and protected. Body parts and legs have woolly hairs. Hydraenidae was cosmopolitan family of true water beetles, they are unable to swim and they float to the surface of water (Diaz-Delgado, 2010). The species of this family was found in streams, paddy fields and flooded meadows (Jach and Balke, 2008). Two autotrophic food sources were important for some insect groups (Nessimian et al., 2008): aquatic macrophytes and algae. In Maranchery wetland herbivorous beetles like Chrysomelidae and Curculionidae with higher percentage was observed with dense vegetation and consumed aquatic macrophytes. According to some authors (Cummins and Klug, 1979; Harper, 1986; Allan, 1995 and Zhou et al., 2017) macrophytes, because of their low digestibility and high levels of cellulose and lignin, are rarely attacked by aquatic herbivores in running water. Aquatic macrophyte exploitation due to larval beetles was noted by Jacobsen et al. (1997). More than 18% aquatic beetles (mainly Curculionidae and Chrysomelidae); and 5% larval dipterans (mainly Chironomidae) consume as macrophytes from water bodies. *Bagous* species of Curculionidae was abundant in paddy fields of this wetland. The species was generally called as rice water weevils or pest in paddy fields, their piercing hook type proboscis is favourable for sucking juice from paddy plants (Morse et al., 1994). This might be the reason for increase of *Bagous* sp. in paddy phase. The other groups are generally semi aquatic in nature may be some favourable conditions of this wetland was preferable for them.

Dipterans are superior in number of individuals as well as in species. Thirty five percent of this wetland was contributed by dipteran larvae. Sixteen species of dipterans were identified from this wetland. They are catogorised into biting and non biting midges. Majority of the species are non biting category. No adult was observed in association with macrophytes. The family Chironomidae and Ceratopogonidae contributed a good percentage in most of the stations. Among the Chironomidae family *Chironomous major* was higher percentage and it was found in all eight stations. Other species found in this wetland are *Ablabesmyia annulata*, *Polypedilum nubifer*, *Paratanytarsus* sp., *Polypedilum leei*, *Tanypus* sp., *Cladotanytarsus* sp., *Monopalopia tillandsia*, *Lueterboniella* sp., *Einefeldia synchrona*, *Dichrotendipus* sp. and *Chonochironomus* sp. Dipterans were found higher in association with *H. verticillata* plant. I present study it is understood that the adult insects approach water bodies mainly to deposit their eggs. Chironomids were segregated by availability of food, space and time. Aquatic dipteran larvae exhibit a wide range of feeding habitat- many species are scavengers or phytophagous on aquatic macrophytes including cultivated rice (Oosterbrooek, 1998). Dipteran larvae of most species require moist or wet environment within the tissues of hydrophytes, decaying organic matter, a parasite or parasitoids of other animals in association with water bodies (Courtney et al., 2009). *Bezzia* species of family Ceratopogonidae was one of the most dominant species in this wetland. They are very rapid- snake like swimmers, the sluggish larvae burrow through sand and feed on microorganisms by raking their heads over the substrate, the knowledge of cycles of tropical Ceratopogonidae was poor (Borkent et al., 2013). Ten different larval chironomid species were identified by Bhosale et al. (2012). An unusual abundance of midges was observed in station 1. The complex nature of *H. verticillata* plant might be suitable for growth of midges in this station. The dominance of *Chironomus major* species in population may be due to versatile nature of feeding on material available on the mud water interface such as detritus macrophytes and algae. The restriction of other species such as *Polypedilum* and *Lueterboniella* may be due to resource based competition with *Chironomus* sp. which does not allow the former to establish. Immigration of spiders to paddy fields occurs after the appearance of chironomids was noted by Hidaka (1990). When chironomids are abundant, the density of spiders increases and they act as biological control agents against plant hoppers and leaf hoppers. In Maranchery wetland no such phenomenon was noticed but chironomids offer a good source for fishes for their diet. Higher percentage of chironomids was observed in paddy phase of this wetland. In contrary to these Kobayashi (1961) reported that an early insecticide application to control the first generation of rice stem borers often brings resurgence of plant and leafhoppers. Chironomid larvae in mud are also important food resource for fish, particularly for bottom-feeders (Katano et al., 1998) and for Odonate larvae (Matsura et al., 1998). On monthly basis species of *Tanypus,* next to *Chironomus* species was recorded, this trend in their population dynamics is due to the trophic factors as the *Tanipus* larvae have been reported to be predator of *Chironomus* species (Simpson et al., 1994). Two species of *Polypedilum* was identified from Maranchery wetland *Polypedilum nubifer and Polypedilum leei. Polypedilum nubifer* is a common, eurytopic midge in tropical and subtropical waters in the Afrotropical, Palaearctic, Oriental, and Australasian regions. Populations can become extremely abundant in warm, shallow, eutrophic waters subject to seasonal drying (Cranston, 2007). The larvae are also considered a major pest of rice fields in China, damaging the roots and leaves of rice seedlings (Xiao et al., 2012). In this wetland flood pulse and the littoral moving of the organic matter provide changes in the resources available to the midges. The dominance of larvae of midges was closely assigned to the type of functional feeding, flood pulse and more specifically with type of substrate (Kangmin, 1988). Biting midges of family Culicidae was reported by species *Anopheles*. Both pupae and larvae were reported in the same species in the wetland.

Out of 58 species of aquatic insects, most of the species were eudominant and certain species, like *Canthydrus luctuosus, Bezzia* sp., *Neureclipsis* sp., *Nannophya* sp., and *Diplonychus rusticus* were dominant species. These species appear to be good exploiters of resource in weed infested aquatic system. There were a number of subdominant species viz., *Chronomid major, Diplonychus annulatum, Hydrovatus confertus, Berosus indicus, Caenis nigropunctata and Ischnura senegalensis.* Leaves of macrophytes show a shift in adaptations in function of environmental challenges. Emergent and floating leaves showed adaptation against evaporation whereas submerged leaves promote gas exchange and light interception and to minimise hydrodynamic stress. Therefore percentage of aquatic insects was higher in submerged vegetations.

In this study, macroinvertebrate populations displayed phase wise trends similar to those previous reports (Gregg and Rose, 1985 and Chilton, 1990). Most populations were greatest at the beginning of phases and declined as it progressed with the exception of those organisms with a longer development period such as in Lepidoptera and Trichoptera. Hydroperiod had a significant and positive influence on invertebrate richness. Specifically, mean total richness increased taxa in short hydroperiod to intermediate hydroperiod compared to long hydroperiods wetlands (Tarr et al., 2005). Previous research has shown that in fishless habitats, invertebrate diversity and abundance increase with respect to hydroperiod (Wissinger et al. 1999; Brooks, 2000 and Duffy, 2002). For species with dispersing adults, pools that have longer hydroperiods are available to colonists for longer periods of time (Schneider and Frost, 1996). In Maranchery wetland, paddy phase showed higher percentage of Coleoptera and Diptera. The species that are found in temporary phase of the wetland represent an important refuge for the flora and fauna during shallow periods. Moreover most of the adult insects used this wetland for their breeding. Therefore, compared to adult insects more percentage of larvae were present in this wetland. According to Wantzen and Junk, (2006) the hydrological fluctuation contributes to a high biodiversity in floodplain ecosystems. The Order Coleoptera and Diptera were predominant in agriculture fields of this wetland ecosystem. Jones et al. (2012) distinguish two categories according to the existence of a sedimentation basin those containing in this basin present a richer diversity. Larger wetlands may have higher immigration rates by breeding adult insects (Roth and Jackson, 1987). Many adult species disperse in flight and find wetlands through visual or olfactory cues that may be accentuated from a larger body of water (Wiggins et al., 1980). Paddy and channel phases of this wetlands do not store inundated water though nutrient input from surrounding areas were increased but water stagnancy resulted in appropriate utilization of available nutrient followed by growth and reproduction thereby increasing in number and diversity of aquatic insect population. Moreover the thick growth of paddy plants offer a safe niche to insects from other predators. Paddy fields are likely to act as refuges for various kinds of natural enemies of arthropod pests that occur in upland crops grown close to paddy fields was reported by Kiritani (2000). Spatial diversity of habitats should support greater diversities of aquatic flora and invertebrates that would be found in structurally simpler wetland basins (Wissinger and Gallagher, 1999). This may be attributed to the increased colonized substrate area offered by the hydrophytes, more abundant food in terms of periphytic algae and detritus matters, and lower vertebrate predation rate in more complex habitats (Heck and Crowder 1991; Shriver et al., 1995). Apart from all identified macroinvertebrates the other groups like nematoda, oligochaetes, euhirudinea and isopods are also recorded but their identification is not conformed in the present study.

Similarity analysis of macroinvertebrates showed that station 1 was standing apart from other clusters mainly due to the higher abundance in this station. Similar to macroinvertebrates stations 5 and 8 and stations 2, 3, and 4 were clubbed together and formed two groups. This is may be due to the evenness of invertebrates as well as insect communities. The cluster analysis groupings based on macroinvertebrates and insect fauna between phases closely reflected the difference in depth and habitat type. Group 1 consisted of 2 phases, wet and stable phases characterized by deep, large and continuous water body. Group 2 contained channels and paddy phases which were shallow and alternating in nature. The phase wise MDS plots showed a stress factor of 0, a stress value revealing a good biological ordination (Clarke, 1993). Based on presence or absence of data the species in the study stations, funnel plots was drawn by testing the distinctness of a sample of insect species, from the distinctness value obtained by taking different species from the master list (Clarke and Warwick, 1999). The null hypothesis assumes that each sample contains species randomly selected from the global list and that it should thus fall within the 95% confidence intervals.

In the case of macroinvertebrates, richness and diversity was higher in wet and stable phases. In the channel and paddy phases, insects were the most numerically abundant group. In wet and stable phases prolific growth of macrophytes was present therefore reduced the competition among macroinvertebrates as well as insects which could have resulted in more richness and diversity in these phases. Diversity analysis and community structure of insects fauna showed higher species diversity (more than 1.0) indicating finely distributed individuals of the different species. This agreed with the observation of Smith and Grassle, (1977). Shannon’s index (H’) of aquatic insects ranged between 2.5 to 1.8, whereas in phase wise evaluation it was ranged between 5.3 to 4.7. Species richness was more or less similar in all the stations. In phase wise analysis species richness was higher in paddy phase and less in stable phase. Higher species diversity in the present study was an indication of less environmental stress and stable environmental condition in different hydro periods. Similar opinion was also put forwarded by Raffaelli and Mason (1981). The unique characteristics of rice fields render them as ideal habitats for many insects as well as instars in this phase. The difference in the growth phase of the paddy and the associated environmental conditions, weeds, nutrients, primary productivity etc. would have provided heterogeneity of habitat in time and space. These vast array of micro habitats provide shelter, food, breeding and nesting grounds thus resulting in successful establishment of entomofauna leading to the higher diversity and richness in paddy phase. The shallow nature of the paddy fields also allowed more light penetration upto the bottom of the field, which in turn facilitated the accumulation of relatively more amount of food material for macrofaunal species in the fields. Apart from the above reasons, in this wetland, organic farming was practised. The threat from agro chemicals which is normally experienced in rice fields was not there. It also would have contributed to the higher diversity here. The diversity index of aquatic insects is not different between organic and conventional rice fields as reported by Namwong et al. (2013).

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Chapter - 9

BIOTA AND ENVIRONMENTAL RELATIONSHIP IN MARANCHERY WETLAND

9.1 Introduction

The community of wetlands is an assemblage of populations of different species that occur together in a particular space and time. The primary focus of a community ecologist is the manner in which groupings of species are distributed in nature, influence on these groupings by interactions between species and by the physical forces of their environment and also their properties (Skidmore, 1987). Tansley (1935) implies that, communities and ecosystems studied as separate entities are wrong. No ecological systems, whether individual, population or community can be studied in isolation from the environment in which it exists. In an ecosystem community that is separated by clear and sharp boundaries, group of species lie adjacent to, but do not integrate into each other (Braak and Prentice, 1988). For example many insects that spend their larval stages in the water but their adult lives as winged stages on land or in the air. For many plants and biota, particularly short lived ones, their relative importance in the community will depend on seasonal changes.

The wetlands not only play a major role in recharging the water regime but also act as shock absorber for the resuming flood and erosion. Wetlands play a significant role in maintaining the diversity of life on earth. Wetlands are well known for high diversity in class, composition and four broad categories of functions *viz.* physical/hydrological, chemical, biological and socio economic (Williams et al., 1990). In the recent past, biotic pressures on these ecosystems have increased tremendously and it has been realized that many species of both plant and animals would be lost prior to their understanding in modern times. In the study of water pollution and the related "health" of aquatic ecosystems, three general approaches have found universal appeal: indices of diversity, similarity indices and biotic indices. The primary purpose of this section is to review, discuss, and evaluate proposed biotic indices. All discussion refers to the use of macroinvertebrates in lotic aquatic environments. More thorough discussion of the comparative merits of diversity, biotic and similarity indices can be found by Washington (1984). Abiotic and biotic factors influence the distributional patterns of macroinvertebrates. Abiotic factors such as seasonal variation of salinity, pH (Alcocer et al., 2001), depth (Gray 1981), habitat, hydrology (Peeters et al., 2004; Rosenberg et al., 1992), water quality (Hellawell 1986), dissolved oxygen (Franken et al., 2001) influence the macroinvertebrates. Similarly biological factors such as predation (Peterson, 1979; Kneib and Knowlton, 1995), competition (Peterson and Andre 1980; Settle and Wilson., 1990), and recruitment (Mullineaux and Butman 1990) also influences the community ecology.

Among invertebrates, aquatic insects are fundamental in understanding trophic structure in wetlands (Cummins, 1973). The trophic ecology of aquatic insects and their functional role in the environment are widely studied from different part of the world (Winterbourn et al., 1994; Jackson and Sweeney, 1995; Merritt and Cummins, 1996; Yule, 1996; Motta and Uieda, 2004; Tomanova et al., 2006; Boyero et al., 2011; Frauendorf et al., 2013 and Ramírez and Gutiérrez-Fonseca, 2014; Granados-Martínez et al., 2016). India is one among the seventeen mega biodiversity nations known in the world, and occupies the 9th position in terms of freshwater mega biodiversity (Chandra et al., 2017). In India, studies were relatively poor about the functional feeding group of aquatic insects (Subramanian and Sivaramakrishnan, 2007). Kole wetland encompasses a diverse array of ecosystems varied as lakes and rivers, ponds and streams, temporary puddles, thermal springs. Kole wetlands have wide fluctuation in annual water column. Despite this, aquatic habitats show far more variety in their physical and chemical characteristics than any other habitats and contain a disproportionately high fraction of the world’s biodiversity. Present study demonstrates the functional feeding groups of aquatic insects and its relations to environmental variables as well as macrophytes in the Maranchery Kole wetland.

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9.2 Results

9.2.1 Functional Feeding groups (FFG) and biomonitoring index of aquatic insects

The FFG classification system was not extensively developed in the original publication and has generated some degree of discussion and confusion as well (Ramírez and Gutiérrez-Fonseca, 2014). However, the main purpose of this classification is to aid in understanding the role that insect fauna play in ecosystem functions. Some of the ecosystem functions where insect fauna play an important role include control of primary production, detritus breakdown, and nutrient mineralization. The present study summarise FFGs based on the premise that they are the result of two key aspects of entomofauna: morphological characteristics related to acquiring food resources (e.g., mouth parts and related structures) and behavioral mechanisms (e.g., feeding behavior). This is the same principle originally used by Cummins (1973) when defining FFGs and by Wallace and Webster (1996) in their review of the role of macroinvertebrates in stream ecosystems. The Table 9.1 represents the family based FFGs of aquatic insects in Maranchery Kole wetland.

Based on the standard reference Cummins (1973) functional feeding groups of aquatic insects in Maranchery Kole lands are categorised into scrapers: scrapers are organisms that consume resources using mouth parts that are growing over substrates, which are adapted to crop the particles closely attached to rocks and other substrates (Ramírez and Gutiérrez-Fonseca, 2014); shredders: shredders are organisms that cut or chew pieces of living or dead plant material, including all plant parts like leaves and wood (Wallace and Webster, 1996); collector-gathers: collector or collector-gathers are organisms with modified mouth parts to sieve or collect small particles (<1mm) accumulated on the bottom of the water column; filter feeders: filterers are organisms with special adaptations to capture particles directly from the water column. Particle types consumed by filterers are very diverse in size and composition (Ramírez and Gutiérrez-Fonseca, 2014); predators: predators that lives by killing and eating other animals or insect that preys on other animals; piercers: piercers are organisms that feed on vascular plants by cutting or piercing the tissue using sharp or chewing mouth parts and consume plant liquids (Cushing and Allan, 2001).

Table 9.1 Functional Feeding groups (FFGs) of aquatic insects in Maranchery Kole wetland during the study period.

Order/Family	Functional feeding groups	Reference
Ephemeroptera		
Ephemerellidae	Generally CG.	Merritt et al. (1996)
Baetidae	Generally CG, SC	Baptista et al. (2006); Merritt et al. (1996)
Caenidae	CG	Merritt et al. (1996)
Odonata		
Coenagrionidae	Pr	Merritt et al. (1996)
Gomphidae	Pr	Merritt et al. (1996)
Libellulidae	Pr	Merritt et al. (1996)
Hemiptera		
Belostomatidae	Pr	Domínguez & Fernández (2009)
Corixidae	Generally Pc-Hb, some Pr or Sc	Merritt et al. (1996)
Hebridae	Pr	Domínguez & Fernández (2009)
Nepidae	Pr	Domínguez & Fernández (2009)

Gerridae	Pr	Domínguez & Fernández (2009)
Pleidae	Pr	Domínguez & Fernández (2009)
Trichoptera		
Hydropsychidae	Generally Ft. Some Pr and seasonal Sc	Merritt et al. (1996)
Polycentropodidae	Generally Ft.	Merritt et al. (1996)
Rhyacophilidae	Generally Ft.	Merritt et al. (1996)
Lepidoptera		
Pyralidae	Sh-Hb	Merritt et al. (1996)
Coleoptera		
Dytiscidae	Generally Pr (L and A)	Merritt et al. (1996)
Noteridae	Pr, CG (L). Pr (A)	Merritt et al. (1996)
Hydrophilidae	Generally Pr (L). Generally CG (A)	Merritt et al. (1996)
Curculionidae	Sh-Hb (L and A)	Merritt et al. (1996)
Chrysomelidae	Sh-Hb (L and A)	Merritt et al. (1996)
Dryopidae	Generally Sc, Sh-Hb (A)	Merritt et al. (1996)
Staphylinidae	Pr, CG, Sh-Hb (A)	Merritt et al. (1996)
Carabidae	Pr	Merritt et al. (1996)
Histeridae	Pc, Pr	Merritt et al. (1996)

Hydraenidae	Sc, CG (A)	Merritt et al. (1996)
Diptera		
Chironominae	Generally CG, Ft (L)	Merritt et al. (1996)
Ceratopogonidae	Some facultative CG and Sc (L)	Merritt et al. (1996)
Culicidae	Generally Ft and CG (L)	Merritt et al. (1996)
Chaoboridae	CG (L)	Merritt et al. (1996)

When most groups within a family belong to a few FFG, it is stated as “generally” or “some”. A=Adult, L=Larvae, CG=Collectors-Gatherers, Ft= Filters, Pr=Predators, Pc=Piercers, Sh=Shredders, Sc=Scrapers. For some cases, trophic guild information is provided to clarify their functional role: Hb=Herbivores. Thus, Sh-Hb is a shredder on live plant tissue.

Station wise and phase wise tabulated metrics of aquatic insects are given in Table 9.2 and 9.3. Station wise and phase wise different functional feeding group (%) is given in Figures 9.1 and 9.2. The taxa richness for the insect species ranged 36 to 46 numbers during the study period. The % EPT taxa (Ephemeroptera, Plecoptera and Trichoptera) formed highest in station 6 (9.72%), lowest in station 4 (4.2%). Ephemeroptera and Trichoptera were represented in this group. Plecoptera was absent in this wetland ecosystem. Percentage of tolerant organisms formed higher in station 2 (98.7%) and lowest in station 7 (8.2%) of the total insects collected in the study. Collector gathers were higher in station 1 (Chironomidae). Dominant taxa of family Chironomidae were in station 1 and 2, that of family Ceratopogonidae in station 3 and 5, that of family Noteridae in station 4, family Libellulidae in station 6 and 7, and family Ephemerellidae in station 8 of the insects fauna sampled. Percentage of predators was higher in stations 4, 6 and 7, whereas percentage of collector gathers are higher in station 1, 2, 3 and 8. In phase wise matrices of aquatic insect fauna shows that, % EPT taxa higher in wet phase (21.5%). Tolerant taxa formed higher in paddy phase (3.6%) whereas percentage of intolerant taxa was in wet phase (91.5%). Percentage of predators were highest in wet phase (49%) followed by stable phase (18.9%), channel phase (10.7%) and paddy phase (4.7%). Percentage of collector gathers was highest in paddy phase (40.8%), channels (25.4%), wet (16.3 % and stable phase (13%) respectively. Dominant taxa in paddy phase was found to be family Caenidae, in channels (family Noteridae), in wet (family Libellulidae) and in stable period (family Staphylanidae). Biomonitoring scores like, Biomonitoring Working Party Score (BMWP) denoted that pollution tolerant families are higher in paddy phase (441), in channel phase it was (373) in wet phase (372) and in stable phase (301) respectively. Average Score pre Taxon (ASPT) score of paddy phase was (2) compared to wet phase (4) (Table 9.4).

Table 9.2 Tabulated metrics of aquatic insects in eight stations in Maranchery Kole wetland during the study period.

Matrices	Stations							
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Total no. of taxa obtained	43.0	43.0	46.0	46.0	40.0	41.0	36.0	42.0
Ephemeroptera taxa	3.0	1.0	9.0	2.0	2	2.0	2.0	3.0
Plecoptera taxa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trichoptera taxa	1.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0
%EPT	4.77	7.37	17.16	3.41	9.17	19.70	19.27	19.26
% of intolerant taxa	2.00	3.33	14.67	2.00	6.00	12.00	7.33	8.67
% of tolerant taxa	98.7	20.5	41.8	36.0	12.5	9.4	8.2	19.4
% of predators	8.53	14.13	12.53	12.27	7.20	18.13	13.60	13.60
FFG(functional feeding group)	CG	CG	PR	PR	PR	PR	PR	CG
Major family	Chironomidae	Chironomidae	Ceratopogonidae	Noteridae	Ceratopogonidae	Libellulidae	Libellulidae	Ephemerellidae

Table 9.3 Tabulated metrics of aquatic insects in four phases in Maranchery Kole wetland during the study period.

	Phases			
Matrices	**Paddy**	**Channel**	**Wet**	**Stable**
Total no. of taxa obtained	44.0	34.0	35.0	28.0
Ephemeroptera taxa	3.0	2.0	1.0	2.0
Plecoptera taxa	0.0	0.0	0.0	0.0
Trichoptera taxa	1.0	3.0	3.0	1.0
%EPT	19.2	17.8	21.5	18.2
% of intolerant taxa	40.0	82.9	91.5	85.8
% of tolerant taxa	3.6	1.4	0.9	0.4
% of predators	47.0	18.2	11.6	5.0
FFG(functional feeding group)	CG	PR	PR	SH-HB
Major family	Caenidae	Noteridae	Libellulidae	Staphylinidae

Table 9.4. Biomonitoring scores of aquatic insects in four phases in Maranchery Kole wetland during the study period.

Biomonitoring score	**Paddy**	**Channel**	**Wet**	**Stable**
BMWP SCORE	441	373	372	301
ASPT SCORE	2	3	3	4

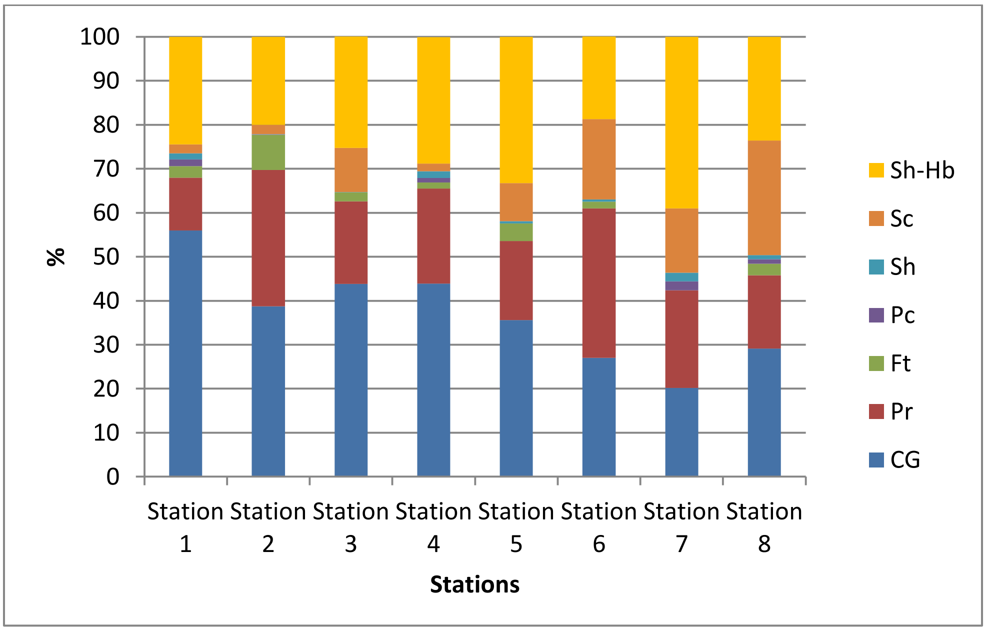


Fig. 9.1. Station wise percentage composition of functional feeding groups of aquatic insects in Maranchery Kole wetland during the study period.

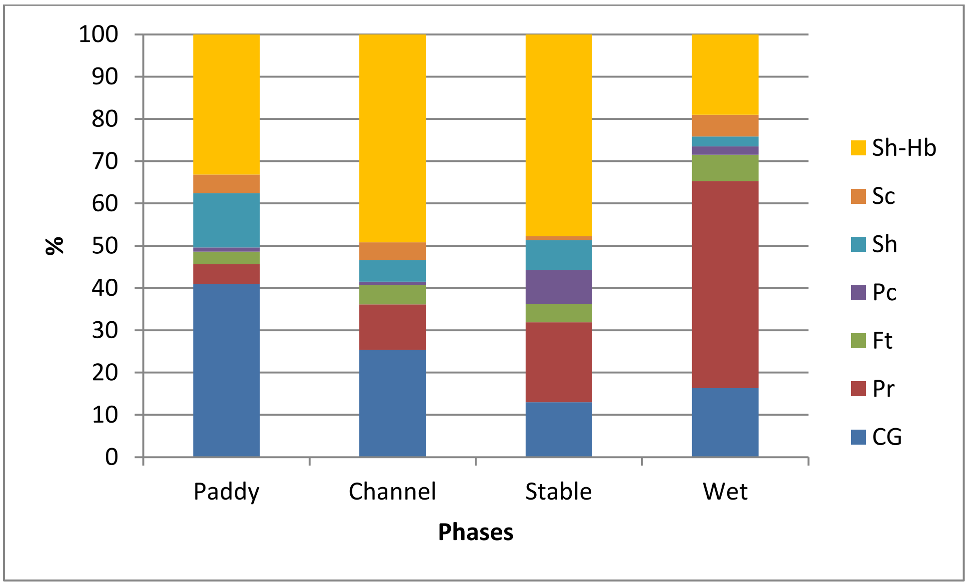


Fig. 9.2. Phase wise percentage composition of functional feeding groups of aquatic insects in Maranchery Kole wetland during the study period.

9.2.2 BIOENV Analysis

The BIOENV analysis in PRIMER also showed that the best environmental variables predicting the distribution of aquatic insect faunal groups were different for different phases. Parameters identified from BIOENV analysis that effect different phases on the distribution aquatic insects are given in Table 9.5. In stable and wet phases of the study area for depth, conductivity, phosphates and macrophyte biomass were the best matching variables (ρ=0.252) (Fig. 9.3), (ρ=0.071) (Fig. 9.4). In paddy phase pH, alkalinity and dissolved oxygen (ρ=0.371) (Fig.9.5), whereas in channel phase depth, conductivity and dissolved oxygen (ρ=0.318) (Fig.9.6) were the best matching variables.

Table 9.5. BIO-ENV results showing the list of variables that affecting the distribution of aquatic insects in four phases in Maranchery Kole wetland.

1. Depth	**2**. Water temperature	**3**. pH	**4**. Conductivity		**5**. Turbidity
6. Alkalinity	**7**. Dissolved Oxygen	**8**. NO_3-N	**9**. NH_3-N	**10**. Po_4-P	**11**. Plant biomass

Stable phase		**Wet phase**		**Paddy phase**		**Channel phase**	
Variables	**Rho**	**Variables**	**Rho**	**Variables**	**Rho**	**Variables**	**Rho**
1,4,10,11	0.252	1,4,10,11	0.071	3,6,7	0.317	1,4,7	0.318
1,4,8,10,11	0.249	1,4,8,10,11	0.070	3,5-7	0.306	1,4,7,10	0.317
1,4,6,10,11	0.245	1,4,6,10,11	0.067	3,6,7 10	0.301	1,2,4,7	0.315
1,8,10,11	0.245	1,8,10,11	0.066	3,5-7,10	0.296	1,2,7	0.315
1,4,11	0.244	1,4,11	0.064	2,3,6,7	0.294	1,2,4,7,10	0.313
1,10,11	0.243	1,10,11	0.064	2,3,5-7	0.292	1,2,7,10	0.308
1,7,8,10,11	0.243	1,7,8,10,11	0.063	2,3,6,7,10	0.287	1,7,10	0.306
1,4,6,11	0.241	1,4,6,11	0.063	6,5-7	0.276	1,7	0.302
1,4,6,8,11	0.241	1,4,6,8,11	0.061	3,6,7,11	0.273	1,4,7,8,10	0.298
1,4,7,10,11	0.240	1,4,7,10,11	0.061	3,5-7,11	0.269	1,2,4,7,8	0.296
1,4,8,10	0.240	1,4,8,10	0.060	2,6,7	0.265	1,4,8,10	0.295

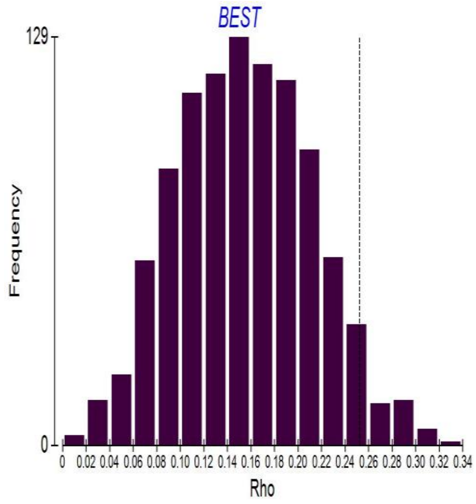


Fig. 9.3. Histogram showing the BIOENV results for aquatic insect abundance (Rho 0.252) in stable phase in Maranchery Kole wetland.

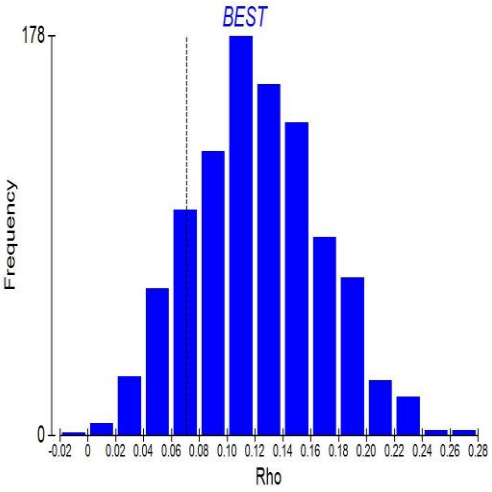


Fig. 9.4. Histogram showing the BIOENV results for aquatic insect abundance (Rho 0.071) in wet phase in Maranchery Kole wetland.

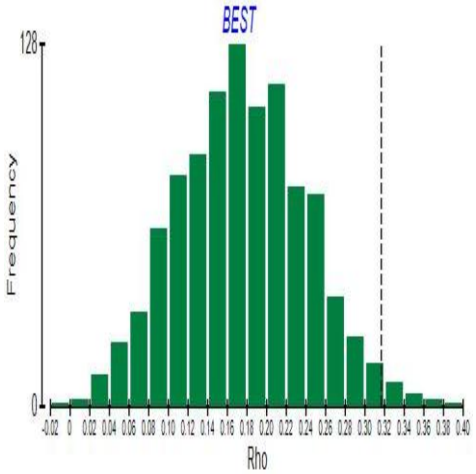


Fig. 9.5. Histogram showing the BIOENV results for aquatic insect abundance (Rho 0.317) in paddy phase in Maranchery Kole wetland.

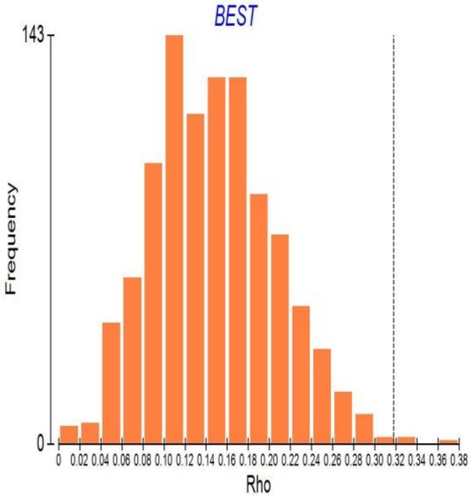
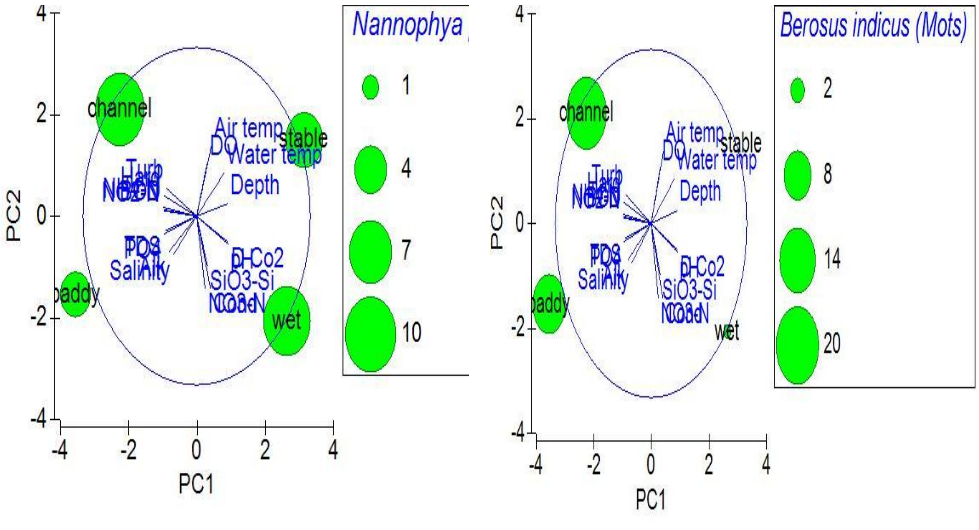


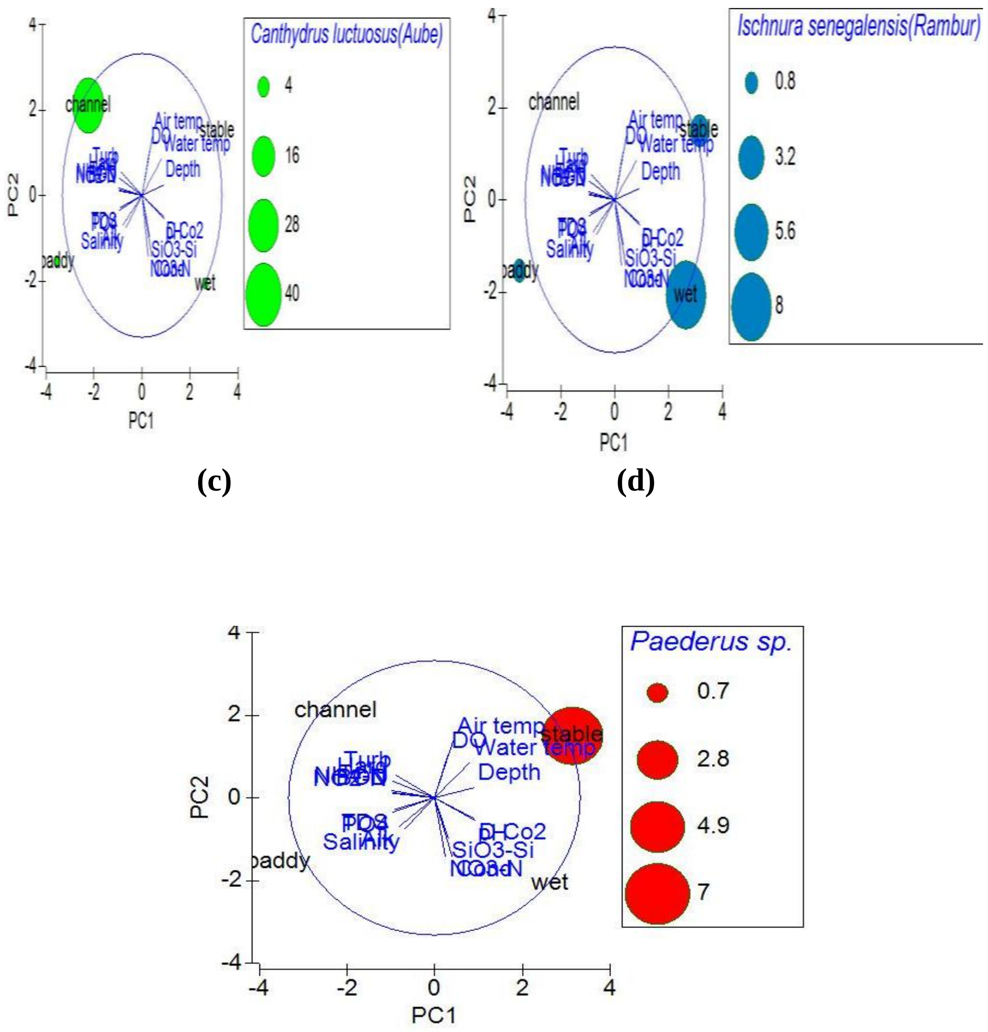
Fig. 9.6. Histogram showing the BIOENV results for aquatic insect abundance (Rho 0.318) in channel phase in Maranchery Kole wetland.

9.2.3 Correlation analysis between aquatic insects and environmental variables

In Maranchery wetland correlation study was carried out with major species of insects and environmental variables and is depicted in Figure 9.7 (a to e). Species of *Nannophya* was higher in percentage in channel and wet phases and lowest in paddy phase. Major influencing factors were TDS, salinity, alkalinity and PO_4-P. Species of *Berosus* and *Canthydrus* were higher in channels of the wetland, influencing factors were depth, temperature and dissolved oxygen. *Ischnura senagalensis* was higher percentage in wet phase and the factors influencing were turbidity, hardness, NO_3 -N, and NH_3-N. *Paederus* sp. was higher in stable phase and the major influencing factors were turbidity, hardness, salinity, TDS, PO_4-P, NO_3-N and NH_3-N.



(a) **(b)**



(c)

(d)

(e)

Fig. 9.7 (a to 6) Principal component analysis super imposed with bubble plots of aquatic insects and its environmental relations with different variables.

9.3 Discussion

Tropical ecosystems are inhabited by diversity of insect fauna with unusual adaptations. Therefore, it is not surprising to find organisms that do not fit in a single functional feeding group (FFG) or perhaps their behavior and function varies over space and time. Available information indicates that some families belong to FFG (Table 9.1). The FFG classification was developed by Cummins (1973) and adopted in multiple ecological projects. The percentage contribution of scrapers was maximum in station 8 and minimum in station 1. Station 6 and 7 also contributed a good percentage of scrappers into this wetland. Scrapers consume a diversity of resources. In station 8 of Maranchery wetland, Ephemerellidae family showed higher abundance of scrapers in association with plant *L. adscendens*. The other major scrapers observed in this wetland were family Baitidae, Corixidae, Hydropsychidae and Dryopidae. Higher scrapers in this station might be due to undisturbed hydrological regime. Past two or three years this area remain unused for cultivation therefore the soil particles have not changed. This will attract scrapers into these stations. According to Ramírez and Gutiérrez-Fonseca (2014) genera of the Ephemeroptera, Odonata, Lepidoptera, and Hemiptera orders showed feeding specialization. Mayflies were detritivores and both dragonflies and hemipterans were carnivores (Motta and Uieda, 2005). In Aghanashini river of Central Western Ghats scrapers were the predominant group observed by Balachandran et al. (2012).

Shredders were higher percentage in station 4 followed by station 1. In Maranchery Kole lands major shredders observed were order Coleoptera of family Curculionidae, Chrysomelidae, Dryopidae and in order Lepidoptera family Pyralidae. These species are higher in association with paddy phase. Only Staphylinidae family showed higher abundance in stable phase. In this phase majority of plants are grown as emergent. Debris of macrophytes and luxurious growth of rice plants may attract shredders into paddy phases. This might be one reason for higher number of shredders in this phase. Major function of shredders is the breakdown of large particles of plant material into smaller pieces and is then transported downstream or available to other stream consumers. Shredders make nutrients available to microbial consumers was reported by Villanueva et al. (2012). Wotton et al. (2008) gave general definition to define shredders as any organism that consumes leaf material is a shredder regardless of its behavior. Snails provide a good example, their feeding behavior involves the use of a radula to remove tissue by scraping the substrates they are feeding on. Villanueva et al. (2012) observed higher percentage of detritivores shredders in stream ecosystems. Order Lepidoptera family Pyralidae are another major shredders observed in the wetland. Pyralidae family shows higher association with live plant *M. quadrifolia* in Maranchery Kole land. Leaves of this plant were consumed by Lepidoptera. Figure 9.8 shows the biocenosis of macrophytes with macroinvertebrates in plant *M. quadrifolia*. Insects that consume living plant tissue are responsible for major herbivory losses by aquatic vascular plants (Cronin et al., 1999). Ding and Blossey (2005) reported that Chrysomelidae beetles are known to specialize on vascular plants and some are used as biocontrols of floating vascular plants. Cuffney et al. (1990); Konishi et al. (2001) in their study gave evidence for shredding macroinvertebrates increase the amount of fine particles in streams, while it remains unclear how these particles are important to insect collectors.

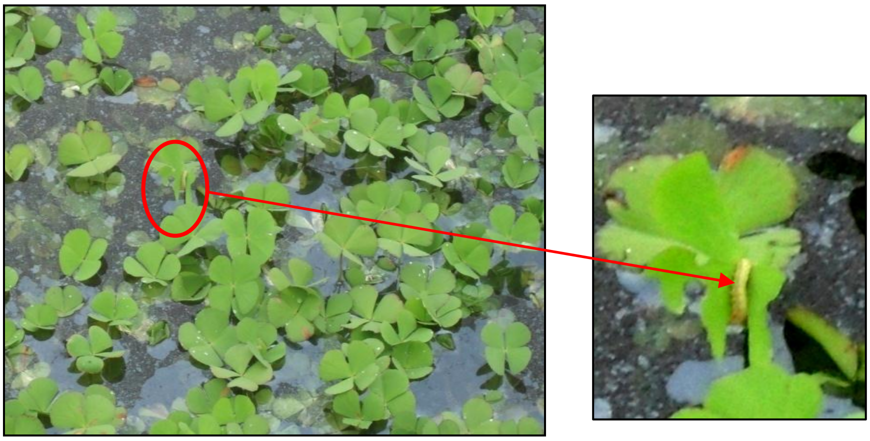


Figure 9.8. Biocenosis of macrophytes and macroinvertebrtes with plant *M. quadrifolia* in Maranchery Kole wetland.

Percentage of collector-gathers are comparatively higher in stations 1 to 5. Station 1 shows higher percentage of collector-gathers followed by stations 3, 4 and 5 whereas station 7 shows very less amount of collector gathers. Wallace and Merritt (1980) recorded that collector- gathers can consume small pieces of leaves. Their mouth parts are not equipped to cut leaves into smaller pieces hence they consume only leaves, that are small in size. In Maranchery wetland major collector-gathers were found in association with *H. verticillata, U. aurea* and *L. adscendens*. Abundance of collector gathers was higher in paddy phase. Chironomid midges are major collectors in this wetland. Collectors are often abundant in stream ecosystems where they tend to be more common in areas with slow flow and fine particles are abundant (Heard and Richardson, 1995). The above statement was in agreement with the present study. Submerged macrophytes like *H. verticillata, U. aurea* and *L. adscendens* were complex in plant structure and usually they present in slow moving shallow regions and carry large amount of suspended sediments to different parts of the plants, this might lead to increase the abundance of collector-gatherers in such plants. Collectors like chironomids have an important role in the food webs of streams, representing a major link between primary producers and the top level consumers (Aguiar et al., 2017). Chironomid larvae are not limited to a single feeding mode, which has been pointed out by some authors (Nessimian and Sanseverino, 1998; Henriques-Oliveira et al., 2003). Family Caenidae, Noteridae and Hydrophilidae are generally classified as collectors. These insects are also found in channels and paddy fields of this Kole lands. Due to different agricultural activities soil particles were loosely bound in paddy fields and presents fine particles in channels and paddy fields that may attract these kinds of insects into these phases.

Filter feeding insects are higher percentage in station 2 followed by stations 1 and 8. Trichoptera larvae of family Polycentropodidae are generally categorized to filters. In this wetland family Polycentropodidae was wide spread in distribution. Presence of modified mouth part was helpful to filter debris from macrophytes. They are very efficient in removing particles from the water column and reduce the export of particles from wetland ecosystem as reported by Oliveira et al. (2003). Vineetha (2015) classified the soil particles in this wetland ecosystem, and categorized into clayey silt, sandy silt, clayey sand, sandy, silty clay and silty sandy. The different particle size often support a good availability of food particles which might be one reason for wide spread distribution of family Polycentropodidae or filters in this wetland. Benke and Wallace, (1980) concluded that some Trichoptera larvae are known for consuming the drifting animals as part of their diet.

Higher percentage of predators was observed in station 6 and very less percentage was seen in station 1. Major predators of this wetland were odonates and hemipterans. Brodin et al. (2006) explained that, labium in Odonata is a highly modified and has a unique structure among aquatic insects for predation. Similarly, some Hemiptera have modified legs to capture prey (e.g., Nepidae and Belostomatidae) by Fontanarrosa et al. (2013). In Maranchery wetland, family Belostomatidae was widely collected throughout the study period. In wet phase of the wetland it supports large numbers of predators of the family Libellulidae. Prolific growth of macrophytes and its associated minor crustaceans were often attracting more predators into wet phase of this wetland. In stations 6 and 7 floating plants *E. crassipes* and *S. molesta* were highly associated with arachnids, ostracods, branchipods, decapods and hirudinea. Odonates are predatory in nature, but they are good source of energy to different animals, especially for birds and other insects and spiders (Basumatary et al., 2015). Therefore, importance of increase in the percentage of odonates in this wetland lead to increase of secondary consumers like fishes and migratory birds.

Maranchery wetlands major piercers were Family Corixidae and Histeridae. Diverse growth of higher level vascular plants *E. crassipes*, *N. pubescens* and *N. indicum* was invaded by insects family Corixidae and Histeridae. Growth of some soft structured vascular plants like *H. aristata*, *Sacciolepis* sp. will also attract these kinds of insects into the wetland. Other major species in this wetland was *Bezzia* sp. of Ceratopogonidae family. Henriques-Oliveira et al. (2003) observed family Ceratopogonidae was detritivorous in the wet and a periphyton feeder in the dry period. From this study it reveals that percentage of collector gathers and predators were abundant in this wetland. Due to flexibility in feeding habitat, for understanding resource utilization in insect communities gut content data analysis of the aquatic insects in trophic groups is more appropriate than the classification of functional feeding groups (Henriques-Oliveira et al., 2003). Dynamics of Kole wetlands and spatial variations related to different land usage varied the habit and habitat of insect communities in the present study was in agreement with the above statement.

The most commonly used richness metrics are total taxa richness and EPT taxa richness (Ephemeroptera, Plecoptera and Trichoptera ratio). Percentage of EPT is calculated and summarized in Table 9.2. Percentage of EPT was higher in stations 6, 7 and 8. In phase wise study, the status of water quality was good to fair range. Morse et al. (2004) opined that in areas like wide spread agricultural or urban land use, EPT species may be rare. They classified EPT taxa richness and total taxa richness assigned to water quality. Table 9.6 represents the water quality index of coastal plain ecosystems proposed by Morse et al. (2004).

Table 9.6. Taxa richness criteria for assigning water quality index of Coastal Plain ecosystems.

EPT Taxa Richness	Total Taxa Richness	Quality status
>27	>83	Excellent
21-27	65-83	Good
14-20	52-67	Good- Fair
7-13	36-51	Fair
0-6	0-35	Poor

In the present study percentage of EPT of stations 3, 6, 7 and 8 showed ‘good to fair category’. Comparing with the study by Morse et al. (2004) stations 2 and 5 comes under fair category and stations 1 and 4 relatively poor quality of water. In Maranchery wetlands EPT ratio was contributed by Ephemeroptera (May flies) and Trichoptera (Caddis flies). Plecoptera or stone flies are absent in this wetland. This study reveals that the sensitive species inhabit because the adverse environmental conditions have gradually eliminated them and the tolerant species establish their colonies and grow in abundance. More over the decrease in family Ephemeroptera was chiefly due to the consumption of fishes in the wetland. Abhijna et al. (2013); Rosenberg et al. (2000) indicates that higher anthropogenic disturbance was severe causing of habitat deterioration of aquatic insect community. May flies are often the most abundant and recognized freshwater insects especially in riffles, running water and marginal vegetation and they form an important component of fish diets (Miserendino and Pizzolon, (2001); Barber-James et al. (2008).

Wet phase of the Maranchery wetland observed higher percentage of intolerant groups of Odonata and Hemiptera. Odonates are important indicators of water quality and pollution levels (Kalita, 2014). They inhabit in diversified habitats near water bodies ranging from stagnant pond water to flowing streams. Silsby (2001) noted that odonates are the important link between aquatic and terrestrial ecosystem. Changes in aquatic communities such as mowing of shoreline vegetation or introduction of aquatic exotic species reduce the quantity of odonates habitat. Paddy fields of Maranchery wetlands are deputed with 40% of odonates and hemipterans. Odonata or 30% of the mainland species utilize paddy fields for oviposition by Ueda (1998). Kiritani (2000) reported that many of the aquatic hemipteran and coleopteran insects including the giant water bug, *Lethocerus,* water scorpions, *Laccotrephes japonensis* and *Ranatra chinensis* are known to reproduce in paddy fields. So the present study is in conformity with the above statements, the nymph stages of odonates and adult hemipteran species were abundant in this wetland. Moreover in wet phase of this wetland it was found that *Diplonichus* sp. was carrying egg mass into the upper part of their body.

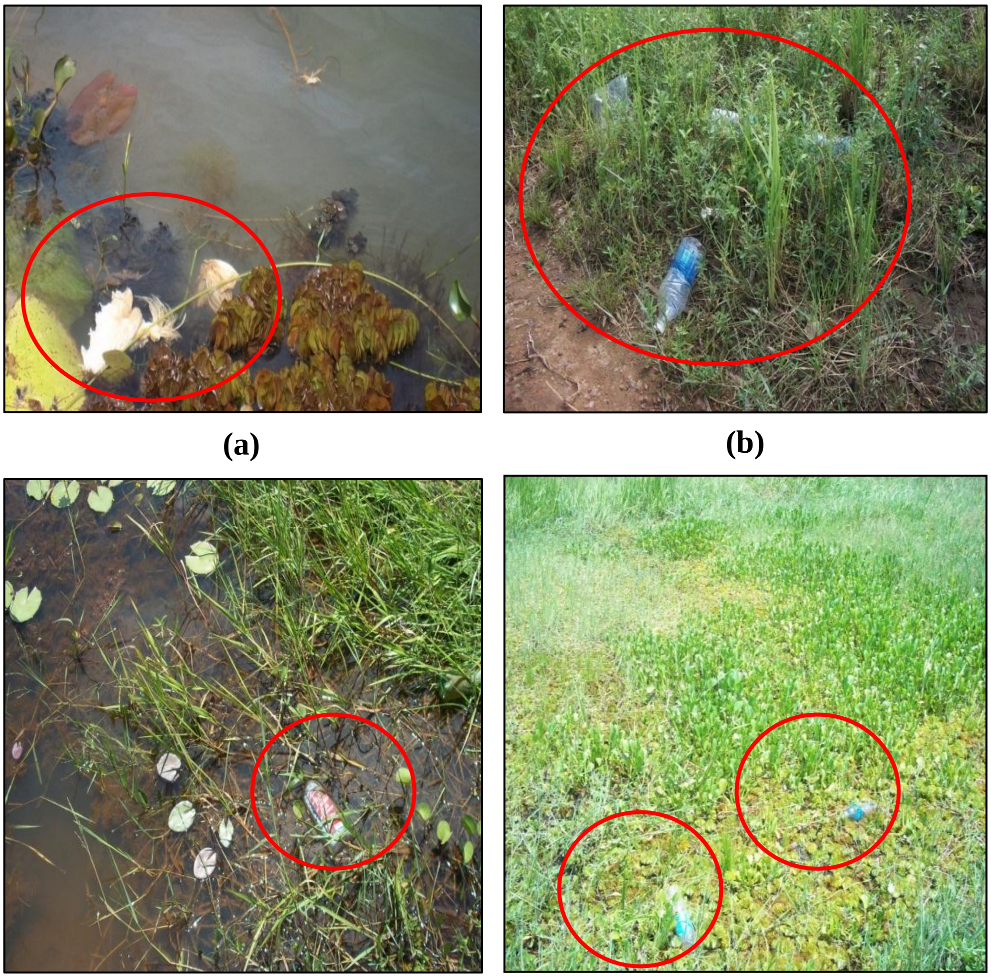
Percentage of tolerant taxa (Diptera) was comparatively higher in paddy fields followed by channels, wet and stable phases in Maranchery wetland. In paddy phase early growth stages of rice plants associated with increased abundance of chironomids. The rich organic content in paddy fields supports the dominance of chironomids in this phase. The threat from agro chemicals which is normally experienced in rice fields also lead to depletion of other intolerant taxa compared to tolerant taxa. Luo et al. (2014) opined that community is a key indicator of the structural stability of the paddy field ecosystem. Many aquatic insect species are intolerant and not found in polluted environment. The lower species richness was expected in greater polluted water. Only few species are pollutant tolerant, which are chiefly dipterans (Namwong et al., 2014). Several workers reported that Chironomidae was a dominant species in the paddy fields (Okuda and Furukawa,1990; Hidaka, 1994; Way and Heong, 1994; Settle et al., 1996). Saha and Mazumdar (2013) observed *Chironomus* sp. larvae as indicator of pollution stress in rice fields of Hooghly District, West Bengal. In the early rice growth stages Chironomidae was one of the dominant species observed in Korean paddy fields (Bang et al., 2010). Condition of a habitat may also be indicated by the presence or absence of a specific taxa. For example, in rivers and streams, dominance by chironomid midges is associated with degraded or polluted habitats, whereas a significant presence of the orders Ephemeroptera, Plecoptera and Tricoptera indicates intact habitats (Weigel and Dimick, 2011).

The Biological Monitoring Working Party (BMWP) score was computed by assigning a score to each family according to its tolerance to pollution (Annexure 1). The score varied from 1 to 10 (Table 9.7). The species with less tolerant to pollution were assigned with high scores and the highly tolerant species were assigned with low score. The total BMWP score was divided by the number of scoring families to calculate the Average Score per Taxon (ASPT) (Namwong et al. 2013).

Table 9.7. Average Score per Taxon (ASPT) score given by Namwong et al. 2013

ASPT score	
Value	Water quality
>6	Clean water
5-6	Fairly clean
4-5	Polluted
<4	Heavily Polluted

The average ASPT value from channels and wet phase (3) was higher than paddy phases (2). The highest was found in stable phase (4). Based on the above table, the aquatic insect ASPT score showed that water body was polluted due to heavily polluted nature. Figure 9.9 (a, b, c and d) given below also indicates that the wetlands are getting polluted due to various factors. Dumping of domestic and poultry wastes, plastic wastes all over the water body apart from encroachment has considering reduced the aesthetic value of these water bodies. People nearby this depend on the wetland for washing cloths and their cattles and domestic activities. It leads to reduction in diverse growth of macrophytes and may be contradicting possibilities like eutrophication etc. In future it can affect the agricultural production of the region.



(a) **(b)**

(c) **(d)**

Fig. 9.9 (a to d) Dumping of poultry and plastic waste in Maranchery wetland observed during the study period.

The functioning of ecosystems is determined by the organisms living together and their interactions among themselves and with other components of that environment (Jones et al. 1994). Biomonitoring is a valuable assessment tool which is largely used in water quality monitoring programmes of all types. While analyzing the relationship between the insect community and environmental variables in different phases weak correlations were noted between depth, conductivity, PO_4-P and plant biomass in wet and stable phases where as in paddy and channel phases correlations were relevant between pH, DO, depth, conductivity and alkalinity. Compared to other phases in inundated period (wet phase) while analyzing the relationship between the insect fauna, water and plant biomass variables it showed relatively good relationship was evident between them. Weak correlation with environmental variables in paddy fields may be due to continuous agricultural practices influence the physico-chemical pattern of soil as well as water column of this wetland. Stenert et al. (2009) opined that agricultural practices adopted in rice fields (water level control, application of herbicide, and machinery usage) were more important driving forces than the environmental variables for the macroinvertebrate structure. In contrary to this it has been reported in a number of studies that environmental variables such as size of the water body, depth, velocity, pH, conductivity, nutrients, amount of dissolved oxygen, riparian flora, and presence of impoundments are associated with distribution of entomofauna (Ogbogu and Akinya 2001; Ogbeibu and Oribhabor 2002; Cottenie, 2005; Buss and Salles 2007). Comprehensive study by Batzer (2013) highlighted the lack of predictable patterns of wetland invertebrates with environmental factors. Aquatic insect density had a significant inverse relationship with water temperature, turbidity, depth, TDS. However, a positive relationship was found between the aquatic insects density and dissolved oxygen

(Connolly et al., 2004). Vineetha (2015) opined that some abiotic (e.g. habitat availability) or biotic variables (e.g. species interactions) that could cause the association with benthic fauna were not directly measured, or variables were not good surrogates for them. Further explanation emphasize that some factors which are not measured like the intensity of disturbance, hydrological stability, length of hydro period, habitat duration, life history strategy, proximity and size of the neighbouring habitat, predation, wetland shape and size etc. would have played a master role in the distribution of benthic fauna in spite of the physico-chemical parameters. This suggests that the relationship with the measured environmental variables might be weaker or overridden by other unmeasured variables.

In the present study aquatic insects in wet and stable phases showed relatively significant correlation with plant biomass. Brown and Gange, (1992) considered that plants dominate most of the ecosystems and lead to succession of communities but at the same time animals did not follow the communities that the plants have dictated. This will often be the case, because the plants provide the starting point for all food webs and determine much of the character of the physical environment in which animals live. Contradictory possibilities are also observed in their studies, sometimes the animals that determine the nature of the plant community. In paddy phase of this wetland, agricultural activities cause repeated disturbance of vegetations, therefore the plant biomass and insects fauna observed weak correlation. Hooper et al. (2005) explained that biotic interactions may play an important element in ecosystem sustainability than abiotic factors regulating invertebrate assemblages, although biotic interaction could not be judged in isolation from abiotic influences. Tatrai et al. (1994) noted that predation by fish is having considerable influence on benthic community structure and population dynamics. In Maranchery wetland, different edible species of fishes, decapods, as well as migratory birds were the most abundant tertiary consumers, so these species have played a very crucial role in this study. Chilton (1990) suggested that the close proximity of differing plant communities could allow for emigration and immigration of invertebrates among macrophytes.

Human caused habitat loss in the form of land transformation or habitat destruction, which is widely understood to be the leading cause of loss of biodiversity (Vitousek, 1994; Pimm and Raven, 2000; Beattie, 2016). In Maranchery wetland several macrophytes species, *N. pubescens, N. indicum, E. crassipes, S. molesta, L. heterophylla, H. verticillata and U. aurea* show monospecific patches of growth in fully inundated periods. Frequent changes in land use pattern may be indirectly or directly involve the development of monospecific community or vegetation. Townsend (1996) found that when the monotony of a single species canopy is having a uniform age structure it is exaggerated and tend to be poor in species. A mixed age population shows diversity through the formation of gaps and through regeneration cycles. Strong et al. (1984) have reviewed studies regarding the presence or absence of interspecific competition amongst phytophagous insects. And in their own study, it was found that interspecific competition between phytophagous insects may be relatively rare. From the above studies it is revealed that, in Maranchery wetland growth of monospecific communities retard the diversity of insects. Recent researchers found that the proportion of herbivores exhibiting interspecific competition is significantly lower than the proportion of hydrophytes, carnivores or detritivores (Weller and. Bossart, 2017). In Maranchery wetland no interspecific competition was found because each order of insects was specific in association with different species of macrophytes. Further the chances of intraspecific competition may be possible, because in a single order different genus/species of entomofauna was associated with a single species of macrophytes. The patchy nature of the environment and the aggregative behavior of the individuals of the two species made coexistence possible without any niche differentiation. Alternatively, unsuccessful competitors may already have been driven to extinction. Furthermore, species may compete rarely (perhaps during population outbreaks) or only in localized patches of especially high density, but the results of such competition may be crucial to their continued existence in a particular location (Sponseller et al., 2001). The niche differentiation in insect communities as well as macrophytes have utilized their resources differently in this wetlands. This may express itself directly within a single habitat or as a difference in a microhabitat.

In Maranchery wetlands correlation study was carried out with major species of insects and environmental variables and is depicted in Figure 9.7 (a to f). Species of *Nannophya* was higher in percentage in channel and wet phases and lowest in paddy phase. Major influencing factors were TDS, salinity, alkalinity and PO_4-P. In the case of *Berosus* and *Canthydrus* species influencing factors were different like depth, temperature and dissolved oxygen. *Ischnura senagalensis* was higher percentage in wet phase and the factors influencing were turbidity, hardness, NO_3 -N, and NH_3-N whereas *Paederus* sp. was higher in stable phase and the major influencing factors were turbidity, hardness, salinity, TDS, PO_4-P, NO_3-N and NH_3-N. The study reveals that the assemblage of aquatic insects and environmental relationships varies with species, genus and family levels. This might be one of the reasons for obtaining weak correlation with environmental variables and insect community with different phases. Vlek et al. (2004) recognized that every taxon does not respond always in a linear way to the same environmental variables. Similar results were observed by Vineetha et al. (2015) in their study of benthic fauna and its relationship with edaphic factors in Maranchery wetlands.

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Chapter - 10

SUMMARY AND CONCLUSION

The present investigation is an endeavour to provide an insight on the ecology of the Maranchery Kole wetland and is an appraisal of thequalitative and quantitative distribution as well as biocenosis of macrophytes and macroinvertebrates.The International Convention of Wetlands designated the Vembanad-Kole,in Kerala as Ramsar sites, for their long termconservation and restoration of the biological diversity and wise use. The Kole wetlands of Kerala are known to be indispensable habitat to a variety ofbiologically and economically important resident of aquatic flora, fauna especially certain migratory birds. Kole wetlands are submerged for almost half of the year and under paddy cultivation for the other half. The shift from water body to paddy field involves a series of processes. Paddy cultivation (*Punja Krishi*[*]) is practiced from January to May every year. The agriculture related activities made the area behave as four different phases during the study period such as normal water bodies (wet phase), paddy fields (paddy phase) and narrow strips of water bodies

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[*] The terms are of regional language Malayalam

(channel phase). Some of the water body remained stable throughout the study period (stable phase). This thesis embodies a comprehensive analysis of the environmental parameters influencing the productivity pattern, distribution, abundance and community structure of macrophytes and macroinvertebrates based on the spatial variations.

Physico-chemical parameters showed clear spatial variations in phase wise studies. Depth was the most variable physical parameter in this study. Due to spatial variations it led to profound changes in the ecosystem functions as well as macrophyte growth. Temperature of the surface water ranged between 24.5^0C to 35^0C. Water pH remained neutral mostly or was otherwise acidic in nature. During the early growth stages of rice plants pH showed alkaline nature due to application of fertilizers and wood ashes. Low turbidity during wet phase was noticed. Macrophytes helped to reduce the turbidity by trapping suspended sediments from the water column. Increasing conductivity during channel phase in Maranchery wetland might be due to evaporation of water leading to increase in major ionic concentration which released the decomposing organic materials from plant matter. TDS were higher during paddy phase. Primary sources for TDS in Kole lands are agricultural and residential runoff, leaching of soil and application of several organic and inorganic fertilizers. Hardness of the wetland did not show any noticeable spatial variations. Dissolved oxygen and BOD showed wide variations in different phases but with in permissible limits. Alkalinity of the wetland was moderate indicating that the condition of the wetland was suitable for fish culture operations. Due to the different phases, nutrient concentration was deferred in Maranchery wetland. Higher values of PO_4-P during paddy and channel phases were related to increased decomposition of macrophytes at higher temperature, release of nutrients and various agricultural activities like tillage, addition of fertilizers whereas lower values could be attributed to its utilization by macrophytes for their growth in wet and stable phases. Increase in NO_3-N concentration during channel phase might be due to leaching of autochthonous materials (macrophyte litter). Compared to other nutrients NO_2-N was in trace amount in this Kole land. Diverse community of macrophytes utilize for their growth and fruiting period take more NO_2-N that could be one reason for decreased level of NO_2-N. Application of fertilizers contributes to increase in ammonia-nitrogen concentration during paddy phase. Inorganic nutrients were lower during wet phase. Hydrological regimes lead to variation in chemical parameters.Prolific growth of macrophytes acts as a biofilter and decreasing the values of environmental characteristics. Apart from the different kinds of vegetations affecting nutrient distribution in wetlands, the cattle and bird excreta was also suspected to have impacted the nutrient levels in shallow phases like channels and paddy phase.

Phase wise analysis shows that spatial variations significantly alter the productivity of these ecosystem. Primary production was having wide variation throughout the study period. In phase wise analysis channel phase shows higher gross primary productivity (GPP) and net primary productivity (NPP). GPP and NPP showed a strong positive correlation significant at 5% level ($P<0.05$). Chlorophyll *a* shows positive correlation with dissolved oxygen, macrophyte biomass, nitrate-nitrogen, phosphate-phosphorus and silicate- silica. NPP showed a positive correlation with algal biomass at 1% level of significance ($P<0.01$). The luxurious growth of aquatic macrophytes in this wetland may be contributed to the higher Chl. *a* content that influence the productivity pattern.

A total of 21 aquatic and semi aquatic macrophytes belonging to 21 genera and 16 families, were recorded.The Angiosperms were represented by 12 families and the Pteridophytes or water ferns by 3 families were identified from this wetland. Maximum species were represented by Poaceae (4 species) and water ferns (3 species) followed by Convolvulaceae and Pontederiaceae (2 species). Among the 21 species two species are categorized by exotic plants. In the present study, it was noted that *Eichhornia crassipes, Salvinia molesta, Nymphaea pubescens, Nymphoides indicum, Hydrilla verticillata, Utricularia aurea, Ludwigia adscendensand Limnophila heterophylla* are found to form monospecific communities in this area. Other macrophytes that are observed or found in association with dominant macrophytes that were *Rotala* sp., *Ipomea pes-capre*, *Convolvulus* sp., *Sagittaria* sp., *Sacciolepis* sp., and *Lemna perpusilla*. Diversity of macrophytes was significantly varied in different phases. Wet and stable phases were characterized by more diversity of macrophytes as the increased habitable area and undisturbed substrate increases the abundance. Channel and paddy phases were showed a reduced diversity. Same pattern was followed in biomass of macrophytes. Frequency of macrophytes was higher in Station 1 to 5.Manual removal of macrophytes during channel and paddy phases observed as well as agricultural related activities disturbed the growth of macrophytes. This leads to decrease in diversity and biomass in these phases. Growth forms of the aquatic plants were encountered during the present investigation, of which 7 numbers are emergent plants and free floating hydrophytes was second highest growth form in this wetland. The other growth forms observed were submerged- anchored hydrophytes, anchored hydrophytes with floating leaves, emergent-anchored with floating shoot and anchored hydrophytes with floating shoot. Exotic invasive species like *E. crassipes* and *S. molesta* were abundant in station 7 and 8 that seems to constitute a major threat to wetland biodiversity. Intense anthropogenic activities were found in these stations. The aggressive alien plants in water bodies appeared to pose a threat to the indigenous medicinal macrophytes. Submerged species like *H. verticillata, U. aurea* was wide spread and present throughout the study period. Stagnant nature of this wetland water column protects delicate species like *H. verticillata* and *U. aurea*. Diversity Index H' showed that Station 4 had the highest diversity (3.29) and Station1 ranked the least with 2.1. Dominance plot shows that wet phase having higher dominance and agreeing with Margalef's index (d) of 3.03. Abundance, biomass and diversity was found decreased in disturbed paddy and channel phases. Natural hydrological regime of the wetland influenced the macrophyte growth to a great extent. From the results, it is evident that the ecological conditions as well as the stagnant nature of water body support a rich macrophytic vascular plant diversity. The poor representation of macrophytes in channels may be due to the lack of proper substratum.

A definite spatial and temporal variation in the macroinvertebrate abundance was obvious in association with different macrophytes. The phase wise variation in macroinvertebrate assemblage could be related to monsoonal influence, macrophyte species structure and growth pattern and agricultural activities. Total macroinvertebrate abundance were higher during wet phase whereas insect fauna showed higher abundance during paddy phase. In station wise evaluation station 6 shows less abundance of insect entomofauna. Total abundance of macroinvertebrates varied largely due to the presence or absence of insect fauna in this wetland. Station wise study reveals that higher abundance of aquatic insects (4192 No./m^2), was associated with *H. verticillata* in Station1, which were submerged during sampling period also this plant having long dissected leaves that leads to higher abundance. In Station 5, *N. pubescens* plant contributed least number of insects (2496 No./m^2) . The floating, undissected leaves harboured the lowest abundance of entomofauna. Mollusca, Branchiopoda, and Arahnida shows higher abundance in association with *Eichhornia crassipes* in station 6. Insect abundance was comparatively less in station 6. Detailed study of aquatic insects abundance shows that each Order of insect fauna was differentiated in different macrophytes. Ephemeroptera were associated with the macrophyte *L. heterophylla*; odonates with *N. indicum*; Hemiptera and Trichoptera with *U. aurea*; Lepidoptera, Coleoptera with *S. molesta,* and Diptera with *H. verticillata.* The study reveals that abundance pattern was closely related with the macrophyte sps. mainly due to different feeding habits.

The macrophyte associated invertebrate community in this wetland varies widely on a phase wise and station wise scale. It comprised of 11 classes belonging to Insecta, Nematoda, Oligochaeta, Euhirudinea, Mollusca, Ostracoda, Branchiopoda, Isopoda, Decapoda, Arachnida, and Pisces.The insects fauna were found dominating during the study period (64.2%) in all the stations and also during phase wise evaluations. Its maximum percentage was contributed in paddy phase (80%), followed by channels (62.1%) wet (38.7 %) and stable phase (32.6%). In station wise analysis 55% and above was contributed by insect fauna in all the eight stations. The percentage contribution of Branchiopoda, Arachnida, Euhirudinea, Mollusca, Decapoda and Ostracoda were in the order 9.8%, 6.8%, 6.5%, 5.8%, 3.3% and 2% respectively. Nematoda, Oligochaeta, Isopoda and Pisces contributed on an average less than 1% in the study stations.

The aquatic insects belonged to 7 orders, 30 families and 58 genera/species. Among the class insecta, Diptera were the most dominant order in all the stations except in station 7, where order Coleoptera dominated. Mean percentage composition of insect fauna entirely varied in four phases. In channel and stable phases, Coleoptera contributed 49.2% and 47.8% respectively. In paddy phase order Dipterans had 40.9% and thatin wet period Odonata contributed about 34.9%.Among insect fauna collected, Coleoptera was diverse in number of genera (18sp.) comprising 20% of insect fauna which includes adults and larval forms. It was represented by 10 families Viz., Dytiscidae, Noteridae, Hydrophylidae, Curculionidae, Chrysomelidae, Hydraenidae, Carabidae, Staphylinidae, Dryopidae and Histeridae. Family Dytiscidae was the most predominant species of *Hydrovatus confertus* and wide spread in eight stations whereas family Noteridae species of *Canthydrus luctuosus* was contributed 4.3% in total coleopterans. Hydrophilidae family was mainly represented by *Enochrus esuriens* and *Berosus indicus.* The other species mainly found in association with hydrophytes were *Helichus* sp., *Bagous* sp., *Cassida* sp., *Henicocerus* sp., *Chlaenius* sp., *Paederus* sp. and *Platylomalus* sp. among the aquatic coleopterans. Ephemeroptera was represented in Maranchery Kole lands by the three families Ephemerellidae, Caenidae and Baetidae. The family Ephemerellidae was contributed by *Ephemerella* sp. The family Caenidae and Baetidae similarly contributed one species each, representing *Caenis nigropunctata* and *Centroptilum* sp. The Odonata was represented by the families Libellulidae, Gomphidae and Coenagrionidae. The important members of family Libellulidae was *Nannophya pygmaea*, and the other nymph species that were mainly found in association with macrophytes were *Crocothemis servilia, Hydrobasileus croceus, Ictinogomphus rapax, Agriocnemis lacteola, Ischnura senegalensis* and *Pseudagrion* sp. Hemipera was categorized under 6 families viz., Nepidae, Belostomatidae, Pleidae, Corixidae, Hebridae and Gerridae. Of these, Belostomatidae was the most common family among Hemiptera in eight stations constituted by two species *Diplonychus rusticus* and *Diplonychus annulatum.* Trichoptera or caddisflies were contributed by three species of *Neureclipsis* sp., *Hydropsyche* sp., and *Himalopsyche phryganea*. Among the Trichoptera taxa, *Neureclipsis* sp. of family Polycentropodidae was common throughout the study period. Order dipterans were one of the tolerant group that represented biting and non biting midges. The families contributed were by Chironomidae, Chaoboridae, Culicidae and Ceratopogonidae. The family Chironomidae was represented by 13 species. Among which *Chironomus major, Polypedilum leei, Polypedilum nubifer, Tanypus carinatus* and *Ablabesmyia annulata* were commonly found with different species of macrophytes. The species such as *Bezzia* sp., *Chironomid major, Ephemerella* sp., *Nannophya* sp., *Canthydrus luctuosus* were the most abundant species during the study period.The transformation from one phase to another in the wet, paddy andchannel phases were through a series of steps which made the death and decaying of macrophytes resulting inhabitat loss, habitat isolation and habitat fragmentation for aquatic organisms for some period. Changes in the physical structure of the study area due to human activities could affect the macrophyte composition and abundance, which would intern have a negative influences on the macroinvertebrate population in the wetland. There are studies which states that changes in the landscape has caused reduction in the area and connectivity of natural habitat. Fragmentation of wetlands is one of the main problem related to the diversity and distribution pattern of entomofauna. In certain extreme cases insect fauna survive by metamorphosis like diapausing eggs, resistant cysts enclosing young, adults or fragments of individuals. Macroinvertebrates like Hirudinea creates mucus coatings, gastropods formed a protective apiphragm of dried mucus across shell opening in the case of adults and young ones survived in moist soil or stream bed. The present study reveals that there are not any egg cases and cysts present with macrophytes. But migration of aquatic insects and larvae into the available macrophyte bed were observed and this might be one reason for decreased diversity and abundance. Diversity indices of macroinvertebrates as well as insects fauna were noticed. In the case of macroinvertebrates richness was compared among different phases and maximum was noticed in stable phase whereas richness of aquatic insects showed a maximum in paddy phase. The abundance also depicted same pattern in both the cases. The results proved that macroinvertebrates other than the aquatic insects the water level fluctuations can cause severe impacts as the fauna is stressed by harsher environmental conditions caused by the drying out process whereas in stable environments, the fauna are less adapted to fluctuations. This may be due to the insect fauna having a wide range of tolerance level and extensive feeding habit.

Macrophyte associated macroinvertebrate assemblage and its environmental relationship also accounted on the ecological quality status of the Maranchery wetland using biomonitoring index of aquatic insects. The indices such as Taxa richness, percentage of intolerant taxa and tolerant taxa, percentage EPT (Ephemeroptera, Plecoptera and Trichoptera ratios), percentage of predators, functional feeding groups (%), biomonitoring working party score (BMWP) and average score per taxon (ASPT) have been used to measure the ecological quality status of aquatic insects fauna of this Kole land, impacted with various types of stress from changing land use pattern, organic enrichment, eutrophication, agriculture runoff and pollution problems. In phase wise matrices of aquatic insect fauna it shows that, percentage EPT taxa was higher in wet phase. Percentage of tolerant taxa formed higher in paddy phase whereas percentage of intolerant taxa was higher in channel phase. Percentage of predators was highest in paddy phase followed by channels, wet and stable phases. Dominant taxa in paddy phase was found to be family Caenidae, in channels (family Noteridae), in wet (family Libellulidae) and in stable period (family Staphylanidae). Biomonitoring scores like, BMWP score denoted that pollution tolerant families are higher in paddy phase. ASPT Score of paddy phase was less compared to wet phase and stable phases. Generally a high ASPT usually characterizes clean sites, disturbed sites generally have low ASPT values.Over all ecological status of different phases showed paddy phase was in disturbed condition. Correlation between environmental parameters, macrophyte biomass with aquatic insects showed that a group of parameters such as depth, pH, alkalinity and nutrients as well as macrophyte biomass were showing a week correlation due to the spatial heterogeneity of the study area. Similar to environmental characteristics certain biotic factors play a key role to structuring the community pattern of this wetland. It could be the habitable patch, with hydrological stability, length of hydroperiod, habitat duration, life history strategy, macrophyte structure and diversity, proximity and size of the neighbouring habitat, intensity of disturbance, competition, predation, etc.

From the present study it was found that the abundance and richness of macroinvertebrates are not distributed homogeneously among aquatic macrophytes which differ in complexity and growth forms that they occupy in the wetland. Since the greatest abundances of invertebrates biocenosis was associated with the most structurally complex macrophyte species.

From this study, it is understood and necessary to maintain water levels sufficient to keep macrophytes . However, to maximise biodiversity, it is not as simple as it is regarded. As water levels and other environmental conditions get changed, the species of macrophyte supporting the highest taxonomic richness also changes. It is vital for water managers or farmers tobe aware that aquatic macrophytes support a diversearray of invertebrates and that a rich macrophyte flora will undoubtedly equate to a rich invertebrate fauna. Water allocations for farming activities must therefore be commensurate with the requirements of all species of macrophytes. It may be that by maintaining the heterogeneity of this type of habitat, a major step in managing both biodiversity and wetland health are achieved.

Based on the results of this study some management options are suggested here.

- Increasing public awareness for halting the environmental degradation is now necessitated for environmental appraisal of all projects and natural ecosystems such as wetlands on cost benefit ratio, in terms not just of ecology and environment but also on the socio-economic scale. The socio-economic survey of the population living around the wetland, is mainly dependent on the ecosystem for fishing activities, rice farming and allied activities. Fishing appears to be a more lucrative profession compared to agricultural practices for the Kole land communities. Further, several of the farming communities in the area have switched over to other avocations that can benefit more economic benefits. This has also led to large scale reclamation of these productive lands for other developmental works destroying the ecology and health of the Kole wetlands.

- The uniqueness of the Kole wetland is the cycle of phases (dry, wet, flooding, channel) on a seasonal basis, that undergoes, for maintaining the hydrology and life support in the system. The paddy cultivation and fishing activities are all linked to the different phases for livelihood measures. The global climate change with its probable regional effects also had its measure of impact on the traditional agricultural practices, when most of wetland has been converted to commercially viable practices like, application of pesticides and chemical fertilizers in the paddy fields. The indiscriminate application of these chemicals in the Kole fields has led to the decrease in diversity of macrophytes and macroinvertebrates as well, that has brought about livelihood changes. Further modification in the seasonal cycle linked to the phases in the Kole lands has propagated invasive water weeds and tolerant organisms like noxious midges affecting the productivity of the region. The low productivity from agriculture and other forms of farming practices has also created barren lands possibly getting reclaimed for developmental objectives. All these lead to mass collapse of the biocenosis of communities like macrophytes and invertebrates as discussed elaborately in this thesis. However, Maranchery wetland offers an excellent example of macrophyte diversity, density and offering a rich variety of food, shelter, nesting and roosting site for migratory birds, fishes and insect communities. The wetland is suitable for enhanced fish farming operations to propagate the native resources. Integrated paddy cum fish farming practice has to be encouraged depending on the various phases and seasonal cycles. The Kerala State Biodiversity Board and other Governmental and non-Governmental organizations should commence effective action in this direction.

- In the past, special relationship existed not only at the political and cultural levels, but also in the areas of agriculture and food security. Rice biopark concept will go a long way in revitalising its paddy farming in Kole wetlands and also help to get a good income generation for the stake holders. So these Kole lands are to be conserved as bioreserves for food security and livelihood sustainability.

- Aquatic insect biodiversity is of considerable interest to society because these animals are so important in the diets of many fish species, including species that are commonly consumed by humans for food. A high diversity of these insects in Maranchery wetland, each with its own specific emergence time, assures that food is available to the fish through much of the year. The application of pesticides and herbicides in the agricultural fields of these wetlands causes rapid changes in the water quality, leading to the decline in diversity and abundance of insect fauna. Thus the usage of fertilizers and pesticides can be reduced and promoting organic farming for cost effective and economical paddy cultivation.

- The senescence of the macrophytic vegetation in the wetland needs further investigation, and this decomposed organic matter is often exploited by the local population for different usages like cattle fodder and organic fertilizer. Several identified macrophyte species are medicinal varieties, collection and preservation of these plants often is a good scope for income generation for the local people. This wetland observed different water weeds such as, *Eichhornia crassipes*, *Lemna pepusilla* and *Salvinia molesta*. Use of traditional knowledge for better use of weeds as mineral recycling agents and conversion of weeds into compost would help to generate revenue. Moreover the magnificent beauty of flowering macrophytes and presence of numerous native and migratory birds could be explored for ecotourism purposes without disturbing the ecosystem. Therefore, Maranchery Kole wetland conservation has to be taken up as a crusade at state level for the welfare of present and future generations.

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ANNEXURES

Annexure-I

BMWP Scores of aquatic insect families

Family	**BMWP scores**
Ephemerellidae	10
Caenidae	7
Baetidae	4
Libellulidae	8
Gomphidae	8
Coenagrionidae	6
Nepidae	5
Belostomatidae	Un Known
Pleidae	5
Corixidae	5
Hebridae	5
Gerridae	5

Family	BMWP scores
Polycentropodidae	7
Hydropsychidae	10
Rhyacophilidae	7
Pyralidae	8
Dytiscidae	5
Noteridae	7
Hydrophilidae	5
Curculionidae	5
Chrisomelidae	5
Dryopidae	5
Hydraenidae	Un Known
Carabidae	Un Known
Staphylinidae	Un Known
Histeridae	Un Known
Chironomidae	2
Chaoboridae	2
Culicidae	2
Ceratopogonidae	Un Known

Annexure II.

List of macroinvertebrates identified from Maranchery Kole wetland during the study period.

Class- Insecta

Order – Ephemeroptera

Suborder	Family	Genus/Species
Rectracheata	Ephemerellidae (larva)	*Ephemerella* sp.
	Caenidae (larva)	*Caenis nigropunctata* Saaristo)
Pisciforma	Baetidae (larva)	*Centroptilum* sp.

Order – Odonata

Suborder	Family	Genus/Species
Anisoptera (Dragon fly)	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)
		Crocothermis servillia (Drury)
		Hydrobasileus croceus(Brauer)
	Gomphidae (larva)	*Ictinogomphus rapax* (Rambur)
Zygoptera (Damsel fly)	Coenagrionidae (larva)	*Agriocnemis lacteola* (Selys)
		Ischnura senegalensis(Rambur)
		Pseudagrion sp.

Order – Hemiptera

Suborder	Family	Genus/Species
Heteroptera	Nepidae	*Ranatra brevicollis* (Fabricius)
	Belostomatidae	*Diplonychus rusticus*(Fabricius)
		Diplonychus annulatum(Fabricius)
	Pleidae	*Paraplea* sp.
	Corixidae	*Micronecta* sp.
	Hebridae	*Hebrus* sp.
	Gerridae	*Gerris* sp.

Order –Trichoptera

Suborder	Family	Genus/Species
Annulipalpia	Polycentropodidae (larva)	*Neureclipsis* sp.
	Hydropsychidae (larva)	*Hydropsyche* sp.
	Rhyacophilidae (Larva)	*Himalopsyche phryganea* (Ross)

Order-Coleoptera (Adult)

Family	Subfamily	Tribe	Genus/Species
Dytiscidae	Notorinae	Laccophilinae	*Laccophilus parvulus* (Aube)
		Hydrovatini	*Hydrovatus confertus*(Sharp)
Noteridae		Hydrocanthini	*Canthydrus luctuosus*(Aube)
		Noterini	*Noterus* sp.
Hydrophilidae		Hydrobiinae	*Enochrus esuriens* (Walker)
		Berosini	*Berosus indicus* (Mots)
Curculionidae	Bagoninae		*Bagous* sp.
Chrisomelidae	Cassidinae		*Cassida* sp.
Dryopidae			*Helichus* sp.
Hydraenidae			*Henicocerus* sp.
Carabidae			*Chlaenius* sp.
Staphylinidae			*Paederus* sp.
Histeridae		Dendrophilinae	*Platylomalus* sp.

Order- Coleoptera (Larvae)

Family	Genus/Species
Dytiscidae	*Cybister* sp. *Hydrovatus* sp. *Laccophilus* sp.
Hydrophilidae	*Berosus* sp. *Stenolophus* sp.

Order- Diptera

Family	Subfamily	Tribe	Genus/Species/Author
Chironomidae	Tanypodinae	Macropelopiini	*Monopalopia tillandsia* (Fittkau)
			Tanypus carinatus (Meigen)
			Ablabesmyia annulata (Johansen)
	Chironominae	Chironomini	*Chironomus major* (Meigen)
			Polypedilum leei (Kieffer)
			Polypedilum nubifer (Kieffer)
			Einefeldia synchrona (Kieffer)
			Lueterboniella sp.
			Chonochironomus sp.
			Dichrotendipus sp.
		Tanytarsini	*Rheotanytarsus pellucidus* (Thienemann & Bause)
			Paratanytarsus sp.
			Cladotanytarsus sp.
Chaoboridae			*Chaoborus* sp. (pupa)
Culicidae			*Anophiles* sp.(pupa) &(larva)
Ceratopogonidae			*Bezzia* sp. (larva)

Other commonly observed Macroinvertebrates groups identified from Maranchery Kole wetland during the study period.

Class	**Family**	**Genus/Species**
Nematoda	Un Id.	
Oligochaeta	Naididae	Un Id.
Euhirudinea	Un. Id.	Un Id.
Mollusca	Viviparidae	*Bellamya bengalensis* (Lamarck)
	Bullinidae	*Indoplanorbis exustus* (Deshayes)
	Ampullaridae	*Pila globosa* (Swainson)
Ostracoda	Cyprididae	*Strandesia elongata* (Hartman) *Stenocypris derputa* (Vavra) *Stenocypris hislopi* (Ferguson) *Chrissia* sp.
Branchiopoda	Cyclestheriidae	*Cyclestheria hislopi* (Baird)
Isopoda	Un Id.	
Decapoda	Penaeidae	*Metapenaeus* sp.
	Palaemonidae	*Macrobrachium rosenbergii* (De Man)
Arahnida		
Water mites (Acari),	Un Id.	
Spiders	Un Id.	
Fish fingerlings	Un Id.	

*Un Id. –Un identified

Annexure III

Community structure and percentage distribution of aquatic insects in eight stations in Maranchery Kole wetland during the study period.

Station 1

Order	Family	Genus/Species	Percentage (%)
Ephemeroptera	Ephemerellidae (larva)	*Ephemerella* sp.	0.38
	Caenidae (larva)	*Caenis nigropunctata*	0.76
	Baetidae (larva)	*Centroptilum* sp.	0.38
Odonata	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)	1.90
		Crocothemis servilia(Drury)	0.76
	Coenagrionidae (larva)	*Agriocnemis lacteola* (Selys)	1.14
		Ischnura senegalensis(Rambur)	2.28
		Pseudagrion sp. (Fraser)	0.76
Hemiptera	Nepidae	*Ranatra brevicollis* (Fabricius)	0.38
	Belostomatidae	*Diplonychus rusticus*(Fabricius)	2.28
		Diplonychus annulatum(Fabricius)	1.52
	Corixidae	*Micronecta* sp.	1.14
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	2.65
Lepidoptera	Pyralidae (Larva)	*Elophila interruptalis*	2.65
		Parapoynx diminutalis	1.52
		Potamomusa sp.	0.38
Coleoptera adult	Hydrophilidae	*Hydrovatus confertus*(Sharp)	1.98
	Noteridae	*Canthydrus luctuosus*(Aube)	4.35
		Noterus sp.	2.77
	Hydrophilidae	Enochrus esuriens (Walker)	3.17
		Berosus indicus (Mots)	0.79
	Curculionidae	*Bagous* sp.	1.58
	Staphylinidae	*Paederus* sp.	1.58

Order	Family	Genus/Species	Percentage (%)
		Hydrovatus sp.	0.76
	Hydrophilidae	*Berosus* sp.	3.41
		Stenolophus sp.	1.90
Diptera	Chironomidae	*Monopalopia tillandsia* Fittkau	4.17
		Tanypus carinatus Meigen	3.41
		Ablabesmyia annulata Johansen	5.31
		Chironomus major Meigen	10.62
		Polypedilum leei Kieffer	6.07
		Polypedilum nubifer Kieffer	4.17
		Einefeldia synchrona Kieffer	1.52
		Lueterboniella Thienemann & Bause	2.65
		Chonochironomus sp. Meigen	0.38
		Dichrotendipes sp. Jobetus	1.52
		Rheotanytarsus pellucidus Thienemann & Bause	3.41
		Paratanytarsus sp. Freeman	5.31
		Cladotanytarsus sp. Kieffer	2.28
	Chaoboridae	*Chaoborus* sp. (pupa)	0.76
	Culicidae	*Anopheles.* sp.(pupa)	1.14
	Ceratopogonidae	*Bezzia* sp. (larva)	3.79
Total	20	43	100.0

Station 2

Order	Family	Genus/Species	Percentage(%)
Ephemeroptera	Caenidae (larva)	*Caenis nigropunctata*	2.8
Odonata	Libellulidae (larva)	*Crocothemis servilia*(Drury)	1.1
		Hydrobasileus croceus(Brauer)	2.3
	Coenagrionidae (larva)	*Agriocnemis lacteola* (Selys)	0.6
		Ischnura senegalensis(Rambur)	2.8
		Pseudagrion sp. (Fraser)	1.7
Hemiptera	Nepidae	*Ranatra brevicollis* (Fabricius)	1.1
	Belostomatidae	*Diplonychus rusticus*(Fabricius)	3.4
		Diplonychus annulatum(Fabricius)	9.1
	Pleidae	*Paraplea* sp.	1.7
	Corixidae	*Micronecta* sp.	4.5
	Hebridae	*Hebrus* sp.	1.7
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	7.4
	Hydropsychidae (larva)	*Hydropsyche* sp.	0.6
Lepidoptera	Pyralidae (Larva)	*Elophila interruptalis*	1.1
		Potamomusa sp.	1.7
		Eoophyla sp.	0.6
Coleoptera adult	Dytiscidae	*Laccophilus parvulus* (Aube)	0.6
		Hydrovatus confertus(Sharp)	1.2
	Noteridae	*Canthydrus luctuosus*(Aube)	2.4
		Noterus sp.	3.6
	Hydrophilidae	Enochrus esuriens (Walker)	0.6
		Berosus indicus (Mots)	1.2
	Curculionidae	*Bagous* sp.	1.8
	Carabidae	*Chlaenius* sp.	0.6
Coleoptera larvae	Dytiscidae	*Cybister* sp.	1.7
		Hydrovatus sp.	1.1
	Hydrophilidae	*Berosus* sp.	1.7
		Stenolophus sp.	0.6
Diptera	Chironomidae	*Monopalopia tillandsia* Fittkau	0.6
		Tanypus carinatus Meigen	3.4
		Ablabesmyia annulata Johansen	2.3
Order	**Family**	**Genus/Species**	**Percentage(%)**

		Chironomus major Meigen	10.2
		Polypedilum nubifer Kieffer	2.8
		Lueterboniella Thienemann & Bause	0.6
		Chonochironomus sp. Meigen	0.6
		Dichrotendipes sp. Jobetus	0.6
		Rheotanytarsus pellucidus Thienemann & Bause	3.4
		Paratanytarsus sp. Freeman	2.3
		Cladotanytarsus sp. Kieffer	2.8
	Chaoboridae	*Chaoborus* sp. (pupa)	0.6
	Culicidae	*Anopheles.* sp. (larva)	1.1
	Ceratopogonidae	*Bezzia* sp. (larva)	7.4
Total	21	43	100.0

Station 3

Order	**Family**	**Genus/Species**	**Percentage(%)**
Ephemeroptera	Ephemerellidae (larva)	*Ephemerella* sp.	4.0
	Caenidae (larva)	*Caenis nigropunctata*	7.2
	Baetidae (larva)	*Centroptilum* sp.	1.6
Odonata	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)	2.8
		Crocothemis servilia(Drury)	0.8
	Gomphidae (larva)	*Ictinogomphus rapax* (Rambur)	0.4
	Coenagrionidae (larva)	*Agriocnemis lacteola* (Selys)	1.6
		Ischnura senegalensis(Rambur)	2.4
		Pseudagrion sp. (Fraser)	0.8
	Belostomatidae	*Diplonychus rusticus*(Fabricius)	1.6
		Diplonychus annulatum(Fabricius)	6.8
	Pleidae	*Paraplea* sp.	0.4
	Hebridae	*Hebrus* sp.	0.4
	Gerridae	*Gerris* sp.	0.8
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	1.6
	Rhyacophilidae (Larva)	*Himalopsyche phryganea*	0.4
Lepidoptera	Pyralidae (Larva)	*Elophila interruptalis*	1.6
		Potamomusa sp.	0.4

Coleoptera adult	Dytiscidae	*Laccophilus parvulus* (Aube)	0.4
		Hydrovatus confertus(Sharp)	5.4
	Noteridae	*Canthydrus luctuosus*(Aube)	2.1
		Noterus sp.	4.2
	Hydrophilidae	Enochrus esuriens (Walker)	0.4
		Berosus indicus (Mots)	5.8
	Curculionidae	*Bagous* sp.	1.7
	Carabidae	*Chlaenius* sp.	1.7
Coleoptera larvae	Dytiscidae	*Cybister* sp.	0.4
		Hydrovatus sp.	2.0
		Laccophilus sp.	1.2
	Hydrophilidae	*Berosus* sp.	0.4
Diptera	Chironomidae	*Monopalopia tillandsia* Fittkau	2.0
		Tanypus carinatus Meigen	1.6
		Ablabesmyia annulata Johansen	4.0
		Chironomus major Meigen	2.0
		Polypedilum leei Kieffer	2.4
		Polypedilum nubifer Kieffer	3.6
		Einefeldia synchrona Kieffer	1.2
		Lueterboniella Thienemann & Bause	3.6
		Chonochironomus sp. Meigen	0.8
		Dichrotendipes sp. Jobetus	2.4
		Rheotanytarsus pellucidus Thienemann & Bause	1.2
		Paratanytarsus sp. Freeman	0.8
		Cladotanytarsus sp. Kieffer	0.8
	Chaoboridae	*Chaoborus* sp. (pupa)	1.2
	Culicidae	*Anopheles.* sp.(pupa)	0.8
	Ceratopogonidae	*Bezzia* sp. (larva)	10.4
Total	23	46	100.0

Station 4

Order	Family	Genus/Species	Percentage(%)
Ephemeroptera	Ephemerellidae (larva)	*Ephemerella* sp.	0.5
	Caenidae (larva)	*Caenis nigropunctata*	1.4
Odonata	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)	8.0
		Crocothemis servilia(Drury)	3.8
	Coenagrionidae (larva)	*Agriocnemis lacteola* (Selys)	0.5
		Ischnura senegalensis(Rambur)	2.8
		Pseudagrion sp. (Fraser)	0.5
	Belostomatidae	*Diplonychus rusticus*(Fabricius)	3.8
		Diplonychus annulatum(Fabricius)	1.9
	Gerridae	Gerris sp.	0.5
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	0.5
	Hydropsychidae (larva)	*Hydropsyche* sp.	0.5
	Rhyacophilidae (Larva)	*Himalopsyche phryganea*	0.5
Lepidoptera	Pyralidae (Larva)	*Elophila interruptalis*	0.5
		Parapoynx diminutalis	0.5
		Potamomusa sp.	1.4
		Eoophyla sp.	0.9
Coleoptera adult	Dytiscidae	*Laccophilus parvulus* (Aube)	0.5
		Hydrovatus confertus(Sharp)	2.4
	Noteridae	*Canthydrus luctuosus*(Aube)	12.2
		Noterus sp.	3.4
	Hydrophilidae	Enochrus esuriens (Walker)	0.5
		Berosus indicus (Mots)	3.4
	Chrysomelidae	*Cassida* sp.	1.0
	Dryopidae	*Helichus* sp. (Erichson)	0.5
	Hydraenidae	*Henicocerus* sp.	0.5
	Staphylinidae	*Paederus* sp.	0.5
Coleoptera larvae	Dytiscidae	*Cybister* sp.	0.5
		Hydrovatus sp.	1.9
		Laccophilus sp.	1.4
	Hydrophilidae	*Berosus* sp.	0.5

		Stenolophus sp.	0.5
Diptera	Chironomidae	*Monopalopia tillandsia* Fittkau	2.8
		Tanypus carinatus Meigen	3.3
		Ablabesmyia annulata Johansen	4.2
		Chironomus major Meigen	3.3
		Polypedilum leei Kieffer	1.4
		Polypedilum nubifer Kieffer	3.3
		Einefeldia synchrona Kieffer	2.3
		Chonochironomus sp. Meigen	0.5
		Dichrotendipes sp. Jobetus	0.5
		Rheotanytarsus pellucidus Thienemann & Bause	1.4
		Paratanytarsus sp. Freeman	0.9
		Cladotanytarsus sp. Kieffer	4.2
	Culicidae	*Anopheles.* sp.(larva)	1.9
	Ceratopogonidae	*Bezzia* sp. (larva)	12.2
Total	22	46	100.0

Station 5

Order	Family	Genus/Species	Percentage(%)
Ephemeroptera	Ephemerellidae (larva)	*Ephemerella* sp.	2.7
	Caenidae (larva)	*Caenis nigropunctata*	6.0
Odonata	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)	6.0
		Crocothemis servilia(Drury)	3.3
	Gomphidae (larva)	*Ictinogomphus rapax* (Rambur)	1.3
		Pseudagrion sp. (Fraser)	1.3
		Diplonychus annulatum(Fabricius)	4.0
	Pleidae	*Paraplea* sp.	1.3
	Corixidae	*Micronecta* sp.	0.7
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	3.3
	Hydropsychidae (larva)	*Hydropsyche* sp.	0.7
Lepidoptera	Pyralidae (Larva)	*Elophila interruptalis*	1.3
		Parapoynx diminutalis	1.3

		Eoophyla sp.	0.7
Coleoptera adult	Dytiscidae	*Laccophilus parvulus* (Aube)	2.0
		Hydrovatus confertus(Sharp)	6.0
	Noteridae	*Canthydrus luctuosus*(Aube)	1.3
		Noterus sp.	0.7
	Hydrophilidae	Enochrus esuriens (Walker)	6.7
		Berosus indicus (Mots)	7.3
	Curculionidae	*Bagous* sp.	0.7
	Dryopidae	*Helichus* sp. (Erichson)	0.7
	Hydraenidae	*Henicocerus* sp.	0.7
		Hydrovatus sp.	2.0
	Hydrophilidae	*Berosus* sp.	2.0
		Stenolophus sp.	0.7
Diptera	Chironomidae	*Monopalopia tillandsia* Fittkau	1.3
		Tanypus carinatus Meigen	0.7
		Ablabesmyia annulata Johansen	1.3
		Chironomus major Meigen	6.0
		Polypedilum leei Kieffer	2.7
		Polypedilum nubifer Kieffer	2.7
		Einefeldia synchrona Kieffer	0.7
		Chonochironomus sp. Meigen	0.7
		Rheotanytarsus pellucidus Thienemann & Bause	2.0
		Paratanytarsus sp. Freeman	2.7
		Cladotanytarsus sp. Kieffer	2.7
	Chaoboridae	*Chaoborus* sp. (pupa)	1.3
	Culicidae	*Anopheles.* sp. (larva)	0.7
	Ceratopogonidae	*Bezzia* sp. (larva)	10.0
Total	20	40	100.0

Station 6

Order	Family	Genus/Species	Percentage (%)
Ephemeroptera	Ephemerellidae (larva)	*Ephemerella* sp.	9.1
	Caenidae (larva)	*Caenis nigropunctata*	7.6
	Baetidae (larva)	*Centroptilum* sp.	1.5
Odonata	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)	13.7
		Crocothemis servilia(Drury)	3.0
		Hydrobasileus croceus(Brauer)	0.5
	Gomphidae (larva)	*Ictinogomphus rapax* (Rambur)	0.5
	Coenagrionidae (larva)	*Agriocnemis lacteola* (Selys)	0.5
		Ischnura senegalensis(Rambur)	2.0
		Pseudagrion sp. (Fraser)	1.0
	Belostomatidae	*Diplonychus rusticus*(Fabricius)	6.6
		Diplonychus annulatum(Fabricius)	4.1
	Pleidae	*Paraplea* sp.	2.0
	Hebridae	*Hebrus* sp.	0.5
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	1.0
	Rhyacophilidae (Larva)	*Himalopsyche phryganea*	0.5
Lepidoptera	Pyralidae (Larva)	*Elophila interruptalis*	2.5
		Parapoynx diminutalis	2.5
Coleoptera adult	Dytiscidae	*Laccophilus parvulus* (Aube)	1.1
		Hydrovatus confertus(Sharp)	2.1
		Noterus sp.	0.5
	Hydrophilidae	Enochrus esuriens (Walker)	0.5
		Berosus indicus (Mots)	2.1
	Curculionidae	*Bagous* sp.	1.6
	Dryopidae	*Helichus* sp. (Erichson)	2.6
	Hydraenidae	*Henicocerus* sp.	1.6
	Carabidae	*Chlaenius* sp.	1.1
		Hydrovatus sp.	1.5
		Laccophilus sp.	1.0
	Hydrophilidae	*Berosus* sp.	1.0
		Stenolophus sp.	0.5
Diptera	Chironomidae	*Tanypus carinatus* Meigen	2.5

		Ablabesmyia annulata Johansen	3.0
		Chironomus major Meigen	2.5
		Polypedilum nubifer Kieffer	0.5
		Lueterboniella Thienemann & Bause	1.5
		Paratanytarsus sp. Freeman	0.5
		Cladotanytarsus sp. Kieffer	1.0
	Chaoboridae	*Chaoborus* sp. (pupa)	0.5
	Culicidae	*Anopheles.* sp. larva)	1.0
	Ceratopogonidae	*Bezzia* sp. (larva)	10.1
Total	22	41	100.0

Station 7

Order	Family	Genus/Species	Percentage(%)
Ephemeroptera	Ephemerellidae (larva)	*Ephemerella* sp.	9.7
	Caenidae (larva)	*Caenis nigropunctata*	4.9
Odonata	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)	12.4
		Crocothemis servilia(Drury)	0.9
	Gomphidae (larva)	*Ictinogomphus rapax* (Rambur)	0.4
		Pseudagrion sp. (Fraser)	0.9
	Belostomatidae	*Diplonychus rusticus*(Fabricius)	6.2
		Diplonychus annulatum(Fabricius)	1.8
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	0.4
	Rhyacophilidae (Larva)	*Himalopsyche phryganea*	0.4
Lepidoptera	Pyralidae (Larva)	*Elophila interruptalis*	1.3
		Parapoynx diminutalis	11.0
Coleoptera adult	Dytiscidae	*Laccophilus parvulus* (Aube)	1.4
		Hydrovatus confertus(Sharp)	6.9
	Noteridae	*Canthydrus luctuosus*(Aube)	9.2
		Noterus sp.	0.5
	Hydrophilidae	Enochrus esuriens (Walker)	3.7
		Berosus indicus (Mots)	0.5
	Carabidae	*Chlaenius* sp.	0.9
	Staphylinidae	*Paederus* sp.	1.8

Coleoptera larvae	Dytiscidae	*Cybister* sp.	0.9
		Laccophilus sp.	1.8
	Hydrophilidae	*Berosus* sp.	2.7
		Stenolophus sp.	0.4
Diptera	Chironomidae	*Monopalopia tillandsia* Fittkau	0.9
		Tanypus carinatus Meigen	1.3
		Ablabesmyia annulata Johansen	1.3
		Chironomus major Meigen	3.1
		Polypedilum leei Kieffer	1.3
		Polypedilum nubifer Kieffer	1.3
		Einefeldia synchrona Kieffer	1.3
		Lueterboniella Thienemann & Bause	2.2
		Chonochironomus sp. Meigen	0.4
		Paratanytarsus sp. Freeman	3.5
	Culicidae	*Anopheles.* sp. (larva)	0.4
	Ceratopogonidae	*Bezzia* sp. (larva)	1.8
Total	18	36	100.0

Station 8

Order	Family	Genus/Species	Percentage(%)
Ephemeroptera	Ephemerellidae (larva)	*Ephemerella* sp.	20.3
	Caenidae (larva)	*Caenis nigropunctata*	5.3
	Baetidae (larva)	*Centroptilum* sp.	0.4
Odonata	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)	6.2
		Crocothemis servilia(Drury)	2.2
		Hydrobasileus croceus(Brauer)	0.4
	Coenagrionidae (larva)	*Agriocnemis lacteola* (Selys)	0.9
		Ischnura senegalensis(Rambur)	4.4
		Pseudagrion sp. (Fraser)	0.4
	Belostomatidae	*Diplonychus rusticus*(Fabricius)	0.4
		Diplonychus annulatum(Fabricius)	0.9
	Pleidae	*Paraplea* sp.	0.9
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	2.2
	Hydropsychidae (larva)	*Hydropsyche* sp.	0.4
Lepidoptera	Pyralidae (Larva)	*Elophila interruptalis*	1.3
		Potamomusa sp.	0.4
Coleoptera adult	Dytiscidae	*Laccophilus parvulus* (Aube)	3.7
		Hydrovatus confertus(Sharp)	6.4
	Noteridae	*Canthydrus luctuosus*(Aube)	1.8
		Noterus sp.	0.5
	Hydrophilidae	Enochrus esuriens (Walker)	0.5
	Curculionidae	*Bagous* sp.	2.3
	Carabidae	*Chlaenius* sp.	2.8
	Staphylinidae	*Paederus* sp.	1.8
	Histeridae	*Platylomalus* sp.	1.4
Coleoptera larvae	Dytiscidae	*Cybister* sp.	0.9
		Hydrovatus sp.	0.4
	Hydrophilidae	*Berosus* sp.	0.9
		Stenolophus sp.	0.4
Diptera	Chironomidae	*Monopalopia tillandsia* Fittkau	1.3
		Tanypus carinatus Meigen	0.4
		Chironomus major Meigen	5.7

		Polypedilum leei Kieffer	3.5
		Polypedilum nubifer Kieffer	2.6
		Einefeldia synchrona Kieffer	0.4
		Dichrotendipes sp. Jobetus	0.4
		Rheotanytarsus pellucidus Thienemann & Bause	2.2
		Paratanytarsus sp. Freeman	3.1
		Cladotanytarsus sp. Kieffer	1.8
	Chaoboridae	*Chaoborus* sp. (pupa)	2.6
	Culicidae	*Anopheles.* sp.(pupa) &(larva)	2.2
	Ceratopogonidae	*Bezzia* sp. (larva)	2.6
Total	23	42	100.0

Community structure and percentage distribution of aquatic insects in various phases in Maranchery Kole wetland during the study period.

Paddy phase

Order	Family	Genus/Species	Percentage(%)
Ephemeroptera	Ephemerellidae (larva)	*Ephemerella* sp.	2.9
	Caenidae (larva)	*Caenis nigropunctata*	7.7
	Baetidae (larva)	*Centroptilum* sp.	2.4
Odonata	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)	1.9
		Crocothemis servilia(Drury)	0.5
	Gomphidae (larva)	*Ictinogomphus rapax* (Rambur)	0.5
	Coenagrionidae (larva)	*Agriocnemis lacteola* (Selys)	1.0
		Ischnura senegalensis(Rambur)	0.5
		Pseudagrion sp. (Fraser)	0.5
Hemiptera	Belostomatidae	*Diplonychus rusticus*(Fabricius)	1.0
		Diplonychus annulatum(Fabricius)	1.0
	Hebridae	*Hebrus* sp.	0.5
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	2.9
Lepidoptera	Pyralidae (Larva)	*Elophila interruptalis*	0.5
		Parapoynx diminutalis	1.4
		Potamomusa sp.	0.5
		Eoophyla sp.	0.5

Coleoptera adult	Dytiscidae	*Hydrovatus confertus*(Sharp)	6.7
	Noteridae	*Canthydrus luctuosus*(Aube)	0.5
		Noterus sp.	5.8
	Hydrophilidae	Enochrus esuriens (Walker)	2.4
		Berosus indicus (Mots)	6.3
	Curculionidae	*Bagous* sp.	2.4
	Carabidae	*Chlaenius* sp.	0.5
	Chrysomelidae	*Cassida* sp.	0.5
Coleoptera larva	Dytiscidae	*Cybister* sp.	0.5
		Hydrovatus sp.	1.0
	Hydrophilidae	*Berosus* sp.	4.3
		Stenolophus sp.	2.4
Diptera	Chironomidae	*Monopalopia tillandsia* Fittkau	2.9
		Tanypus carinatus Meigen	2.9
		Ablabesmyia annulata Johansen	2.4
		Chironomus major Meigen	3.8
		Polypedilum leei Kieffer	4.3
		Polypedilum nubifer Kieffer	3.4
		Einefeldia synchrona Kieffer	1.4
		Lueterboniella Thienemann & Bause	1.9
		Chonochironomus sp. Meigen	0.5
		Dichrotendipes sp. Jobetus	3.8
		Rheotanytarsus pellucidus Thienemann & Bause	1.9
		Paratanytarsus sp. Freeman	1.0
		Cladotanytarsus sp. Kieffer	1.4
	Chaoboridae	*Chaoborus* sp. (pupa)	1.9
	Culicidae	*Anopheles.* sp.(pupa) & (larva)	1.0
	Ceratopogonidae	*Bezzia* sp. (larva)	6.3
Total	20	44	100.0

Channel phase

Order	**Family**	**Genus/Species**	**Percentage(%)**
Ephemroptera	Ephemerellidae (larva)	*Ephemerella* sp.	3.1
	Caenidae (larva)	*Caenis nigropunctata*	4.6
Odonata	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)	5.4
		Crocothemis servilia(Drury)	2.3
	Gomphidae (larva)	*Ictinogomphus rapax* (Rambur)	0.8
		Pseudagrion sp. (Fraser)	0.8
Hemiptera	Belostomatidae	*Diplonychus rusticus*(Fabricius)	0.8
		Diplonychus annulatum(Fabricius)	0.8
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	3.1
	Hydropsychidae (larva)	*Hydropsyche* sp.	0.8
	Rhyacophilidae (Larva)	*Himalopsyche phryganea*	0.8
Lepidoptera	Pyralidae (Larva)	*Elophila interruptalis*	0.8
		Parapoynx diminutalis	1.5
Coleoptera adult	Dytiscidae	*Hydrovatus confertus*(Sharp)	3.8
	Noteridae	*Canthydrus luctuosus*(Aube)	17.7
		Noterus sp.	3.1
	Hydrophilidae	Enochrus esuriens (Walker)	8.5
		Berosus indicus (Mots)	10.0
	Curculionidae	*Bagous* sp.	0.8
	Dryopidae	*Helichus* sp. (Erichson)	1.5
	Hydraenidae	*Henicocerus* sp.	1.5
Coleoptera larva	Dytiscidae	*Cybister* sp.	0.8
		Laccophilus sp.	0.8
	Hydrophilidae	*Berosus* sp.	0.8
Diptera	Chironomidae	*Monopalopia tillandsia* Fittkau	1.5
		Tanypus carinatus Meigen	2.3
		Ablabesmyia annulata Johansen	0.8
		Chironomus major Meigen	3.1
		Einefeldia synchrona Kieffer	0.8
		Chonochironomus sp. Meigen	1.5
		Dichrotendipes sp. Jobetus	0.8
		Cladotanytarsus sp. Kieffer	7.7

	Culicidae	*Anopheles.* sp.(pupa) &(larva)	0.8
	Ceratopogonidae	*Bezzia* sp. (larva)	6.2
Total	19	34	100.0

Stable phase

Order	**Family**	**Genus/Species**	**Percentage(%)**
Ephemeroptera	Caenidae (larva)	*Caenis nigropunctata*	5.8
	Baetidae (larva)	*Centroptilum* sp.	1.4
Odonata	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)	8.7
		Hydrobasileus croceus(Brauer)	1.4
		Ischnura senegalensis(Rambur)	2.9
		Pseudagrion sp. (Fraser)	1.4
		Diplonychus annulatum(Fabricius)	1.4
Hemiptera	Pleidae	*Paraplea* sp.	2.9
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	4.3
Lepidoptera	Pyralidae (Larva)	*Elophila interruptalis*	5.8
		Parapoynx diminutalis	1.4
		Potamomusa sp.	1.4
Coleoptera adult	Dytiscidae	*Laccophilus parvulus* (Aube)	5.8
		Noterus sp.	1.4
	Hydrophilidae	Enochrus esuriens (Walker)	8.7
	Curculionidae	*Bagous* sp.	1.4
	Carabidae	*Chlaenius* sp.	8.7
	Staphylinidae	*Paederus* sp.	10.1
	Histeridae	*Platylomalus* sp.	1.4
Coleoptera larva	Dytiscidae	*Cybister* sp.	1.4
		Hydrovatus sp.	1.4
		Laccophilus sp.	2.9
	Hydrophilidae	*Berosus* sp.	2.9
		Stenolophus sp.	1.4
Diptera	Chironomidae	*Tanypus carinatus* Meigen	1.4
		Chironomus major Meigen	1.4
	Culicidae	*Anopheles.* sp.(pupa) &(larva)	1.4
	Ceratopogonidae	*Bezzia* sp. (larva)	8.7
Total	16	28	100.0

Wet phase

Order	Family	*Genus/Species*	Percentage(%)
Ephemeroptera	Caenidae (larva)	*Caenis nigropunctata*	2.3
Odonata	Libellulidae (larva)	*Nannophya pygmaea* (Rambur)	12.4
		Crocothemis servilia(Drury)	3.1
		Hydrobasileus croceus(Brauer)	2.3
	Coenagrionidae (larva)	*Agriocnemis lacteola* (Selys)	3.1
		Ischnura senegalensis(Rambur)	11.6
		Pseudagrion sp. (Fraser)	2.3
Hemiptera	Nepidae	*Ranatra brevicollis* (Fabricius)	0.8
	Belostomatidae	*Diplonychus rusticus*(Fabricius)	3.9
		Diplonychus annulatum(Fabricius)	1.6
	Pleidae	*Paraplea* sp.	2.3
	Corixidae	*Micronecta* sp.	6.2
	Hebridae	*Hebrus* sp.	0.8
Trichoptera	Polycentropodidae (larva)	*Neureclipsis* sp.	4.7
	Hydropsychidae (larva)	*Hydropsyche* sp.	0.8
	Rhyacophilidae (Larva)	*Himalopsyche phryganea*	0.8
	Pyralidae (Larva)	*Elophila interruptalis*	3.1
		Potamomusa sp.	2.3
Coleoptera adult	Dytiscidae	*Laccophilus parvulus* (Aube)	3.1
		Hydrovatus confertus(Sharp)	3.1
	Noteridae	*Canthydrus luctuosus*(Aube)	1.6
		Berosus indicus (Mots)	0.8
		Hydrovatus sp.	5.4
		Laccophilus sp.	0.8
	Hydrophilidae	*Berosus* sp.	3.1
		Stenolophus sp.	1.6
Diptera	Chironomidae	*Ablabesmyia annulata* Johansen	1.6
		Chironomus major Meigen	5.4
		Polypedilum nubifer Kieffer	1.6
		Einefeldia synchrona Kieffer	0.8
		Lueterboniella Thienemann & Bause	0.8
		Rheotanytarsus pellucidus Thienemann & Bause	0.8

		Paratanytarsus sp. Freeman	0.8
	Chaoboridae	*Chaoborus* sp. (pupa)	1.6
	Ceratopogonidae	*Bezzia* sp. (larva)	3.1
Total	17	35	100.0

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LIST OF PUBLICATIONS

Community Structure of Macrophyte Associated Invertebrates in a Tropical Kole Wetland, Kerala, India

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Abstract

Aquatic macrophytes provide a good ecological niche for macro invertebrates and may occupy the littoral region of wetlands. This contribution discusses the macrophyte associated macroinvertebrate assemblage and abundance in the Maranchery Kole wetland that is part of Vembanad Kole wetland system, a Ramsar site on the west coast of India. It lies submerged under water for about six months in a year giving both terrestrial and water related properties. Six macrophyte species were observed from the four study stations of the wetland among which Hydrilla verticillata, Utricularia aurea, Eichhornia crassipes, are more common and showed maximum biomass. The macrophyte associated invertebrate community in the wetland carried out from October 2010 to September 2011 period varied widely during the pre monsoon, post monsoon and monsoon seasons. It comprised of 10 taxa belonging to insects, insect larvae, arachnids, decapods, molluscs, branchiopods, hirudinea, nematodes, isopods and, fish fingerlings. Insect larvae was found to dominate during premonsoon (34%), monsoon (36%), whereas decapods (47%) dominated during postmonsoon season. The macrophyte, Hydrilla verticillata was associated with the maximum numerical abundance (400 No/m^2) of macro invertebrates during the monsoon season. Thus the high growth and density of macrophytes in Maranchery Kole wetland was conducive for the abundance and diversity of several macroinvertebrates. This would be help in the propagation of native fish species in such wetlands involving the local self-government bodies and other people's participatory programs.

Keywords: Kole wetland, macrophytes, invertebrates, nutrients.

Introduction

Fresh water habitats are among the most valuable and threatened ecosystems[1]. They are the fragile ecosystems that are susceptible to damage even with only a little change in the composition of biotic and abiotic factors. Kole wetlands are one of the important floodplain wetlands of Kerala[2] and these ecosystems which provides answer for the livelihood concerns of the thousands of inhabitants in and around this region also support a wide spectrum of biodiversity which depends on the annual rise and fall of the floods.

It is generally known that aquatic plants provide a physically and chemically complex habitat in aquatic ecosystems, and architectural features of this habitat can act invertebrate species diversity, density and distribution[3]. Macro invertebrates perform several critical role in ecosystem by virtue of their numerical abundance, diversity and trophic significance. Macrophytes are generally found in littoral zones in lakes and rivers. The value and abundance of habitat provided by each species of macrophytes for invertebrates may vary depending on the zone they occupy[4]. While several investigation have been conducted on the spatio-temporal variability in invertebrate and macrophyte associations[5-7], few studies have been carried out in wetlands and few have specifically dealt with the issue of how changes in water level, and related environmental parameters, may influence macrophytes and the invertebrates which use them[8,9,10]. Studies were very rare in Kerala especially the macro invertebrates associations with macrophytes. Productivity and fishery potential of South west coast of India was investigated with special reference emphasis to Ramsar sites[11]. In Kole wetlands water column was reduced seasonally this spatial variation may influence habitat choices in invertebrates and result in movement between macrophyte species which may occur at different depths and have different complexities of structure. Keeping in view the importance of Kole wetlands and general dearth of literature, the present work was undertaken to assess the physico-chemical property of water, macrophyte growth and water column fluctuations on macro invertebrate abundance and diversity.

Morphometry and Geographical location: Variability is the principal feature of this wetland as it varies widely from season to season. Based on the pattern of rainfall in Kerala, three seasons are recognized, Monsoon (June-September) when the south-west monsoon is active, post monsoon (October-January) when the north-east monsoon become active and pre monsoon (February -May). The Kole wetland is located in the Veliamkode and Maranchery panchayats in the Malappuram