DIVERSITY AND ECOLOGY OF THE FRESHWATER MACROPHYTES FROM THE LOWER STRETCHES OF *KOLE* WETLANDS OF MALAPPURAM AND THRISSUR DISTRICTS.

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Certificate

This is to certify that the research work presented in this thesis entitled **"DIVERSITY AND ECOLOGY OF THE FRESHWATER MACROPHYTES FROM THE LOWER STRETCHES OF *KOLE* WETLANDS OF MALAPPURAM AND THRISSUR DISTRICTS."** is based on the original work done by Mrs. Jyothi P.V. under our guidance at Post Graduate Department and Research Centre of Aquaculture & Fishery Microbiology, M.E.S. Ponnani College, Ponnani, Malappuram District, Kerala, India 679 586, in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy and that no part of this work has previously formed the basis for award of any degree, diploma, associateship, fellowship or any other similar title or recognition.

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Declaration

I hereby declare that the work presented in this thesis entitled **"DIVERSITY AND ECOLOGY OF THE FRESHWATER MACROPHYTES FROM THE LOWER STRETCHES OF *KOLE* WETLANDS OF MALAPPURAM AND THRISSUR DISTRICTS.”** is based on the original research work done by me under the guidance of Dr S. Suresh Kumar, Professor of Biological Oceanography and Director, School of Ocean Science and Technology, Kerala University of Fisheries and Ocean Studies Panangad 682506, Kerala, India and Dr. M. Razia Beevi, Associate Professor and Head of Department, Post Graduate Department and Research Centre of Aquaculture & Fishery Microbiology, M. E. S. Ponnani College, Ponnani, Malappuram - 679 586 and that no part of this work has previously formed the basis for award of any degree, diploma, associateship, fellowship or any other similar title or recognition.

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Dedicated for
my parents and aunt

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Preface

The Ponnani *Kole* land is distributed in Chavakkad and Choondal to Thavannur, covering Chavakkad and Thalapally taluks of Thrissur district and Ponnani Taluk of Malappuram district, the northernmost extension of Vembanad *Kole* –the Ramsar site. It is a low lying area with alluvium deposits brought down by the Bharathapuzha river. These *Kole* lands are waterlogged areas used for paddy cultivation, fishing, duck farming and are a vital ecosystem for water birds. This wetland comes under the 'Central Asian-Indian Flyway' and serves as 'stepping stone' for the trans-continental migrant birds. The study area is extending from the southern bank of Bharathapuzha in the north to Naranipuzha in the south in a stretch of twenty kilometres. Macrophytes being the primary producers of this ecosystem, its diversity and ecology study is very significant.

However, to the best of our knowledge, no serious attempts were made to study the ecological impacts of these *Kole* wetlands especially emphasising biodiversity, physicochemical characters and human dependence. A few published research reports existing were based on the primary objective of the potentiality of Thrissur *Kole* wetland for rice cultivation. Even though the avian fauna of these *Kole* wetlands is documented, no comprehensive documentation of distribution, diversity and ecology of aquatic macrophytes have been undertaken. So the present study was carried out with a hypothesis that the community structure of the macrophytes in the *Kole* wetland varies with the region, time, water and sediment quality parameters. The results emerging from the study on composition and distribution of macrophytes of *Kole* lands can provide accurate information on species richness. Results also point out the importance of macrophytes not only in the ecosystem level but also their relevance in the medicinal and ornamental fields.

The thesis concentrated mainly on diversity and ecology of freshwater macrophytes in Ponnani *Kole* lands lying between 10°41.098 to10° 47.156 North latitude and 75°56.067 to 76°03.688 East longitude based on ecological interest. Sampling for qualitative and quantitative distribution of macrophytes in relation to environmental variables was conducted at 12 stations from 2014 to 2016. The thesis is presented in six chapters.

The first chapter provides the general introduction, the review of literature, geographic location of the study area, objective relevance, the significance of the research work and detailed methodology. The other chapters are discussed with a separate introduction, small review, materials and methods, results, discussion and conclusion.

The second chapter deals with the documentation of freshwater macrophytes from the study area. The identification of macrophytes up to species level was carried out with the help of keys and description given based on floras and monographs. The collected plants were categorised into seven major physiognomic forms such as Free floating, Suspended hydrophytes, Submerged hydrophytes, Anchored floating, Emergent hydrophytes, Wetland plants, Mangrove and associates (Sunil and Sivadasan, 2009). Photographs were taken.

The third chapter intends to explain the seasonal variation in diversity and distribution pattern of plant communities in Ponnani *Kole* wetlands. To provide information on diversity and community structure of macrophytes in the study area the indices, viz. Species number (S), Abundance (Biomass; N), Shannon- Wiener diversity index (SDI - H'), Simpson evenness (SEI - 1-ƛ), Average taxonomic distinctness (AvTD - Δ+) and Variation in taxonomic distinctness (VarTD - Λ+) were worked out as per the methods of Clark and Warwick (2001a and 2001b); funnel plot and k dominance plot were constructed. Differences in the mean diversity indices and mean biomass of various growth forms between seasons in the selected area were compared using ANOVA and further by Duncan's multiple range test (Snedecor and Cochran, 1969).

The fourth chapter describes the community assemblage pattern of macrophytes and their variations within and among areas affected by environmental disturbances in Ponnani *Kole* wetland system. The macrophyte community structures in the study site were characterised with reference to areas of saline intrusion, intense agricultural activities and sewage disposal. To provide information on the community structure of the study area the diversity indices, viz. Species number (S), Abundance (M), Shannon-Wiener Diversity Index (SDI - H') and Simpson's Evenness Index (SEI - 1-λ) were calculated from the biomass of each species collected from stations and Average Taxonomic Distinctness (AvTD - Δ+) and Variation in Taxonomic Distinctness (VarTD - Λ+) from the presence or absence data using Primer 6.0 software (Clarke and Warwick 1998). Preliminary analysis of biomass of macrophytes data showed no significant variation in the macrophyte community composition within the different disturbance zones; hence the data were pooled per disturbance zone. Differences between the mean diversity indices recorded from areas of three disturbances and control were compared using ANOVA's with Duncan's multiple range post-hoc analysis (Snedecor and Cochran, 1969) in the statistical package SPSS 17.0. The k-dominance plot and funnel plots were constructed. To examine spatial patterns in macrophyte assemblages in four different zones the Bray-Curtis dissimilarity metrics of biomass was evaluated using non-metric multidimensional scaling (NMDS) for representing their similarity/dissimilarity in assemblage pattern (Clarke 1993).

The fifth chapter indented to develop an understanding of seasonal variation in hydrology and sediment structure of different areas, with disturbances and without disturbance, in Ponnani *Kole* wetland ecosystem. Statistical analysis for Two-way ANOVA (Analysis of Variance) was done using SPSS 17.0 for testing the significant differences, if any, among the parameters between stations and seasons. The range and the mean along with a standard deviation of various physicochemical characteristics of different stations studied were analysed for three seasons. Similarly to test the effect of the environmental parameters, analysis of variance (Two Way ANOVA) between stations and between seasons was done, and the F value was taken at 5% level. To study the association of macrophyte species with environmental parameters Canonical correspondence analysis (CCA) with a forward selection procedure was carried.

The sixth chapter aimed at exploring the possibilities of utilising the untapped endemic aquatic plant resources which have high potential on medicinal plants in health care and ornamental plants for the aquarium industry. The present investigation revealed the presence of 26 species of medicinal herbs under 23 genera and 18 families and 26 species of ornamental plants under 19 genera and 15 families. The data collected in this study highlights the diversity of plants with ornamental and medicinal values. The outcome generates a better understanding of ornamental and medicinal plants of commercial use in *Kole* lands to humanity.

The sixth chapter is followed by the summary and conclusions of the investigation. The list of literature consulted and sited followed this portion as references.

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ABBREVIATIONS USED

ANOVA	Analysis of Variance
APHA	American Public Health Association
AvTD (Δ+)	Average taxonomic distinctness
BOD	Biochemical oxygen demand
Ca	Calcium
CCA	Canonical correspondence analysis
Cm	Centimeter
Cu	Copper
DMRT	Duncan Multiple Range Tests
DO	Dissolved oxygen
EC	Electrical conductivity
et al.	*et alli* (Latin word, meaning 'and others')
Fe	Iron
GBO	Global Biodiversity Outlook
IDH	Intermediate Disturbance Hypothesis
IOPs	International Organization Partners
IPCC	International Panel on Climate Change
IUCN	International Union for the Conservation of Nature
IWMI	International Water Management Institute
kg/ha	Kilogram per hectare
KLDC	Kerala Land Development Corporation
KLDC	Kerala Land Development Corporation
MEA	Millennium Ecosystem Assessment
Mg	Magnesium
mg/kg	Milligram per hectar

mg/L	Milligram per litre
mm	Millimetre
Mn	Manganese
mS	millisiemens
MSL	Mean Sea Level
N	Abundance, Biomass
NCT	National Capital Territory
NMDS	Non-Metric Multi-Dimensional Scaling
NTU	Nephelometric turbidity Unit
pH	Power of Hydrogen
ppm	parts per million
PRIMER	Plymouth Routines in Multivariate Ecological Research
S	Total number of species
SAC	Space Application Centre
SDI (H’)	Shannon – Weiner Diversity Index
SEI (1-ƛ)	Simpson’s Evenness Index
sp.	Species
SPSS	Statistical Programme for Social Sciences version
TDS	Total dissolved solids
TEEB	The Economics of Ecosystems and Biodiversity
VarTD (Δ)	Variation in Taxonomic Distinctness
WFD	Water Framework Directive
WTO	World Trade Organisation
WWF	World Wildlife Fund
Zn	Zinc

Chapter-1

GENERAL INTRODUCTION

1.1 INTRODUCTION

1.1.1 Wetlands

Ramsar Convention (1971-Article 1.1) states that "wetlands are areas of marsh fen, peatland or water, natural or artificial; permanent or temporary; static or flowing water; fresh, brackish or salt, including marine areas; water depth at low tide does not exceed six meters". It includes riparian and coastal zone adjacent to the wetlands and islands or bodies of marine water deeper than six meters at low tide lying within wetlands. Wetlands are the region between terrestrial and aquatic ecosystems where the water table is frequently at or near the surface or land is covered by shallow water (Mitsch and Gosselink, 1993). They are often cited as a "kidney of catchment areas" (Mitchell, 1994) thereby reducing eutrophication in adjacent water bodies. Ecologically wetlands occupied with filtration, storage and supply of water, flood control, retention of sediment, and provide habitats for diverse flora and fauna (Abebe and Geheb, 2003). Asibor (2009) asserts that wetlands are generally applauded for their wide range of functions and values in the ecosystem; as they must possess water, soil and wetland plants. They are one of the most productive ecosystems in the earth (Ghermandi *et al*., 2008) and provide many vital services to human society (Russi *et al*., 2013). Wetlands are of great significance ecologically, since they support different food chains and food webs, regulate the hydrological cycle and provide haven to large numbers of flora and fauna. Wetlands have rich nutrient status, carrying capacity and enormous production potential hence considered as food and fodder resources for animals including human beings. However, wetlands are also ecologically susceptible and adaptive systems (Turner *et al*., 2000) and play a vital role in stabilising the microclimate of the area. Wetlands differ from other land forms or water bodies having characteristic vegetation of aquatic plants, adapted to the unique hydric (hydrated) soil and are measured as the most biologically diverse ecosystem. Algae in open waters represent the floristic diversity and macrophytes dominate the wetlands (Airsang and Lakshman, 2013). The worth of the world's wetlands is increasingly receiving due attention as they tag on a healthy environment to the earth. Inundated wetlands are very useful in storing rainwater and are the primary source for recharging groundwater aquifers. During flooding, they alleviate flood and trap suspended solids and nutrients. Thus streams flowing into lakes through wetlands will carry suspended particles and nutrients than they directly enter into the lake. According to Bezabih and Mosissa (2017) anthropogenic activities continuously change the land uses which in turn speed up the ecological changes of wetlands. Wetland conservation is essential and vital for sustainable food production and ensuring the availability of water for all life forms. Loss of wetland ecosystem is mainly due to deforestation, agriculture practices, watersheds, depletion of groundwater *etc*. Reinstallation of wetlands will be very difficult once it is used for other activities.

1.1.2 Ecological Value of Wetlands

Wetlands provide many services and commodities to humanity. They execute copious valuable functions like recycle nutrients, purify water, attenuate floods, maintain stream flow, recharge groundwater, provide drinking water, fish, fodder, fuel, and buffer shorelines against erosion and recreation to society. Wetland supports numerous and wealthy diversity of animal and plant species (Maltby, 2009) and the forfeit they offer have enormous economic and social value. Eutrophication accelerated by agricultural run-off, industrial effluents and domestic sewage have been posturing severe peril to the endurance of wetlands (Prasad *et al.*, 2002). Wetlands are endowed with important storm flow barriers, the mangroves which protect coastal communities. They can impound and store excess carbon produced by human activities as well as store groundwater to combat the impacts of drought. They are significant spots for fishing and bird-watching. Among aquatic systems, wetlands present the utmost seasonal variability of physical and chemical characteristics in response to terrestrial and climatic events (Gopal *et al*., 2000; Junk *et al.,* 2006). Understanding the physical and chemical conditions in wetland waters and sediments, and the way they vary between wetland types is critical to understand how the ecosystem operates and how to restore or recuperate despoiled wetlands. Great environment assortment and a marked natural disturbance system make some wetlands susceptible to the invasion by exotic species, especially from the invasive aquatic plants (Junk *et al.,* 2006).

1.1.3 Wetlands – Global status

Wetlands found throughout the world except in Antarctica. Wetlands cover 6% of the world's land surface and contain about 12% of the global carbon pool, playing an important role in the worldwide carbon cycle (International Panel on Climate Change (IPCC) 1996; Ferrati *et al*., 2005). Worldwide, the areal coverage of wetland ecosystems ranges from 917 million hectares (m ha) (Lehner and Doll, 2004) with an expected monetary value of about US$15 trillion a year (MEA, 2005). More than 50% of the area of certain wetland types had been lost during the 20th century in parts of Australia and New Zealand, Europe and North America (MEA, 2005). Junk *et al.* (2013) opined that the amount of wetland loss around the world varies between 30 to 90% depending on the region. According to Davidson (2014), wetland losses in the 20th century were 64-71 %, and in Asia alone, about 5000km^2 of wetland area are lost annually to agriculture, dam construction, and other uses (McAllister *et al*., 2001). Loss of wetland area results in an adverse impact on ecosystem goods and services (Zedler and Kercher, 2005). Wetland services are unduly extensive compared to their area, 40% of renewable ecosystem services provided by wetlands account for 1.5% of the area globally (Zedler, 2003).

According to Global Biodiversity Outlook-4 report, the *Wetland Extent Index* showed approximately 40 % decline across the world in the extent of both marine and inland wetlands over 40 years, although regional differences exist. The index also found that "human-made wetlands have increased over the 38 years, especially in southern Asia due to the conversion of natural wetlands into paddy fields." It is important to note that the gain in human-made wetlands does not equalise the losses in the natural wetland area. The Economics of Ecosystems and Biodiversity (TEEB) reported that the water-related ecosystem services and wetlands are being tainted at an alarming pace (Russi *et al*., 2013). Study on spatial and temporal dynamics of wetland vegetation of Poyang Lake in China related to water level fluctuations by Tan and Jiang (2016) underscores the above reality. Baig *et al*., (2017) assessed the changes in land cover of

Indus delta coastal wetland, Uchhali complex an inland wetland (protected areas) and Nurri Lagoon (unprotected area) and identified the factors causing the degradation of these wetlands. They also studied the conservation strategies used to assess the difference between the conditions of protected and unprotected wetlands. Leon *et al.,* (2018) studied the costs and benefits of water storage management to improve flood control in wetland systems. Gulbin *et al.* (2019) found wetland loss is a significant contributor to flooding along with regional climate change and the restoration presents an excellent balancing measure tumbling the negative impacts of other flood management strategies.

1.1.4 Wetlands – National status

Indian wetland ecosystems prop up diverse and unique habitats and are distributed across various topographic and climatic regimes. They are considered to be a vital part of the hydrological cycle and are highly productive systems in their natural forms. The upkeep of wetlands is essential and necessary in India for ensuring sustainable food production and water availability for living beings. India is a signatory to the Ramsar Convention on Wetlands, which includes in its ambit a wide variety of habitats, such as marshes, swamps, lakes, coastal lagoons, mangroves, peatlands, coral reefs and numerous man-made wetlands, such as ponds, salt pans, reservoirs, gravel pits, sewage farms, and canals. Majority of the inland wetlands are directly or indirectly reliant on the major rivers like Ganga, Brahmaputra, Narmada, Godavari, Krishna, Kaveri, Tapti. They occur in the hot arid regions of Gujarat and Rajasthan, the deltaic regions of the east and west coasts, highlands of central India, wet, humid zones of south peninsular India, Andaman and Nicobar and Lakshwadeep islands. The largest wetland system in India is the Indo-Gangetic flood plain, extending from the river Indus in the west to the Brahmaputra in the east with the wetlands of the Himalayan terai and the Indo-Gangetic plains (Prasad *et al.*, 2002). The Central Government is desirous of mainstreaming full range of wetland biodiversity and ecosystem service values in sectoral development planning and decision making based on integrated management approach (Wetlands Rules, 2016). Wetlands in India provide multiple services such as irrigation, domestic water supply, freshwater fisheries, groundwater recharge, flood control, carbon sequestration, pollution abatement and water tourism. Indian wetlands occupy 58.2 million ha, including areas under paddy cultivation, face incredible anthropogenic pressures like changes in land use or land cover pattern, rising expansion projects and improper use of watersheds, which in turn seriously influence the aquatic biodiversity (Singh *et al.,* 2006; Kumar and Gupta 2009; Alexander *et al.,* 2010; Anand *et al.,* 2010; Chackacherry, 2010; John and Francis, 2010; Prasad, 2010; Ramachandra, 2010; Rasingam, 2010). SAC (2011) reported that India has about 757.06 thousand wetlands with a total wetland area of 15.3 m ha, accounting for nearly 4.7% of the total geographical area of the country. The area under inland wetlands accounts for 69%, coastal wetlands 27%, and other wetlands (smaller than 2.25 ha) 4%. The aquatic vegetation in all these wetlands put together account for 1.32 m ha (9% of total wetland area) in post-monsoon and 2.06 m ha (14% of total wetland area) in pre-monsoon (SAC, 2011). Wetlands such as coral reefs, beaches, reservoirs, lakes and rivers are measured to be an important part of tourism practices and are expected to be a key part of the increase in demand for tourism locations (MEA, 2005; Ramsar Convention on Wetlands and WTO, 2012). Every year an average of seven million tourist visit Kerala's backwaters, beaches and wildlife sanctuaries; three million visit Uttarakhand's lakes and other natural wetlands; one million visit Dal lake; and twenty thousand visits lake Tsomoriri (Bassi *et al*., 2014). Urbanisation exerts significant influences on the structure and function of wetlands by modifying the hydrological and sedimentation regimes, and the dynamics of nutrients and chemical pollutants. Studies of Khandekar (2011) found that out of 629 water bodies identified in the National Capital Territory (NCT) of Delhi, 232 cannot be revived on account of large scale encroachments. Similarly, greater Bengaluru Region lost 66 wetlands with a water spread area of around 1100 ha due to urban slump (Ramachandra and Kumar, 2008). Limited analysis on the impact of climate change on wetlands in India suggests that high altitude wetlands and coastal wetlands (including mangroves and coral reefs) are some of the most sensitive classes that will be affected by climate change (Patel *et al*., 2009). The total extent of coastal ecosystems (including mangroves) in India is around 43,000 km^2 (Kathiresan and Thakur, 2008). Swamy *et al.* (2016) focused on the floristic survey of Poncharum wildlife sanctuary of Telangana state in India.

1.1.5 Wetlands - Kerala status

Wetlands in Kerala are distributed all along the coastal and in the inland regions. A database on wetland status of Kerala based on remote sensing techniques was made by the Government of India (SAC, 2011). According to SAC (2011), 1,60,590 ha. of wetland area is present in Kerala, including river/streams (65,162 ha.), lagoons (38,442 ha.), reservoirs (26,167 ha.) and waterlogged areas (20,305ha.). The International Convention of Wetlands designated three wetland ecosystems in Kerala as Ramsar sites on 19th August 2002, for the conservation of biological diversity and for sustaining human life through the ecological and hydrological functions they perform. They are the Vembanad–*Kole*, Ashtamudi and Sasthamkotta wetlands. The district-wise distribution of wetlands in Kerala showed that Alappuzha district has the highest area under wetland with 26,079 ha., mainly due to the presence of Vembanad *Kole* wetland and Wayanad district has the lowest area under wetland (3,866 ha.) (SAC, 2011). Kerala Agricultural University reported a high level of eutrophication of the Vembanad lake and pesticide residue from rice polders and nutrient discharge from urban settlements were aggravating the pollution, playing havoc with the fragile wetland ecosystem and jeopardising its tourism potential (Anon. 2017a)

1.1.6 Indian wetlands - a biodiversity hotspot

Wetlands play important role in supporting species diversity. Indian lakes, rivers and other freshwater bodies support a large variety of biota representing almost all taxonomic groups. Some vertebrates and invertebrates depend on wetlands for their entire life cycle, while others rely only partially during their life cycle. The total numbers of aquatic plant species surpass 1200, and they supply food resource particularly for waterfowls (Prasad *et al*., 2002). The freshwater ecosystems of the Western Ghats, a biogeographic region in southern India covering a total area of 136,800 km^2, alone has about 290 species of fishes; 77 species of Molluscs; 171 species of Odonates; 608 species of aquatic plants; and 137 species of amphibians. Out of these, almost 53% of freshwater fish, 36% of freshwater Mollusc, and 24% of aquatic plant species are endemic to this region (Molur *et al*., 2011). Loktak Lake in Manipur, the largest natural water body in North-eastern India is famous for its floating mats of vegetation locally called as phumdi, a sole ecosystem having different soil mass, vegetation and organic matter at various stages of decomposition (Sharma, 2009). Indian wetlands like Bharatpur wildlife sanctuary in Rajasthan and little Rann of Kachchh and coastal areas of Saurashtra in Gujarat are important breeding stations for wildlife and afford a shelter for migratory birds.

1.1.7 Threats to wetland ecosystem

Most common threats of wetlands are the results of increased pressure of social, economic and climatic factors on the natural resources. Wetland is fatally used and exploited ecosystems for sustainability (Molur *et al*., 2011). Dependence for water and other resources made enormous pressures on these ecosystem resulting in direct impacts on species diversity and populations (Molur *et al*., 2011). For example, many wetland-dependent species including 21% of bird species; 37% of mammal species; and 20% of freshwater fish species are either extinct or globally threatened (MEA, 2005). Despite the increasing public awareness towards the importance of natural environments particularly wetlands, a real understanding of sensitivity and fragility of these vital ecosystems is not much optimistic. Thirty percentage loss of wetlands over 38 years from 1970–2008 was recorded globally with largest loss in Asia and Europe; and smallest in North America and Oceania (Dixon *et al*., 2016). The fate of the world's remaining wetlands and the species which depend upon them is very uncertain.

1.1.8 Wetland loss in India – a threat to ecological balance

Indian wetlands are facing severe anthropogenic pressures. Rapid increase in human population, substantial changes in land use/land cover, burgeoning development projects and improper use of watersheds have all caused a substantial decline of wetland resources of the country. Untenable levels of grazing and fishing activities have also resulted in the degradation of wetlands. Reinstallation of these transformed wetlands is quite hard once these sites are occupied for non-wetland uses. Hence, the demand for wetland products (water, fish, wood, fibre, medicinal plants *etc.*) will increase with an increase in population. Two types of wetland loss in India were observed viz. acute and chronic losses. Wetland filling with soil constitutes acute loss whereas; the gradual exclusion of forest covers with succeeding erosion and wetland sedimentation over many decades was a chronic loss (Prasad *et al*., 2002). Since wetlands are common property resource, it is an uphill task to protect or conserve these ecosystems unless; the principal stakeholders are involved in the process. Angelini *et al*. (2008) and Nathuhara (2013) opined that paddy fields could substitute the natural wetland loss because of their rich biological diversity. Kerala had around 328,402 hectares of wetlands in 2004, which over the years had fallen to 160,590 hectares, dramatic 49 per cent decrease. (Anon. 2017b)

1.1.9 Ramsar convention

The Ramsar Convention is a global agreement for the conservation and sustainable use of wetlands named after the city of Ramsar in Iran, where the convention was signed in 1971. The Ramsar convention had tinted the wetland ecosystems as the opening point of water management strategies. The vision of the convention is to build up and uphold an international network of wetlands by safeguarding ecosystem components and services which are imperative for the protection of global biodiversity and supporting human life. Five International Organization Partners (IOPs) are working strongly with the convention and linked with the treaty since its beginnings. They are BirdLife International, The International Union for the Conservation of Nature (IUCN), The International Water Management Institute (IWMI), Wetlands International and World Wildlife Fund (WWF).

The convention entered into power in 1975 and till January 2016 had 169 contracting parties from all parts of the world. More than 2,220 wetlands have selected for special protection as “Ramsar sites”, covering 214 million hectares. The mission of the Ramsar convention, adopted by the contracting parties in 1999 and refined in 2002, is the conservation and prudent utilisation of all wetlands through local and national measures and international assistance for achieving sustainable growth throughout the world. Since January 2016 the convention operated for the period 2016-2024 under its fourth strategic plan adopted by Resolution XII.2 of COP12 (Punta del Este and Uruguay, 2015). Ramsar Secretariat (2013) identified 1,052 sites in Europe; 289 sites in Asia; 359 sites in Africa; 175 sites in South America; 211 sites in North America; and 79sites in Oceania region as Ramsar sites. As per the Ramsar convention definition most of the natural water bodies (rivers, lakes, coastal lagoons, mangroves, peat land, coral reefs) and man-made wetlands (ponds, farm ponds, irrigated fields, sacred groves, salt pans, reservoirs, gravel pits, sewage farms and canals) in India constitute the wetland ecosystem, but only 26 wetlands have been designated as Ramsar sites (Ramsar Secretariat, 2013). However, many other wetlands which execute important functions are sustained to be overlooked in the policy process. As a result, many wetland ecosystems are susceptible, and many are already tainted and lost due to population explosion and involuntary urbanisation (Central Pollution Control Board, 2008). National level studies indicate the designation of a Ramsar site along with proper protection under the Ramsar convention tends to increase bird abundance and species richness (Kleijn *et al*., 2014). Wetlands are one of the most threatened ecosystems in India due to loss of vegetation, saline intrusion, excessive inundation, water pollution, species invasion, reclamation, road construction and urbanisation.

1.1.10 *Kole* lands

Kole lands are one of the imperative flood plain wetlands in Kerala, allied to sea through channels and backwaters (Tessy and Sreekumar, 2008a) and afford livelihood for inhabitants and support wide spectrum species diversity. Seasonal variation in the water column may sway habitat change for invertebrates and macrophyte species in different depth with different complexities of structure. *Kole* wetlands in Kerala were under rice cultivation for the past 200 years since earlier Maharaja allowed changing this wetland into paddy fields in the early 18th century (Anon., 1989).

The word *Kole* in Malayalam (the regional language in Kerala, India) means ‘bumper yield if a flood does not damage the crops’ (Johnkutty and Venugopal, 1993). *Kole* wetlands are low lying areas placed 0.5 to 1m below Mean Sea Level (MSL) and remain submerged for about six months in a year, having precise farming technique from December to May, or else flooded from June to November. *Kole* lands cover an area of 13,632 hectares spread over Thrissur and Malappuram districts (Sujana and Sivaperuman, 2008) considered as the rice granary of Kerala, part of the unique Vembanad *Kole* wetland ecosystem. The *Kole* lands in Kerala extend from Chalakudy river in the south to Bharathappuzha river in the north. These wetlands and distributed from Velukkara in the south on the Chalakudy river bank in Mukundapuram taluk to Mullassery of Chavakkad taluk and Tholur-Kaiparama areas of Thrissur taluk is designated as ‘Thrissur *Kole*’. The contiguous area from Chavakkad and Choondal to

Thavannur, covering Chavakkad and Thalapally taluks of Thrissur district and Ponnani taluk of Malappuram district form the 'Ponnani *Kole*' (Johnkutty and Venugopal, 1993). According to Jayan and Sathyanathan (2010) *Kole* wetlands are water-logged paddy cultivating areas such as Kuttanad (in Alappuzha, Kottayam and Pathanamthitta), Pokkali (in Alappuzha, Ernakulam and Thrissur) and Kaipad (in Kozhikode and Kannur) districts of Kerala.

The Vembanad-*Kole* largest brackish wetland ecosystem in the southwest coast of India supports the third largest population of waterfowl in India during winter months. Rice cultivation, fishing, mining, water transport and tourism are critical on-site activities endowed with goods and services by *Kole* lands. Supporting agricultural activities, in the non-*Kole* lands in nearby areas include the cultivation of garden crops like coconut, arecanut and plantains, is the primary off-site services provided by the *Kole* lands. *Kole* lands also offer offsite ecological benefits like flood control, groundwater recharge and nutrient retention. Non marketed on-site benefits found in the *Kole* lands include recreational opportunities, habitat and nesting place for migratory birds, support of plant and animal diversity *etc.* Hence *Kole* lands are considered as multiple use wetland ecosystems subjected to seasonal alterations. The recent title of Vembanad-*Kole* wetland system as a Ramsar site has elevated the status of these *Kole* lands. Although there are studies on the bird fauna of *Kole* lands (Jayson, 2002) no reliable information is available on the fish fauna, flora and other biotic components of *Kole* wetland system. Government has revealed substantial attention in the development of *Kole* wetlands, by constituting Kerala Land Development Corporation (KLDC) and Punja special office (James, 2002). Reclamation activities, field conversion for sand and clay mining, hunting of avian fauna and coconut, arecanut and plantains cultivation are the main threats facing by *Kole* wetlands in Ponnani. Freshwater shortage and water quality deterioration due to saline intrusion have also been reported from various parts of this wetland ecosystem.

1.1.11 Flora and fauna in *Kole* wetlands

Freshwater ecosystems offer habitat for many plant species, fishes, birds, insects, and other animals. Their interaction with abiotic factors provides a balanced ecosystem and plants supply food and shelter for other inhabitants. *Kole* lands are rich in floristic and faunal diversity which is higher than any other freshwater ecosystems. Wetland flora includes representatives of all taxonomic groups like algae, mosses, ferns and flowering plants. Aquatic macrophytes are the dominant community growing either submerged or floating on the surface either regularly or periodically depending on the availability of water. They execute a key role in the structure and function of the aquatic ecosystem by providing habitat and shelter for other aquatic communities and contribute biomass and nutrients to various trophic levels in the ecosystem. Unnithan *et al.* (2005) recorded almost 100 species of phytoplankton from the backwaters of Kerala. Joseph (2002a) documented three groups of aquatic macrophytes like submerged forms, free-floating ones and mangrove and associates in Kerala. Unnithan *et al.* (2005) recorded 20 groups of Zooplanktons in eleven backwaters of Kerala and pointed out they are the major group in the energy transfer and plays an important task in the secondary production of wetlands. The wetlands are gifted with diverse fish fauna characterised by many rare, endangered and endemic species. *Kole* land offer suitable habitats for avian visitors. During their annual migrations, they stop at sites for very short period to rest and feed, and these ‘stepping stones’ are vital for their survival. Trichur and Ponnani *Kole* fields are the regions with such international importance. Protecting the migrant water birds is the collective task of all countries in the flyway. According to Stewart (2001) and Jayson and Sivaperuman (2005) *Kole* wetlands are feeding, breeding and roosting ground for many species of avian fauna. One hundred eighty-two (182) species of birds and 13 species of fishes were reported from *Kole* wetlands of Kerala by Jayson and Sivaperuman (2005). Urgent measures to be taken for the conservation of these specific ecosystems as these *Kole* wetlands are stepping stones for transcontinental migrants of avifauna.

1.1.12 Macrophytes

The term ‘aquatic macrophytes’ refers to hefty plants obvious to the naked eye, with their vegetative body budding permanently or periodically in aquatic habitats. They are the key component of wetland ecosystem since they provide food for invertebrates and vertebrates, influence nutrient cycle, alter the water and sediment physico-chemistry and also enhance habitat complexity leading to change the spatial structure and developing biodiversity in the littoral zone. They add significantly to the productivity of water bodies, mobilise mineral elements from the bottom sediments and offer shelter to aquatic invertebrates and fishes. Some aquatic plants are used for waste water treatment.

Macrophytes contribute significantly to the structural diversity of wetland environments by providing shelter for macro-invertebrates and are a good source of food for waterfowl (Cazzanelli *et al*., 2008). Aquatic vascular plants not only supply food, locale and shelter for another aquatic biota such as macroinvertebrates, fish and water birds, but also improve self-purification capacity of waters (Bornette and Puijalon, 2011). Aquatic vegetation in wetlands is treated as an important target of conservation and reinstallation due to the sensitive nature towards water level fluctuations compared to other biological groups like macro-invertebrates and fish (Merritt *et al*., 2009). Man-made lentic habitats offer a suitable environment for macrophytes and harbouring a high diversity of common and threatened species (Svitok *et al.*, 2011, Chester and Robson 2013, Hrivnak *et al*., 2014).

Species of macrophytes and their biomass distribution in aquatic ecosystems have inspired their use in a vast array of commercial, technological and cultural activities, having important ramifications in many formal and informal economic sectors of developing countries. Aquatic macrophytes are used to control eutrophication and environmental pollution; involved in aesthetical and spiritual services; source of food, medicine, soil fertiliser and pharmaceutical products.

1.2 SIGNIFICANCE OF THE STUDY

The *Kole* wetland, one of the largest highly productive and one of the rice granaries of Kerala, has been declared in Ramsar convention for protection. Ponnani *Kole,* the study area, is situated in south-west of Malappuram and north-west of Thrissur districts, is the northern most extension of the Vembanad *Kole* Ramsar site. However, to the best of our knowledge, no solemn attempts were made to study the ecological impacts of these *Kole* wetlands especially emphasising biodiversity, physico chemical characters and human dependence. A few published research reports existing were based on the primary objective of Johnkutty and Venugopal (1993) evaluated the potentiality of Thrissur *Kole* wetland for rice cultivation. Even though the Avian fauna of these *Kole* wetlands is documented by Jayson and Sivaperuman (2005), no inclusive documentation of distribution and diversity of aquatic macrophytes have been undertaken. Aquatic macrophytes are vital for proper protection and function of a healthy and attractive wetland system or any other water body (Batty and Younger, 2002; Scholz and Trepel, 2004). No comprehensive study on biodiversity, hydrology and sedimentology were carried out in Ponnani *Kole* wetland ecosystem. So the present study was carried out with a hypothesis that the community structure of the macrophytes in the *Kole* wetland varies with the region, time, water and sediment quality parameters. The results emerging from the study on composition and distribution of macrophytes of *Kole* lands can provide concrete information on species richness. Results also point out the importance of macrophytes not only in the ecosystem level but also their relevance in the medicinal and ornamental fields. A common trend in Kerala is keeping the wetlands uncultivated as an overture for diverting it for other uses, and *Kole* land is not an exceptional case (Nikhil and Azeez, 2009a).

1.3 OBJECTIVES OF THE STUDY

- To conduct primary documentation of freshwater macrophytes in Ponnani *Kole* wetlands extending in Malappuram and Thrissur districts.
- To bring out spatial and temporal variation in the community structure of freshwater macrophytes in lower *Kole* wetlands extending in Malappuram and Thrissur districts.
- To reveal community assemblage of macrophytes in the area of disturbance (area of agricultural activity, area of saline intrusion, sewage disposal areas) in specific localities of the Ponnani *Kole* wetlands.
- To study the correlation between the macrophyte distribution with the environmental variables
- To analyse the sustainable utilisation of the aquatic macrophytes (medicinal and ornamental) in this unique wetland ecosystem

1.4 REVIEW OF LITERATURE

Wetland is a generic name used to describe the universe of wet habits enduring with periodic inundation or prolonged soil saturation adequate for the establishment of aquatic plants. A shift in the outlook that, 'wetlands as wastelands', is required to create awareness to the community on the intrinsic economic values and environmental services provided by the wetlands. According to Cowardin *et al.* (1979) wetlands are "the 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". The vegetation dynamics of freshwater wetlands have been the subject of significant research and recognised the wetland changes in response to water-level fluctuations and other environmental factors (van der Valk, 1981; Kantrud *et al.,* 1989). Wetland was described as versatile and vibrant water logged ecosystem with enormous wealth (Maltby, 1991). According to Hammer (1997) depth of water, a period of flooding and water chemistry were the vital factors shaping the endurance of plants in a wetland system. Patten *et al.* (1990) and Dugan (1993) specified the values and benefits of wetlands in its contribution to the global ecology. Significance of riparian wetlands for assessing biodiversity characteristics was discussed by Toner and Keddy (1997). Loss of biodiversity in future is predicted to be greater for aquatic ecosystems than for terrestrial ecosystems (Kulshrestha and Sharma, 2006). Keddy (2000) defined wetland as an ecosystem that "arises when inundation by water produces soils dominated by aerobic processes and forces the biota, particularly rooted plant, to exhibit adaptation to tolerate flooding. Wetland ecosystems are regarded as biodiversity isles that support extensive food chains and vital sites for conservation; susceptible to the small changes in the composition of biotic and abiotic factors (Getzner, 2002). According to Freyfogle (2007), wetlands are ecotones having an intermediate position between dry land and open water with terrestrial and aquatic characters and their unique properties. Wetlands are the threatened habitat mostly affected by development activities and are lost more rapidly than any other habitat in the world (Moses, 2008). Biogeochemical aspects of wetlands were explained by Reddy and Delauane (2008). Flood control, groundwater recharge, coastal protection, sediment traps, atmospheric equilibrium, waste treatments and biological productivity are the wetland functions pointed out by Chidi and

Ominigbo (2010). According to Nyman (2011) even though wetlands are ecologically sensitive systems, they provide important services to society.

1.4.1 World wetland status

Wetlands are the most threatened ecosystems worldwide even though several international treaties advocate the habitual inventory and efforts aimed for protection (MEA, 2005; Darwall *et al*., 2008; SCBD, 2010). Maltby and Turner (1983) reported the world wetland status, and according to them 6% of the land surface in the universe were covered by different types of wetlands. The factors directly or indirectly accountable for the decline of wetlands in the world were pointed out by Parish and Prentice (1989). Chambers (1999) noticed that water bodies all over the world especially wetlands and flora and fauna associated with them are imperative to every culture on earth and form an unambiguous part of the sacred and cultural legacy of all human cultures. International Convention on Wetlands (Ramsar, 1971) in December 2003 had 138 signatories, and 1328 "wetlands of international importance" (known as "Ramsar sites") were designated, 28% have been facilitated by WWF since 1999 (Schuyt and Brander, 2004). UNEP (2007) reported a 50% reduction in wetland areas in the global scenario. Asibor (2009) reported one-third of all endangered species in the earth were wetland dependent. There has been a growing alarm over the incessant degradation of the wetlands in the world (Pattanaik *et al*., 2008; Sandilyan *et al*., 2008; Kannan and Pandiyan, 2010). According to Zedler and Kercher (2005); Daniels and Cumming (2008) factors responsible for wetland loss encompass vegetation clearing, agriculture drainage, infrastructure expansion and invasion of species**.** Matthews (2013) gave a concise report on the history and development of the Ramsar convention on wetlands.

1.4.2 Indian wetland status

Several studies on wetland management had been carried out in India. Comprehensive work on wetland flora was first shaped by Biswas and Calder (1984). The first scientific mapping of Indian wetlands was carried out using satellite data of 1992–1993 by Space Applications Centre (SAC) in Ahmedabad and estimated the areal extent of wetlands to be about 7.6 m ha (Garg *et al*.,1998), but paddy fields, rivers and irrigation channels were excluded. SAC (2011) prepared National wetland atlas of our country, and a total of 201,503 wetlands were identified and mapped on 1:50,000 scale.

The Several works have been done on the aquatic macrophytes and phytosociology in different freshwater ecosystems of India (Gupta, 1996; Dabgar, 2006; Kar and Barbhaiya, 2007; Chandra *et al.,* 2008 Deshkar, 2008;). Kaul and Handoo (1990) made recommendations on the ecology and management of some typical wetlands of Kashmir. Other relevant studies related to the management of wetlands in India include those carried out by Patel *et al.* (1990) in Kheda district in Gujarat, Davis *et al.* (1990) and Sharma and Saini (1990) in Keoladeo National Park, Bharatpur and made suggestions for better management. It is predicted that freshwater wetlands alone support 20 per cent of the known range of biodiversity in India (Deepa and Ramachandra, 1999). Changes in vegetation pattern, water quality, corrosion, siltation, cattle grazing and poaching recorded in India were the reasons for wetland deterioration (Anjaneyulu, 1991; Trisal, 1993). Naskar (1990) and Jha (1995) studied the wetland vegetation of upper, middle Gangetic plains and the lower Gangetic plains. Harike, the biggest wetland in northern India was studied by Singh and Singh (1990). Selvam (2003) studied the health and wealth of mangrove wetlands in India and pointed out the influence of fresh water inflow and tidal amplitude to this ecosystem. Terrestrial and aquatic flora of hills and plains of West Bengal were explored by Das (2004); Dutta *et al*. (2002)., The utility of wetland vegetation in Maladah district of West Bengal, studied by Chowdhury and Das (2009). Baruah *et al*. (2011) and Dutta *et al*. (2011) studied the riparian flora and river health of Subansiri river in Assam. Borah and Sarma (2012) carried out the phytosociological investigation and human impact on two wetlands of Sonitpur district of Assam. Saud *et al.* (2012) reported encroachment activities, agricultural practices and human settlement within the wetland and its buffer zone ensuing an imbalance in Urpod wetland ecosystem of Assam. Deka and Kanta (2014) focused on the ecological studies of macrophytes in two wetland systems in Nalbari district of Assam. Impact on ecosystem services in Wular lake in India by invasive aquatic plants was studied by Keller *et al*. (2018).

1.4.3 Kerala wetland status

Nair *et al*. (2001) reported a total of 217 wetlands in Kerala in which 64 designated as "inland wetlands" (area 34,199.5 ha), whereas 93 are "coastal wetlands (area 93,730.5 ha). Kerala Land Development Corporation (KLDC, 1976) prepared a project report for Thrissur *Kole* lands, and Mangalabhanu (1977) prepared a report for Ponnani *Kole* lands. Study on the distribution of mangrove wetland ecosystem in Kerala was worked out by Basha (1991) and Mohanan (1997). Kurup (1991) reported the avian fauna of Kadalundi and Purathur estuaries of the Malabar coast of Kerala. Survey of coastal wetlands of Kerala was done by Kurup (1996). Johnkutty and Venugopal (1993) studied the rice cultivation practices in *Kole* lands of Kerala. Nair and Sankar (2002) measured wetlands as important habitats for fish and wildlife species, including rare and endangered birds. Kumari (2010) studied the unique system of rice production in Kuttanad and *Kole* lands of Thrissur district. Majeed *et al*. (2009) suggested that wetland reinstatement depends on the hydrogeomorphic and geochemical environment that is responsible for shaping plant communities. Balachandran *et al*. (2002) focused on the multiple uses of Kerala wetlands such as agriculture, pisiculture, reclamation, area for waste disposal, discharging industrial effluents and municipal wastewater, seasoning the wood, feeding stations for ducks, coir retting and place for hunting and fishing.

Jayson (2002) and Nameer (2005) conducted detailed ecological studies on the avifauna of Vembanad *Kole* wetland. Ecological studies of Muriyad wetland with special emphasis on phytoplankton, zooplankton and fish diversity was done by Thomas *et al.* (2003). Ecology of Purple moorhen, a swamp bird in Azhinhillam wetland in Malappuram district, was studied by Menon (2008). Aquatic macrophytes of *Kole* wetlands in northern Kerala were documented by Sujana and Sivaperuman (2008); phytoplankton and zooplankton of Thrissur *Kole* lands were studied by Tessy and Sreekumar (2008b). Nikhil and Azeez (2009a) observed the change in land use pattern of *Kole* lands in Kerala. Gopalan *et al*. (2014) brought out a brief report on the community structure of macrophyte associated invertebrates of Maranchery *Kole* lands. Recently Kuruvilla (2014), Kuruvilla and Ann Maria (2017) studied the avian diversity of *Kole* lands in Thrissur. Habitat based evaluation of water birds in Palakkal *Kole* lands of Thrissur was more emphasised by Kuruvilla (2016).

1.4.4 Macrophytes

Aquatic macrophytes are exemplary ecosystem engineers (Jones *et al*., 1994, O'Hare *et al*., 2012) and Botanists have focused on aquatic macrophytes from the early twentieth century. According to Lacoul and Freedman (2006); Chambers *et al.* (2008) macrophytes include a diverse group of macrophytic organisms- angiosperms, ferns, mosses, liverworts and some freshwater macroalgae that occur seasonally or permanently in a wet environment. The use of macrophytes as bioindicators assumes that predictable relations subsist between assemblage attributes and physico-chemical conditions (Robach *et al*., 1996; Ali *et al*.,1999). According to Diehl and Kornijow (1998); Horppila and Nurminen (2003) macrophytes are primary producers, indicators of eutrophication, sensitive to acidification or salinisation and stabilisers of sediment in an ecosystem. Ward (1990) revealed that macrophytes could modify the structure and spatial distribution of benthic invertebrates and persuade habitat conditions. Dvorak (1996) suggested that macrophytes serve as a substrate for periphyton and shelter for invertebrates, fish, amphibians and reptiles. Macrophytes sustain the clear water state by sediment stabilisation and promotion of zooplankton population (Jeppesen *et al*., 1998; Vermaat *et al*., 2000; Madsen *et al*., 2001). Macrophytes provide shelter for zooplankton and are the habitation of predatory fish (Gulati and Van Donk, 2002). Among other implications, aquatic macrophytes are very productive (Wetzel, 2001) with significant structuring role on aquatic environments (Dibble and Harrel, 1997; Jeppensen *et al*., 1998; Hrivnak *et al*., 2009; Tamire and Mengistou 2012). Anthropogenic disturbances negatively affect the equilibrium of macrophyte systems (Steneck and Carlton, 2001). Nichols *et al.* (2000) pointed out that vegetation responses are not linear to environmental factors and Murphy (2002) observed the highest macrophyte diversity in the mesotrophic or slightly eutrophic lakes. Madsen *et al*. (2001) studied the function of sediment properties and rate of water flow on the growth of submersed macrophytes. Vande-Haterd and Ter-Heerdt (2007) revealed that macrophytes could suppress algal bloom, stabilise the sediment and reduce resuspension of detritus by absorbing nutrients from habitat. Some macrophytes directly assist human societies by providing food, biomass, and building materials (Egertson *et al.*, 2004; Bornette and Puijalon 2011). But several species are considered as aquatic weeds due to massive colonization and negative effects upon aquatic diversity and ecosystem functioning (Camargo *et al.*, 2003). According to Scheffer and Jeppesen (2007); Smith (2011) macrophytes support and safeguard food webs and provide ecosystem services, but some macrophytes have an array of adverse effects on habitat structure (Pusey and Arthington, 2003) that in turn affect other members of the aquatic food web. Aquatic macrophytes are key components of aquatic and wetland ecosystems (Rejmankova, 2011) by oxygenation of water (Caraco *et al.*, 2006), increase in productivity and nutrient retention (Engelhardt and Ritchie 2002) in the ecosystem. Aquatic plants can appraise the ecological quality of surface waters (Birk *et al.,* 2012) due to their response to nutrients, and are regarded as functional indicators of eutrophication Fabris *et al.,* 2009; Birk and Willby, 2010). Macrophytes are also susceptible to acidification (Tremp and Kohler, 1995), alkalinity and hardness (Vestergaard and Sand-Jensen, 2000a; Triest, 2006). Growth of aquatic plants is also subjective to the rate of water flow (Dawson, 1988), hydrological regime (Haslam, 1987), light availability (Brabec and Szoszkiewicz, 2006; Triest, 2006) and hydro-morphological alterations (O'Hare *et al.*, 2006; Carey *et al.*, 2011). Richness of macrophytes in wetlands depends size (Vestergaard and Sand-Jensen, 2000b; Oertli *et al.,* 2002) altitude (Jones *et al.,* 2003) land use (Smith and Haukos, 2002) water chemistry (Jeppesen *et al.,* 2000; Heegaard *et al.*, 2001; Lougheed *et al.*, 2001) and hydrological fluctuations (Maltchik *et al.*, 2007). Use of aquatic macrophytes by waterfowl for gratifying their high energy requirements during the migratory period was pointed out by Klaassen and Nolet (2007). Aquatic macrophytes are indicators of water quality in an ecosystem (Lacoul and Freedman, 2006; Solimini *et al*. 2006) and their efficiency as an indicator in Wet Tropics region of north Queensland was studied by Mackay *et al*. (2010).

Cook (1996) provided accurate information about the aquatic vascular plants and their biology and listed 352 aquatic and wetland plants from Kerala, in which 15 species were endemic to Kerala. Hooker (1897) included aquatic flora in the general list, and Subramanyam (1962) described the aquatic angiosperms in India. Lavania *et al.* (1990) listed 470 taxa from aquatic and semi-aquatic habitats from the Indian subcontinent. An account of macrophytes of India was published in Assam (Islam, 1988), Bengal (Ghosh, 2005), Bihar (Singh and Singh, 1990), Madhya Pradesh (Srivastava and Kumar, 1987), Maharashtra (Karthikeyan *et al.,* 1982), Kerala (Sunil and Sivadasan 2009) and Uttar Pradesh (Singh and Tomar, 1982). Joseph (2002b) conveyed that floristic inventories of Indian aquatic macrophytes so far published were pertained to the northern and central part of the country. Anupama and Sivadasan (2004) identified 15 true Mangroves and 49 Mangrove associates from Kerala. Attempts have been made by Das *et al*. (1996), Panda and Misra (2011) to collect information on ethnobotanical aspects of wetland plants in India. Bhattacharjya and Bora (2008) reported the role of aquatic medicinal weeds in Nalbari district, Assam and Malaya *et al*. (2012) revealed that many macrophytes could be considered as bio-resources and medicines by local inhabitants. Seema (2002) studied aquatic macrophytes of Salim Ali bird sanctuary in Thattekad, Bindu *et al.* (2004) studied the ecological impacts of aquatic macrophytes in rice field ecosystem of Kuttanadu, Gleena and Vincent (2006) studied the weed flora in the Muriyad wetland system in Kerala. Mangroves and mangrove associates of Kerala were studied by Lakshmi *et al.* (2009); floristic studies in Ambalamedu - an industrial belt of Kerala was conducted by Reshmi *et al.* (2010); biodiversity studies in Anachal wetland ecosystem conducted by Aiswarya *et al.* (2010). Jyothi and Sureshkumar (2014a) identified 75 species of aquatic macrophytes belonging to 53 genera and 32 families from Ponnani *Kole* lands in northern Kerala. Macrophytes of medicinal significance in different systems of medicine (Jyothi and Sureshkumar, 2014b) and sustainable utilisation of aquatic ornamental macrophytes (Jyothi and Sureshkumar, 2016) in Ponnani *Kole* were studied. Mild disturbances across Ponnani *Kole* lands also discussed by Jyothi and Sureshkumar (2018).

1.4.5 Physicochemical characters

The environmental characteristics of wetlands were studied across the world. The environmental parameters of the Parana river in Argentina (Marchese 1987) and Takkobu lake in the Kushiro wetland, Japan (Stora *et al*., 1995) were studied. Physical properties of the sediment in Atchafalaya Delta was studied by Poach and Faulkner (1998) and North Sea continental margin by Slomp *et al.* (1998). Hayworth (2000) observed the hydrological fluctuation in South Florida cypress system. Riis and Hawes (2002) studied the relation between water level fluctuations and vegetation diversity of shallow water in New Zealand lakes. Carbon and nitrogen content in Mediterranean coastal wetlands was analysed by Gascon *et al.* (2007). Takamura *et al.* (2009) studied the environmental factors influencing benthic organisms in Takkobu lake and Kushiro wetland in Japan. Culler *et al*. (2013) recorded physicochemical variables in constructed wetlands on Maryland, the United States and Nazarhaghighia *et al*. (2014) in Anzali international wetland, north-western Iran. Physicochemical characteristics of temporary aquatic habitats including vernal pools, emergent wetlands and intermittent streams in northeastern Ohio were studied by Hamilton (2013). Howard (2014) documented the influence of environmental variables on biotic communities of ephemeral wetlands in southern Appalachia in southeastern United States.

A number of studies on various physico-chemical and biological aspects of wetlands were done in India. Physico-chemical properties of water in Keoladeo National, park, was studied by Ali and Vijayan (1986) and Vijayan (1991). The influence of physicochemical properties on the faunistic composition of Ansupa lake in Orissa was studied by Bhunya and Mohanty (1990). Physico-chemical environment of Wular Lake in Kashmir was studied by Akram (1992) and Chilika lake by Siddique and Rao (1995). Seasonal variation in physicochemical parameters of Halai reservoir of Vidisha district in India was studied by Jain *et al.* (1996). James *et al.* (1997) studied the Vembanad-*Kole* wetland system in relation to drainage basin management. Pattanaik (2001) studied wetland hydrology, and James (2002) observed the hydrological interventions in Chilika. The concentration of Phosphate and Nitrate to determine water quality in Bhopal lake ecosystem in India was studied by Tamot and Sharma (2006).

Studies on physicochemical properties of water and soil in Kerala coastal belt were carried out by Nair and Balchand (1992), Naqvi and Jayakumar (2000) and Naqvi *et al*. (2000). Physicochemical properties of Cochin backwaters in Kerala was studied by Thomson (2001). Biochemical aspects of mangrove ecosystem in Ernakulam district of Kerala (Zeena and Chandramohanakumar, 2004) and Vembanad *Kole* (Bijoy and Unnithan, 2004) were studied. Sasidharan (2004) and Aloysius (2005) carried out physicochemical studies in Ernakulam Pokkali wetlands and Kuttanadu wetland ecosystem of Kerala respectively.

1.4.6 Hydrology

Now a days global environmental issue in research is the quality of water which is influenced by various natural processes and anthropogenic activities (Ouyang, 2005; Shrestha and Kazama, 2007). Bu *et al.* (2009) pointed out the importance of information on water quality and pollution sources for implementing sustainable water use management strategies. Hujare (2008) suggested that an increase in industrialisation, urbanisation and developmental actions have brought inevitable water crisis. Riverine ecosystems sustain untainted water quality while traversing through hills, before reaching plains, due to less human activities and can be regarded as good and potable water for sustenance of aquatic life (Saha *et al*., 2001; Akpan, 2004; Cerqueira *et al*., 2008). Manjare *et al.* (2010) noticed the pollution of natural aquatic resources leading to depletion of water quality and aquatic biota by the discharge of pollutants from domestic sewage, industrial waste waters and agricultural runoff. Vaishali and Punita (2013) reported the pollution of river Mini, at Sindhrot, Vadodara due to the direct discharge of untreated sewage and industrial effluents. Water pollution has a striking upshot on aquatic ecosystem balance, socio-economic development and human health (Milovanovic, 2007). Many studies have been made on physico-chemical parameters of various freshwater ecosystems during the last few decades. Some of the most recent works on water quality of various aquatic environments were those of Offem *et al.* (2011), Iwuoha and Osuji (2012), Matini *et al.* (2012), Devi *et al.* (2013) and Shova and Raj (2013). Panda *et al*. (2004) studied the water quality status of temple ponds in Bhubaneswar city. Seasonal variations in water quality parameters of a perennial lake in Mysore city was studied by Sachidanandamurthy and Yajurvedi (2004). Lokeshwari and Chandrappa (2005) pointed out the altered behaviour of the Bellandur lake in Banglore city from an ecologically healthy reservoir to an artificial reservoir of domestic sewage and industrial effluents due to the impact of urbanisation. Kumar and Patterson (2007) studied the hydrobiology of Manakudy estuary in the southwest coast of India. Panigrahi *et al.* (2007) investigated the spatiotemporal variability of water quality parameters of Chilika lagoon in Orissa. Prasad and Patil

(2008) studied the physico-chemical features of Krishna river water in Western Maharashtra. Pushparajan *et al*. (2012) studied that temperature, salinity, dissolved oxygen and pH were the most important variables influencing the abundance of organisms in the estuarine environment in Pitchavaram mangroves. Siraj *et al*. (2010) and Ishaq and Khan (2013) investigated the hydrological attributes of Shallabugh wetland in Kashmir and River Tons and Asan in Dehradun District of Uttarakhand in India. Their findings highlighted the deterioration of water quality of both water bodies due to industrial, commercial and anthropogenic activities.

Radhika *et al.* (2004) and Sujitha *et al*. (2012) studied water quality parameters in Vellayani lake and Karamana river in Thiruvananthapuram district respectively. Vineetha *et al*. (2010) studied the water quality and productivity in *Kole* lands and Shaji *et al*. (2009) in well waters of Kerala. Limnological features of Thirumullavaram temple pond of Kollam municipality was studied by Sulabha and Prakasam (2006) and found that water source was suitable for drinking, swimming and secondary production after appropriate treatment. Nikhil and Azeez (2009b) studied the water chemistry of Bharathapuzha and found that the spatial and temporal variation is mainly due to the land use changes in the catchment area as well as the impact of dams in the river. Hydrogeochemical status of Cochin estuary due to urbanisation, industrialisation and harbour activities was studied by Robin *et al*. (2012). Gopalan *et al*. (2014) studied the seasonal variation in the water column level influencing the habitat choices of invertebrates and the distribution of macrophytes in different depths having different complexities of structure.

1.4.7 Sedimentology

Soil is the abiotic module of life-supporting system in wetlands and is measured to be the soul of different life forms including aquatic macrophytes. No clear borderline between soil and sediment because both are interlinked by hydrological and terrestrial phases which can be explained by underwater soil, terrestrial soil and alluvial soil. There is a substantial contest on the distinction between soils and sediments (Blum, 2005). Mitsch and Gosselink (2000) suggested the importance of sediment in the nutrient cycle including nitrogen, phosphorus and carbon within a wetland ecosystem. Soil environment in wetland ecosystem is also affected by hydroperiod, nutrient availability, chemical cycle, climate and biota (Craft, 2001). Stronkhorst *et al.* (2001) pointed out the dynamic nature of sediment due to the biogeochemical reactions occurring inside the water body and the crucial role in limnological studies of the overlying waters. They act as a natural buffer of nutrients to the overlying waters (Mucha *et al.*, 2003) and form the habitat for benthic macroinvertebrates whose metabolic activities add to the aquatic productivity (Ezekiel *et al.*, 2011). Stolt *et al.* (2000) and McCready *et al.* (2006) pointed out the role of sediment such as nutrient retention, providing habitat for living organisms and act as pollution sink in wetlands by capturing hydrophobic chemical pollutants entering water bodies. According to Rinklebe *et al.* (2007), heavy metals in floodplain soils and sediment remediation with detoxification mechanisms relating plants are gaining extensive global interest. Stolt *et al.* (2000) observed that wetland sites with extended period of saturation had a high amount of organic carbon due to anaerobic conditions preventing decomposition. The release of organic carbon into the sediment by aquatic macrophytes stimulates the chemical degradation of organic carbon results in the augmentation of reductive properties of sediments (Laing *et al.*, 2009). Sediment size and sediment accumulation are important factors influencing distribution, abundance and diversity of macrophytes in running waters (Kuhar *et al.*, 2007). According to Willby *et al.* (2000); Clarke and Wharton (2001); Hrivnak *et al.* (2006) stability of sediment types within the vibrant stream is a precondition for the long-term existence of macrophytes. Macrophytes influence nutrient recycling by retaining nutrients and minerals from water column and sediments using their submerged leaves and anchored roots (Clarke, 2000; Schulz *et al.*, 2003; Spencer and Ksander, 2003). Water quality and sediment characteristics are documented as the primary determinants of sediment denitrification and N_2O production (Zhong *et al.*, 2010; Rissanen *et al.*, 2011; Liu *et al.*, 2015). Aquatic plant communities can significantly influence sediment denitrification in fresh waters (Forshay and Dodson, 2011; Wang *et al.*, 2013; Jacobs and Harrison, 2014). Saunders and Kalff (2001) documented sediment denitrification as the most important pathway of nitrogen removal in lakes, followed by uptake by aquatic macrophytes. Environmental variables that affect sediment denitrification can be categorised as proximal or distal regulators including NO_3 concentration, oxygen supply, water content, carbon availability, sediment temperature and overlying water (Saggar *et al.*, 2013).

Many international studies have been taken place for sedimentological studies in a wetland ecosystem. Davidsson and Stahl (2000) studied the influence of organic carbon on nitrogen transformation in wetland soils in southern Sweden. The soil characteristics in a constructed salt marsh along the North Carolina (Craft, 2001) and the nutrient dynamics especially of sulphur and carbon in a hypersaline lagoon was studied (Cotner *et al*., 2003). The sediment and water quality from Lakes Pamvotis Greece was recorded by Kagalou *et al.* (2006). Sediment quality during the dry season in Port Curtis estuary in Australia was documented by Currie and Small (2005). Soil characteristics of Wangsuk stream and Gwarim reservoir in Korea were studied by Gi *et al.* (2007) and found nitrogen, organic carbon, phosphorus, calcium, magnesium, potassium and sodium have a significant role in the distribution of aquatic plants in the wetland ecosystem. Beumer *et al.* (2007) extensively studied the sediment chemistry after winter flooding in Brooks valley in the Netherlands. The impacts of drying and rewetting of sediment in Swan Coastal Plain in Western Australia was given by Sommer and Horwitz (2009). Hassan *et al*. (2010) pointed out the role of submerged macrophytes to reflect the concentration gradients of nutrients and heavy metals in water and sediments of Qattieneh Lake in Syria. Kogel-Knabner *et al.* (2010) explained the importance of paddy soil not only as of the source for sustaining global food security through rice production but also making the largest anthropogenic wetlands on earth with a decisive role in ecosystem functions. Tukura *et al*. (2012) studied the physicochemical characteristics of water and sediments in Mada river in the Nasarawa state of Nigeria. Lupi *et al*. (2013) pointed out the different management practices in the rice fields in Italy to maintain sediment quality. Water and soil quality in the field of paddy cum tilapia integrated culture in Bako, Ethiopia was studied by Desta *et al*. (2014).

Many researchers studied sediment characteristics of Indian wetlands. Pollution Status of wetlands and the qualities of sediment in urban areas of Coimbatore were highlighted by Mohanraj *et al*. (2000). Seasonal variation in the pattern of nutrient distribution and behaviour based on tidal rhythm in the Mulki estuary of the Southwestern coast of India was studied by Vijayakumar *et al*. (2000). Rajasegar *et al.* (2002) studied the sediment nutrients in Vellar estuary concerning shrimp farming, where low-level nitrogen recorded in monsoon. This was contradictory to the results of a similar study by Walls *et al*. (2005), where flooding increased soil nutrients by sedimentation. The sediment characteristics in Madhurantakam Lake in Tamilnadu were reported by Moorthy *et al*. (2005). Seasonal composition, texture and distribution of organic carbon, nitrogen and phosphorus of sediments in the Arasalar estuary in Karaikkal, South-east coast of India were studied by Bragadeeswaran *et al.* (2007). Sarkar (2011) studied the water and sediment quality in Sundarban biosphere. Limnochemical study of river Yamuna in Yamunanagar was done by Chopra *et al.* (2012). Environmental parameters in Yamuna river (Ishaq and Khan 2014) and Thengapattanam estuary in Tamilnadu (Anitha and Sugirtha, 2013) were reported. Sediment texture of Mansar Lake in Jammu and Kashmir was studied by Chandrakiran and Kuldeep (2013) and found sand was predominant followed by silt and clay. Shiji *et al*. (2015) reported the amount and different forms of the phosphorous present in the sediments of Kavvayi wetland in the south-west coast of India. Certain chemical characteristics of sediments of river Ganga at Vaishali district in Bihar were evaluated by Kumari (2018) for executing the master variables, characterising the sediment stability.

Kumary *et al.* (2001) studied the sediment characteristics of Poonthura estuary. Santhosh (2002) noticed the accumulation of organic matter (0.29% to a maximum of 6.5 %) from the uplands during the monsoon season in sediments of Paravur-Kappil backwater systems in Kollam district of Kerala. But Krishnakumar (2002) reported that the organic content was higher than 6.5% in most of the sites in the Karamana river. Thomas *et al.* (2003) studied the physical characteristics of soil with variation in texture from clay, sand to gravel in Muriyad *Kole* land. Seasonal change in the distribution pattern of organic carbon, nitrate, nitrogen and available phosphorus in the mangrove sediments in Valapattanam and Thalassery riverine ecosystem of Kerala state was studied by Lakshmi and Unni (2003). Thampatti and Jose (2005) reviewed the impact of preventing natural saline intrusion on nutrient dynamics of Kuttanad ecosystem by the closure of the Thanneermukkum regulator. Sujatha *et al*. (2009) focused on physico chemical characters of Ashtamudi and Vembanadu lakes and revealed that Vembanad lake was more deteriorated compared to Ashtamudi lake. Sobha *et al.* (2009) reported that the anthropogenic sources of pollution were the major factors behind the increased nutrient level in different aquatic systems of Thiruvananthapuram. Martin *et al.* (2011)

studied the texture of sediment in Cochin estuary and found clayey silt in the north estuary, silty clay in the central estuary and silty sand in the south estuary.

1.5 MATERIALS AND METHODS

1.5.1 Study area- Ponnani *Kole* lands

Thrissur –Malappuram stretch is the largest *Kole* land of Kerala, a part of Vembanad-*Kole* wetland ecosystem comprising of 151250 ha of land included as a Ramsar site in 2002, fed by ten rivers (Srinivasan, 2010). These *Kole* lands are basically waterlogged areas used for paddy cultivation, fishing, duck farming and are a vital ecosystem for water birds. This wetland comes under the 'Central Asian-Indian Flyway' (Anon.,1996) and serves as 'stepping stone' for the trans-continental migrant birds (Srinivasan 2010). Many indigenous water birds are spotted in Thrissur–Malappuram *Kole* lands, significant area for avian fauna. The study area is geographically distributed in Chavakkad and Choondal to Thavannur, covering Chavakkad and Thalapally taluks of Thrissur district and Ponnani Taluk of Malappuram district forming the 'Ponnani *Kole*' (Johnkutty and Venugopal, 1993). Ponnani *Kole* is a low lying area with alluvium deposits brought down by the Bharathapuzha river. It is extending from the southern bank of Bharathapuzha in the north to Naranipuzha in the south in a stretch of twenty kilometres, the northernmost extension of Vembanad *Kole* – the Ramsar site.

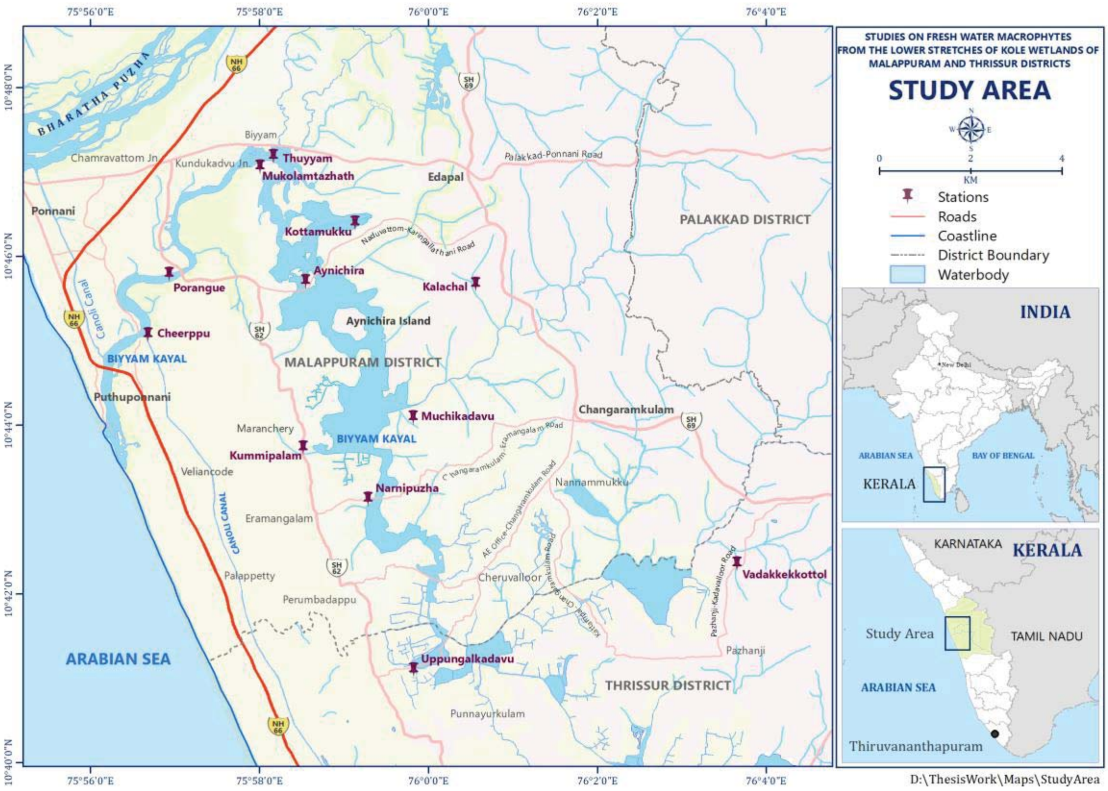

Figure 1.1 Map showing the study area

1.5.2 Climate

Moderate climatic conditions are experienced in the *Kole* land area. The study area receives an average annual rainfall of 2047 mm (Table S1) during the study period. As in other areas of the state, *Kole* lands also receive two well-defined rainy seasons, the South-west and North-east Monsoons. Depression rain is also another source of water for the *Kole* lands. The pre-monsoon extending from March to May represents the period of poor rain fall. The monsoon period from June to September comprises the south-west monsoon, and maximum rainfall occurs during this period. The post-monsoon period from October to February includes the north-east monsoon.

1.5.3. Stations

For the present study twelve stations were fixed in Ponnani *Koles* lying between $10^{\circ}41.098$ to10° 47.156 North latitude and $75^{\circ}56.067$ to $76^{\circ}03.688$ East longitude based on ecological interest (Figure 1.1). Since the seasonal variables of a year showed fluctuations, two-year samplings were carried out from these twelve stations spread across Ponnani *Koles*. These stations were pooled, as disturbed and undisturbed area and also based on the type of disturbances developed in the study area. The pooling of the data was done after verifying that there is no significant difference (P>0.05) in the mean value from different stations. Seasonal variations for continuous two-year observations have shown to be very useful to explain the ecological status of the study area.

Table 1.1. Details of sampling locations

No.	Stations	Latitude and Longitude
1	Porangue	N 10°45.672, E 75°56.958
2	Cheerppu	N 10°45.069, E 75°56.684
3	Mukolamthazhath	N 10°47.060, E 75°58.009
4	Aynichira	N 10°46.654, E 75°58.552
5	Kottamukku	N 10°46.461, E 75°58.067
6	Kalachal	N 10°45.666, E 76°00.564
7	Naranipuzha	N 10°43.109, E 75°59.380
8	Uppungalkadavu	N 10°41.098, E 75°59.831
9	Vadakkekkottol	N 10°42.329, E 76°03.688
10	Muchikadavu	N 10°44.090, E 75°59.825
11	Kummipalam	N 10° 43.595, E 75°58.530
12	Thuyyam	N 10 ° 47.156, E75°58.151

Table 1.2. Details of field visit for sampling

Sl No	Name of Stations	2014-2015			2015-2016		
		Date of collection					
		Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon
1	Porangue	10-10-14	16-04-15	23-07-15	02-11-15	01-05-16	06-08-16
2	Cheerppu	10-10-14	16-04-15	23-07-15	02-11-15	01-05-16	06-08-16
3	Mukolamtazhath	10-10-14	16-04-15	23-07-15	02-11-15	01-05-16	06-08-16
4	Aynichira	10-10-14	16-04-15	23-07-15	02-11-15	01-05-16	06-08-16
5	Kottamukku	10-10-14	16-04-15	23-07-15	02-11-15	01-05-16	06-08-16
6	Kalachal	10-10-14	16-04-15	23-07-15	02-11-15	01-05-16	06-08-16
7	Naranipuzha	12-10-14	19-04-15	26-07-15	06-11-15	04-05-16	08-08-16
8	Uppungalkadavu	12-10-14	19-04-15	26-07-15	06-11-15	04-05-16	08-08-16
9	Vadakkekkottol	12-10-14	19-04-15	26-07-15	06-11-15	04-05-16	08-08-16
10	Muchikadavu	12-10-14	19-04-15	26-07-15	06-11-15	04-05-16	08-08-16
11	Kummipalam	12-10-14	19-04-15	26-07-15	06-11-15	04-05-16	08-08-16
12	Thuyyam	12-10-14	19-04-15	26-07-15	06-11-15	04-05-16	08-08-16

1. Porangue

Figure 1.2. A view of Porangue station

Porangue a disturbed area where saline intrusion happens very often. Bank of the river was polluted with plastic waste and domestic effluents. Halophytes and salt tolerant plants like *Ipomoea pes-caprae, Acanthus ilicifolius, Avicennia officinalis, Cyperus javanicus, Schoenoplectiella supina* and *Sporobolus virginicus* were common in this station. During monsoon floating macrophytes like *Eichhornia crassipes, Pistia stratiotes* and *Salvinia adnata* were flushing to this station by water current from near by water resources. The water level was almost stationary in all the three seasons. The station is located near Biyyam kayal. Shutters across Biyyam kayal made the necessary storage of water for the summer season. The saline water also affects the underground water including near by wells which will adversely affect the drinking water supply.

2. Cheerppu

Figure 1.3. A view of Cheerppu station

An area of saline intrusion where coir retting is in practice. Bank of the water body is enriched with salt tolerant plants. Depth of water body is comparatively higher than other stations. The station is located near Kundukadavu Bridge over Biyyam

Kayal. In post-monsoon and pre-monsoon only mangroves like *Ipomoea pes-caprae, Acanthus ilicifolius* and *Avicennia officinalis* were present and in monsoon few free-floating macrophytes like *Eichhornia crassipes,* and *Salvinia adnata* were flushed into this area.

3.Mukolamtazhath


Figure 1.4. A view of Mukolamtazhath station

A typical wetland ecosystem enriched with different species of macrophytes. Copious growth of aquatic plants was observed. The area was occupied with different growth forms of macrophytes. Suspended hydrophytes like *Utricularia* and *Hydrilla,* similarly anchored floating like *Nymphoides* were very common. Water in this area was cool, clear and potable. In monsoon, fishing was regularly practiced. Women labours were engaged in clam fishery. People commonly use this water for domestic purpose. Depth of water body maintained throughout the year using shutters. Minimum anthropogenic disturbances were observed in this area.

4. Aynichira


Figure 1.5. A view of Aynichira station

Aynichira is a typical wetland ecosystem, serving as a home for many species of freshwater macrophytes. This area of wetland is of standing water that supports different growth forms of aquatic plants. The water is also clear and less turbid. Anchored floating plants like *Nelumbo nucifera* and *Nymphaea* sp. were very common in monsoon and post-monsoon whereas in pre-monsoon typical wetland plants under Cyperaceae and Poaceae were present. Reclamation activities have been started in this area for the construction road. This may lead to disturbances for the biodiversity of this ecosystem. The emergence of this new category of land use is a source of major concern.

5. Kottamukku

Figure 1.6. A view of Kottamukku station

Typical wetland ecosystem called as 'thamarakayal' due to the abundance of *Nelumbo* species. It is a place of lotus cultivation in monsoon, and post-monsoon and stakeholders are involved in marketing lotus flowers. Station was rich with different growth forms of macrophytes. But in pre-monsoon due to the fall in water level, the area was occupied mainly by wetland grasses especially members of the Cyperaceae.

6. Kalachal

Figure 1.7. A view of Kalachal station

This is an agricultural area having rice cultivation where reclamation activities have started. Building constructions also started on one side of the paddy field. Illegal encroachment of wetland areas for house construction was noticed on the other side. Washing and cleaning of vehicles polluting the water. In flooded seasons typical suspended, submerged and anchored floating hydrophytes were present but in pre-monsoon only wetland plants were noticed. Cattle grazing and duck farming were also taking place here. The flood water received during monsoon showers accumulated in *Kole* lands and the paddy fields will be submerged. The flood may often spoil the bunds and damage the crop. Because of this adversity, farmers were forsaken the double-crop system, and now they firmly stick on to single crop system.

7. Naranipuzha

Figure 1.8. A view of Naranipuzha station

The southern end of Ponnani *Kole* is Narnipuzha river. Rich with different species of macrophytes. Free floating, suspended hydrophytes, submerged hydrophytes and anchored floating were common in monsoon and post-monsoon; emergent hydrophytes and wetland plants were noticed in pre-monsoon. Rate of water flow is comparatively higher than other stations. Turbidity and hardness of water are relatively less, and the amount of total dissolved solids in minimum level indicates the portability of water. Fish farming was practicing in this station. Constructions of roads have started on one side of the river. Reclamation activities made disturbances for the flow of the river. Disposal of solid waste such as containers, rags, domestic refuse was observed on the bank of the river.

8. Uppungalkadavu

Figure 1.9. A view of Uppungalkadavu station

A typical *Kole* land where rice cultivation is in practice. Earthen bunds and dams constructed in the area for improving agricultural crops. Canals and channels made the vast field divided into small blocks. Water pumped out from the field is stored in the canals interspersed throughout the area. This water and timely showers were used to produce a high yield. Cattle grazing and duck farming were also very common. In monsoon area will be flooded and suspended, submerged and anchored floating hydrophytes were common and in pre-monsoon, only wetland grasses were observed. Major part of the area the land is flat and remained submerged for six months in a year.

This area is a stepping stone for migratory birds.

9. Vadakkekkottol

Figure 1.10. A view of Vadakkekkottol station

The agricultural area where rice cultivation was not practicing, leaving as waste land. Farmers were increasingly unwilling to cultivate their lands either leaving them as fallows or converting for other uses. Large areas of this wetland were reclaimed for housing plots and cultivation of banana, areca nut, and coconut. The landowners reduced the width of the drainage canals into the paddy fields, thus obstructing the water flow. The loss of habitat adversely affected the migratory birds by reducing available roosting place and foraging areas.

10. Muchikadavu


Figure 1.11. A view of Muchikadavu station

A typical *Kole* wetland where rice cultivation was practicing. Large scale rice production is done by constructing earthen bunds. Bunds and canals are the infrastructural improvements in this area. Formation of canals and channels for irrigation divided the paddy field into several blocks locally known as padavus. The water pumped out from the fields was stored in a network of canals interspersed throughout the area. Cattle grazing and duck farming were also taking place in this station. But the Infrastructure development in the form of roads and other lines of communications fragmented the contiguity of this wetland. This *Kole* land is an attracting sight for many wetland birds as it supports good nesting habit and habitats with aquatic flora Migratory birds visit the station in post-monsoon and they use this rice ecosystem as stopover or transit areas because of easy food availability.

11. Kummipalam


Figure 1.12. A view of Kummipalam station

A waste land where domestic sewage disposal and water contamination with oil discharge from vehicles were noticed. Over growth of *Eichhornia crassipes, Pistia stratiotes* and *Salvinia adnata* were observed. This may be due to the leaching of fertilisers from nearby paddy fields. Stagnant water with higher turbidity was noticed in this station. The bank of the water body was contaminated with solid waste such as additive containers, rags and domestic refuse due to the restrictions for waste dumping in town areas these wastes are now dumped into nearby *Kole* lands.

12. Thuyyam


Figure 1.13. A view of Thuyyam station

Typical wetland area enriched with different species of macrophytes. One of the major weeds invading this area is *Ipomoea carnea* which is an exotic plant. The area was flooded in monsoon and maximum growth of macrophytes noticed in post-monsoon. Reclamation activities have started for coconut plantation and building construction. Closing of shutters at the end of monsoon season greatly influenced the ecosystem of this wetland. No water flow in the main canals, making the study area, a static pool. As a part of the cultivation process, water with huge load of pesticides and chemical fertilisers from the paddy fields were drained into this stagnant water body. Persistence of chemical fertilisers triggered the excessive growth of macrophytes. Washing vehicle was also common at the bank of this water body leading to oil discharge into water.

1.5.4 Sampling and Analysis methods

1.5.4.1. Sampling

Sampling surveys were conducted in the study area during 2014-16, covering all the three seasons,from12stations (Fig.1.1).From each station,100m transect (Gleason,1920)was laid parallel to the bank and observed for the macrophyte diversity and plants were collected for identification. Sample collection was started from station Porangue (Station No.1) and continued up to Thuyyam (Station No.12) (Table.1.2). At each station, along the transect, one spot was selected randomly by lot for sampling and then three more samples were collected with uniform distance to achieve systematic random sampling. Thus quadruplicate of samples were collected for the estimation of macrophyte abundance, hydro graphic parameters and sediment parameters.

1.5.4.2 Vegetation Study

The taxonomic characteristics of the aquatic macrophytes were recorded along with their local names, abundance, spread/distribution, growth form and use in medicinal and ornamental levels. The collected specimens were pressed, and herbarium specimens were prepared according to the standard instructions given by Jain and Rao (1977). The voucher specimens were deposited in M.E.S Ponnani College Herbarium with taxonomical and ecological information (Daubenmire, 1947). Taxonomic identification of the collected plants were carried out using Flora of British India (Hooker, 1897), Flora of the Presidency of Madras (Gamble, 1915), Flora of Calicut (Manilal and Sivarajan 1982) and Flora of Alappuzha District (Sunil and Sivadasan 2009). Author citation and binomial of collected species were verified with the International Plant Names Index (IPNI, 2019) and The Plant List (2019). The collected plants were categorised into seven major physiognomic forms such as Free-floating, Suspended hydrophytes, Submerged hydrophytes, Anchored floating, Emergent hydrophytes, Wetland plants, Mangrove and associates (Sunil and Sivadasan, 2009).

Free-floating hydrophytes: Plants reside on the water surface, making contact with air. They mainly occur in sheltered habitat and stagnant water.

Suspended hydrophytes: Plants exist below the surface water, but not anchored. Regularly found in stagnant water bodies.

Submerged hydrophytes: Plants subsist well below the surface water and are usually anchored

Anchored hydrophytes: Plants inhabit shallow, stagnant waters and are anchored to the substrate. They develop branches which trail or creep on the water surface with rooting nodes.

Emergent hydrophytes: Plants dwell most of their life in water by producing aerial representative organs. Majority of the members are showing heterophylly.

Wetland plants: Coastal low lands, margins of pond, lakes, canals and paddy fields provide ideal habitat for wetland species. They entail saturated soil for their endurance.

Mangrove and associates: Mangroves are salt-tolerant halophytes and are adapted to the saline environment. They have complex salt filtering system and root system to cope with salt water immersion and wave action. They also adapted to anoxic conditions of waterlogged mud.

At each station, random samples of $1m^2$ quadrates, along the fixed transect, were collected in quadruplicates for biomass determination (Westlake, 1965). All the macrophytes collected from each quadrate was placed in separate labelled polythene bags and transported to the laboratory, washed thoroughly, completely drained, sorted and dried separately in a hot air oven at 105°C to constant weight for dry weight biomass determination (Wetzel and Likens, 2000).

1.5.4.3 Hydrographic parameters.

Water samples were collected before the collection of macrophytes and sediment to prevent consequent disturbances lead to re-suspension of sediments and contamination of the water. For hydrological analysis, two litres of sample water were collected directly from the surface level in acid-free plastic bottles. The collected water samples were kept in the dark and cool (4°C) environment by placing them in boxes with ice cubes before transported to the laboratory for water analysis. Quadruplicate samples thus collected are transported to the laboratory for further analysis.

From each station *in situ* measurements of temperature, pH and speed of water flow were recorded. The temperature was measured using a mercury thermometer. pH, electrical conductivity (EC) and Total dissolved solids (TDS) were measured using pH meter, Conductivity meter 335 and TDS meter respectively (APHA, 2005). Rate of flow was measured using Electromagnetic current meter. Turbidity was measured with turbidometer using Nephlometric method (APHA, 2005). The samples for DO and BOD analysis from the surface of water bodies were collected separately in BOD bottles and fixed at the station after collection following the Winkler method (Strickland and Parsons, 1972). Total hardness, total alkalinity and total acidity were measured titrimetrically following the method of APHA (2005). Ca, Mg, Chloride, Fluoride, Iron, Nitrate, Phosphate and Sulphate were analysed using the method of Strickland and Parsons (1972). Details of methods of analysis for water quality are given in Table 1.3

Table 1.3 Methods of analysis of water samples collected from Ponnani *Kole* wetlands

No.	Parameter	Unit	Method	Instrument
1	Turbidity	NTU	Nephlometric method (APHA, 2005)	Turbidometer
2	pH	-	Electrometry (APHA, 2005)	pH meter systronix 375
3	Electric conductivity	mS	Electrometry (APHA, 2005)	Conductivity meter 335
4	Hardness (as Ca CO_3)	mg/L	EDTA Titrimetry (APHA, 2005)	
5	Temperature	0°C	Thermometry (APHA, 2005)	Mercury thermometer
6	Acidity	mg/L	Titration method (APHA, 2005)	
7	Alkalinity	mg/L	Titration method (APHA, 2005)	
8	TDS	ppm mg/L	Gravimetry (APHA, 2005)	TDS meter
9	Calcium	mg/L	Spectrophotometry Strickland and Parsons(1972)	UV-Visible Spectrophotometer
10	Magnesium	mg/L	Spectrophotometry Strickland and Parsons (1972)	UV-Visible Spectrophotometer
11	Chloride	mg/L	Flame photometry Strickland and Parsons (1972)	UV-Visible Spectrophotometer
12	Fluoride	mg/L	Spectrophotometry Strickland and Parsons (1972)	UV-Visible Spectrophotometer
13	Iron (as Fe)	mg/L	Spectrophotometry Strickland and Parsons (1972)	UV-Visible Spectrophotometer
14	DO	mgO_2/L	Modified Winkler method (APHA, 2005)	
15	BOD	mgO_2/L	Modified Winkler method (APHA, 2005)	
16	Sulphate	mg/L	Turbidimetric method Strickland and Parsons (1972)	UV-Visible Spectrophotometer
17	Phosphate	mg/L	Flame photometry Strickland and Parsons(1972)	UV-Visible Spectrophotometer
18	Nitrate	mg/L	Micro geldas method Strickland and Parsons (1972)	Photometer (Merk Q118)
19	Depth of water column	mm	Graduated weighted rope	
20	Rate of flow		Velocity area method	Electromagnetic Current Meter

1.5.4.4 Sediment parameters

Sediment was sampled using a Van Veen Grab, soil samples were collected in quadruplicate, from the spots from which water samples were collected. The samples were, packed individually in polythene packets, and transported to the laboratory in cool boxes. 100 g of soil sample was taken in a conical flask, and 200 ml of distilled water was added to prepare (1:2) soil: water suspension (Chopra and Kanwar, 2007) by thorough shaking for 12 hours on a shaker. The suspension was filtered, and the filtrate was made up to 250 ml for further analysis. pH was measured on a pH meter (Potentiometric method). Flame Photometer (Elico, model-128) was used for the estimation of potassium (K+). The spectrophotometer was used for the estimation of Sulphur (Arora and Bajwa, 1994). Calcium (Ca2+) and magnesium (Mg2+) were estimated by EDTA (Ethylene diamine tetra acetic acid) method (Vogel, 1978). Soil samples were analysed for estimation of heavy metals *viz*., Fe, Mn, Zn and Cu also by atomic absorption spectrophotometry (Lindsay *et al*., 1978). Organic carbon in the sample was determined by Walkley and Black method (Jackson, 1973). The available phosphorous in the sample was determined by Olsen's method (Olsen *et al*.,1954). Boron was estimated by Azomethine H method (John *et al*., 1975). Details of methods of analysis for sediment quality parameters are given in Table 1.4.

Table 1.4 Methods of analysis for sediment parameters

No.	Parameter	Unit	Method	Instrument
1	pH	-	Potentiometric method	pH meter
2	Electric conductivity	mS	Electrometry (APHA, 2005)	Conductivity meter 335
3	Organic carbon	dS/m	Walkley Black method Jackson (1973).	
4	Phosphorus	kg/ha	Olsen's method (Olsen *et al*.,1954)	Spectrophotometer
5	Potassium	kg/ha	Ethylene diamine tetra-acetic acid method (Black, 1965)	Flame Photometer Elico, model-128
6	Calcium	mg/kg	Ethylene diamine tetra-acetic acid method (Vogel, 1978)	Flame Photometer
7	Magnesium	mg/kg	Ethylene diamine tetra-acetic acid method (Vogel, 1978)	Flame Photometer
8	Sulphur	mg/kg	(Arora and Bajwa, 1994)	Spectrophotometer
9	Copper	ppm	(Lindsay *et al*., 1978)	Atomic absorption spectrophotometry
10	Iron	ppm	(Lindsay *et al*., 1978)	Atomic absorption spectrophotometry
11	Zinc	ppm	(Lindsay *et al*., 1978)	Atomic absorption spectrophotometry
12	Manganese	ppm	(Lindsay *et al*., 1978)	Atomic absorption spectrophotometry
13	Boron	mg/kg	Azomethine H method (John *et al*., 1975)	Spectrophotometer

1.5.5 Statistical Analysis

The software programme viz. SPSS (Statistical Programme for Social Sciences version 17.0) and PRIMER 6 (Plymouth Routines in Multivariate Ecological Research, Version 6.1.9) were used for statistical analysis of the data. The base data for biological, hydrological and sedimentological parameters of each sample were averaged to obtain a mean value for each station. Descriptive statistics (SPSS v. 17.0) was used to describe data. The mean values from different stations of the study area were compared using One-way ANOVA. If the means of the data obtained from different stations do not vary significantly ($P>0.05$), the data is pooled and presented. If the means showed, significant variation between stations, Duncan Multiple Range Tests (DMRT) was performed to test the significant differences between means of various parameters recorded from different sites and between three different seasons. Statistical analysis 2 Way ANOVA (Analysis of Variance), standard deviation and correlation was done based on SPSS 17.0 software packages for Windows for testing the presence of significant differences and correlation among water and sediment variables between stations and seasons.

Diversity Indices

The basic idea of a diversity index is to find a quantitative guesstimate of biological variability that can be used to evaluate biological entities made up of distinct components in space or in time**.** Comparison is often an indispensable goal; a diversity index should in code execute the conditions that permit for a valid statistical treatment of the data, using methods such as ANOVA. In modern ecological practice, diversity indices are therefore used in concurrence with multivariate analyses. Diversity is a combination of two factors; species richness and the distribution of individuals among the species are referred to as evenness or equitability. The formation of indices gives scientists a standardised tool to compare both ecosystem and species health. The two most widely used species diversity indices are Shannon and Simpson indices. They are adopted by ecologists to describe the average degree of vagueness in predicting the species of an individual picked at random from a given community. As the number of species increases, the uncertainty of occurrence also increases along with the distribution of individuals more evenly among the species already present.

1. Biomass (Abundance; N)

It is a measure of diversity based on the weight of individuals (fresh /dry weight) of a specific group present in the given area. Carlo *et al*. (1998) suggested each species is measured based its abundance (usually the number of individuals per unit area, although other measures such as biomass are also possible). All diversity and evenness indices are based on the relative abundance of species, ***i.e.,*** on estimates of *pi* in which $pi = N_i/N$ with N_i the abundance of the ith species in the sample and $N = \sum N_i$.

2. Total number of Species (S)

It is another index of diversity in which the number of species in a community alone is considered, and relative abundance is ignored. Species richness is the number of different species in a given area. It is represented as S. It is the basic unit to measure the homogeneity of an ecosystem. Usually, species richness is used in conservation studies for determining the sensitivity of ecosystems and their resident species. This measure is strongly dependent on sampling size and effort.

3. Shannon – Weiner Diversity Index (H')

The Shannon index is an accepted diversity index in the ecological literature, where it is also known as the Shannon–Wiener diversity index. This index means all species are represented in a sample and that they are randomly sampled. It takes into account the number of species and evenness of species.

$$H' = \sum \text{SPi log 2 Pi}$$

which can be written as

$$H' = 3.3219 \frac{\text{N logn N} - \sum \text{ni log ni}}{N}$$

Where H' = species diversity in bits of information per individuals

Ni= proportion of samples belong to the ith species (number of individuals in the ith species) N= total number of individuals in the collection and

∑=sum

Shannon – Weiner Diversity Index allows to know not only the number of species but how the abundance of the species is distributed among all the species in the community.

4. Simpson's Evenness Index ((1-ƛ)

Simpson's diversity index measures a diversity score for a community. It is based on the number of different species in the community and the number of individuals present for each of those species. The higher score indicates the diversity of the community. It also measures the probability of two individuals randomly selected from a sample will belong to the same species. It makes sense to consider species richness and species evenness as two independent characteristics of biological communities that together constitute its diversity (Heip, 1974).

D=1- ƛ,

Where, ƛ= ∑

$$\sum_{I=1} Pi2$$

Pi=ni/N

ni= Number of individuals of i, i2 etc, and N= total number of individuals.

5. Taxonomic Distinctness' Index

This is the average taxonomic distance apart of every pair of individuals in the sample chosen at random, along the taxonomic tree drawn following the standard Linear classification, conditional that they must belong to different species. It is the discrete distance between every pair of the individual. Warwick and Clarke (1995) proposed two new indices called taxonomic diversity and taxonomic distinctness. Taxonomic diversity is the average (weighted) path length in the taxonomic tree between every pair of individuals whereas taxonomic distinctness is defined as the ratio between the observed taxonomic diversity and the value that would be obtained if all individuals belong to the same genus. Taxonomic diversity index includes aspects of taxonomic relatedness and evenness and taxonomic distinctness measures pure taxonomic relatedness. The use of taxonomic distinctness addresses the hierarchical level at which diversity is expressed. Taxonomic distinctness can be divided into (1) average taxonomic distinctness (Δ+) and (2) variation in taxonomic distinctness ((Λ+).

a. Average taxonomic distinctness (AvTD; Δ+)

Average Taxonomic Distinctness of a sampling site or region has been defined as the average taxonomic distance between any two randomly chosen species through a taxonomic hierarchy, or the average degree to which species in the assemblage are related to each other (Clarke and Warwick, 1998). It is, therefore, a measure of taxonomic spread rather than species richness. It is used to obtain only presence or absence information for each species.

Average taxonomic distinctness (Δ+) was calculated using the following formula:

$\Delta+ = [\sum\sum i < j\ Ɯij] / [S(S-1)/2]$

Where S is the number of species present, the double summation is over the set {i=1, S; j=1,S…S, such that i=j} and Ɯij is the weight (path length) given to the taxonomic relationship between species and I and j. Δ+ can be thought of as the average path length between any two randomly chosen species from the study. AvTD will be effective in contrasting situations in which there are a limited number of higher taxa for a given number of species where the same number of species is more taxonomically unrelated. This can be used to offer a common set of step-length weightings for analyses of particular habitat studies.

b.Variation in taxonomic distinctness (VarTD; Λ+)

Variation in Taxonomic Distinctness, which is a measure of the variation in path lengths through the taxonomic tree. This index is usually high in disturbed situations as some taxa become over-represented and others under-represented. Presence of some genera with many species would tend to reduce AvTD, but this could be counterbalanced by the presence of families represented by only 1 (or a very few) species. Such a difference in structure will be well reflected in the variability of distinctness weights making up the average. VarTD is projecting the taxonomic (or phylogenetic) relatedness of species. It complements the AvTD which is the mean path length through the taxonomic tree connecting every pair of species. VarTD is the variance of these pair wise path lengths and reflects the unevenness of the taxonomic tree (Clarke and Warwick, 2001a).

Variation in taxonomic distinctness (VarTD; Λ+) was calculated using the following formula.

Λ+ = [ΣΣi ≠ j (ɯɯij-ɯ)2] / [S(S-1)]

= [{ΣΣi ≠ jɯij2} / {S(S-1)}] - ɯ2

The most useful feature of AvTD and VarTD is their lack of dependence on sampling-effort or sample-size. Average taxonomic distinctness index (AvTD, Δ+) and Variation in taxonomic distinctness (VarTD; Λ+) were studied graphically by funnel plot. Combined (Δ+) and (Λ+) provide a statistically healthy outline of taxonomic (or phylogenetic) relatedness patterns within an assemblage, which has the potential to be applied for a wide range of data (Clarke and Warwick, 2001b). These two indices are independent of species richness, and one of their most positive features is their lack of dependence on sampling-effort or sample-size (Clarke and Warwick, 1998).

6. Funnel Plots

Funnel plot measures the distinctness both AvTD and VarTD, based on presence or absence of data of the species in the study area was drawn by testing the distinctness of a sample of *m* species from the distinctness value obtained by taking *m* species from the master list (Clarke and Warwick, 2001b). The exact randomisation method needs heavy computation but can be approximated by using variance formula. This makes a 'confidence funnel', against which distinctness values for any specific area, environment type and condition of pollution can be analysed and addresses the question of whether the locality has a 'lower than expected' average taxonomic spread. Some habitat types have lower values of taxonomic distinctness than others, but unless the habitats are degraded, the Λ+ values do not fall below the lower boundary of the 'funnel' (Clarke and Warwick, 1998). 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. Since the theoretical means remains constant while the variance decreases as the number of species *m* increases, the 95% confidence intervals take the form of a 'funnel'.

7. NMDS (Non-Metric Multi-Dimensional Scaling)

This method was proposed by Shepard (1962) and Kruskal (1964) and was used to find out the similarities between each pair of entities to produce a 'plot' which identically shows the interrelationships of all. This map or configuration in a specific number of dimensions visually displays the ranking of the similarity matrix with the great 'goodness fit' or lowest stress. Also it combines the cluster results with ordination to further investigate whether the combination was an effective way of checking the sufficiency and mutual consistency of both representations. The data from the Bray-Curtis similarity coefficient matrix were used to construct the 'plot'.

8. Dominance Plot

According to Lambshead *et al*. (1983), the cumulative percentage (percentage of total abundance made up by the k^{th} most dominant plus all more dominant species) is plotted against rank k or log-rank k. To facilitate comparison between communities with the number of species S, a 'Lorenzen curve' may be plotted. Here the species rank k is transformed to (k/s)x 100. Thus X-axis always ranges between 0 and 100.

9. **Canonical correspondence analysis (CCA)**

Multivariate analysis was used to identify the main gradient in the composition of the macrophyte community using the programme PAST (Paleontological Statistics Software Package for Education and Data Analysis) version 3 (Hammer *et al*., 2001). CCA is a multivariate method to explain the relationship between biological assemblages of species and their environment. The method is planned to extort synthetic environmental gradients from biological data-sets. The gradients are the basis for succinctly describing and visualising the differential habitat preferences (niches) of taxa *via* an ordination diagram (ter Braak and Verdonschot, 1995). The most frequent use is to identify environmental gradients in biological data-sets (Barker, 1994) in particular, which environmental variables are imperative in determining community composition.

Chapter-2

AQUATIC MACROPHYTES OF PONNANI *KOLE* WETLAND ECOSYSTEM

ABSTRACT

The *Kole* wetland harbours a rich floristic and faunal diversity which is much greater than any other freshwater ecosystems. Although *Kole* wetland is vastly productive, it faces several anthropogenic stresses which result in loss of species richness, decrease in agriculture production, scarcity of portable water, variation in flooding pattern and depletion of aesthetic value. Reclamation of land and alterations in land use pattern are the most severe problems, which can impart harmful impacts on aquatic flora. The study recorded 87 species of true aquatic macrophytes belonging to 58 genera of 32 families. Out of the 87 identified taxa, 82 were angiosperms spread over 53 genera of 28 families, 4 were pteridophytes spread over four genera of 3 families, and one was a macroscopic alga. The plants were identified with the help of existing keys, taxonomic revisions and monographs. Out of 28 families of angiosperms, Cyperaceae and Poaceae were most abundant with 11 species each belonging to six and nine genera respectively. The next richest family was Convolvulaceae with six species belonging to 4 genera. Plantaginaceae and Hydrocharitaceae were represented by five species each. The genus *Cyperus* was the richest with five species followed by *Limnophila* with four species whereas *Rotala, Ludwigia, Oldenlandia*, *Ipomoea, Lindernia* and *Utricularia* were represented by three species each. Out of 82 angiosperms recorded, 34 were monocots, and 48 were dicots. Among seven physiognomic forms Wetland plants were dominated and represented by 37 species followed by Emergent Hydrophytes (13), Anchored Floating (10), Mangrove and associates (9), Suspended Hydrophytes (8), free floating (6) and Submerged Hydrophytes (4). The database developed through the current investigation will serve as a preliminary article for the impact assessment of the area and also for the policy resolutions for the administration and conservation of wetlands in general and the aquatic vegetation of this very important delicate ecosystem in particular.

2.1 INTRODUCTION

Macrophytes are producers of aquatic environment; growing permanently or periodically submerged below, floating on, or growing up through the water surface. The definitions which reflect the ecology include (1) "wetland aquatic plants are in general found growing in wetlands *i.e.*; in or on water or where soils are flooded or saturated long enough for the development of aerobic condition in the root zone and have evolved some specific adaptations to anaerobic environment"(Cronk and Fennessy, 2001). And (2) "any plant which is growing in water or on a substrate, at least occasionally, undersupplied in oxygen as a result of excessive water content" (Cowardin *et al*., 1979). Freshwater macrophytes include Charales, Vascular Cryptogams and Spermatophytes. The term macrophyte used in this study includes all hydrophytic or semi hydrophytic vascular plants that grow submerged partly submerged or free floating together with vascular cryptogams, and macroscopic algae.

Majority of aquatic plants are angiosperms. They are usually categorised based on their physiognomic forms, *i.e.* solely on how the plants are growing in physical relationship to the water and sediment. The general categories are emergent, submerged, floating-leaved and floating (Sculthorpe, 1967). Stems and leaves of submerged species tend to be soft (lacking lignin) with leaves either ribbon-like or highly divided making them flexible to withstand water movement without damage. Submerged plants acquire dissolved oxygen and carbon dioxide from the water column, and many can use dissolved bicarbonate (HCO_3^-) in photosynthesis as well. Rooted submerged species attain the majority of their nutrients from the sediments, although some nutrients particularly micronutrients may be absorbed from the water column (Barko and Smart, 1981). Rootless species are solely dependent on water column as their nutrient source.

Jain *et al.* (2007) studied the aquatic and semi-aquatic plants in wetlands of Manipur in Northeastern India used for herbal remedies. Rasingam (2010) reported 62 wetland plants under 46 genera and 29 families from the little Andaman Islands in India; where *Schoenoplectus mucronatus* of Cyperaceae and *Achyranthus aspera* var. *porphyristachya* of Amaranthaceae reported as a new addition to the flora of Andaman & Nicobar Islands. Panda and Misra (2011) pointed out the ethnomedicinal significance and conservation methods of some wetland plants of Orissa. Sukumaran and Jeeva (2011) did the floristic survey of wetland angiosperms in Kanyakumari district. Zhang *et al*. (2014b) studied the diversity of 350 wetland plant species under 66 families used traditionally in China for a wide range of purposes. Swamy *et al*. (2016) observed the wetland flora of Pocharam Lake in Medak district in Telangana and reported 110 species of angiosperms under 80 genera and 37 families. During the investigation, they recorded 124 species of wetland plants under 81 genera and 31 families. They also observed Poaceae and Cyperaceae were the families with a maximum number of species. Bhagyaleena and Gopalan (2012) studied the medicinal significance of aquatic flora of ponds in Palakkad. Rajilesh *et al*. (2016) studied the aquatic and marshy plants of Idukki district. The study revealed a total of 259 species under 51 families in which Poaceae with 43 species forms the dominant family followed by Cyperaceae with 42 species. Ansari *et al*. (2017) studied the aquatic and wetland flora of Kerala and listed 699 species belong to 266 genera under 73 families, constituting almost 15% of the total recorded species from the state. Conservation of macrophytes faces quite a few challenges due to the lack of public awareness about its consequence, and no concerted effort has so far been conducted to manuscript the diversity of aquatic macrophytes of *Kole* wetlands. Therefore there is an imperative need to survey and document the present status, ecology and taxonomy of these plants for their conservation and utilisation for sustainable development. In this context, a study has been carried out for the documentation of aquatic macrophytes of Ponnani *Kole* wetlands.

2.2 MATERIALS AND METHODS

Seasonal observations were carried out in all the stations for two years (2014-16). Detailed field notes were prepared covering the aspects like location name, geographic coordinates, habitat system, local name, physiognomic forms, relative dominance and local use. Community variables such as community assemblages, competition, and other physical conditions of the habitat were also recorded. Voucher specimens of all taxa were collected, prepared the herbarium sheets with all taxonomic details and deposited in the Department of Botany, MES Ponnani college, Malappuram. Collection, identification and preservation were carried out as described in chapter 1 section 1.5.4.2. Classification of Bentham and Hooker (1862–1883) is used for the preparation of Table 2.1. Flowering and fruiting season of the aquatic macrophytes were recorded and presented. The common vernacular name provided is the name prevalent in Northern Kerala.

2.3 RESULTS

The study recorded 87 species of true aquatic macrophytes belonging to 58 genera of 32 families (Table 2.1). Out of the 87 identified taxa, 82 were angiosperms spread over 53 genera of 28 families, 4 were pteridophytes spread over four genera of 3 families, and one was a macroscopic alga (Table 2.1). Out of 28 families of angiosperms, Cyperaceae and Poaceae were most abundant with 11 species each belonging to six and nine genera respectively. The next richest family was Convolvulaceae with six species belonging to 4 genera. Plantaginaceae and Hydrocharitaceae were represented by five species each. The genus *Cyperus* was the richest with five species followed by *Limnophila* with four species whereas *Rotala, Ludwigia, Oldenlandia, Ipomoea, Lindernia* and *Utricularia* were represented by three species each. The other genera were *Nymphaea, Nymphoides, Hygrophila*, *Alternanthera*, *Perischaria*, *Monochoria*, *Najas, Schoenoplectiella, Eragrostis* and *Oryza* representing two species each. Families like Nelumbonaceae, Malvaceae, Leguminosae, Halorrhagidaceae, Molluginaceae, Apiaceae, Lamiaceae, Avicenniaceae, Ceratophyllaceae, Aponogetonaceae, Characeae, Pteridaceae and Marsileaceae were represented by only one species each. Out of 82 angiosperms recorded, 34 were monocots, and 48 were dicots. Among seven physiognomic forms Wetland plants were dominated and represented by 37 species followed by Emergent Hydrophytes (13), Anchored Floating (10), Mangrove and associates (9), Suspended Hydrophytes (8), free floating (6) and Submerged Hydrophytes (4) (Table2.1).

Table 2.1.Check list of fresh water macrophytes collected during the study from Ponnani *Kole* wetlands.Its habits, status and relative abundance

Sl.no	DIVISION	Class	Order	Family	Species	Habit*	Status**	Relative abundance (gm.M^{-2})
1	PHANEROGAMAE	DICOTYLEDONAE	Ranales	Nymphaeaceae	*Nymphaea nouchali* Burm. f.	AF	Moderate	3359.66
2					*Nymphaea pubescence* Willd.	AF	Moderate	2654.83
3				Nelumbonaceae	*Nelumbo nucifera* Gaertn.	AF	Rare	69.2
4			Malvales	Malvaceae	*Melochia corchorifolia* L.	WP	Rare	19.95
5			Rosales	Leguminosae	*Aeschynomene indica* L.	WP	Moderate	1019.03
6				Halorrhagidaceae	*Myriophyllum oliganthum* (Wight & Arn.) F.Muell.	EH	Moderate	93.01
7			Myrtales	Lythraceae	*Rotala indica* (Willd.) Koehne	WP	Low	55.54
8					*Rotala macrandra* Koehne	WP	Moderate	462.32
9					*Rotala malampuzhensis* R.V.Nair ex C.D.K.Cook	WP	Low	65.54
10				Onagraceae	*Ludwigia adscendens* (L.) H. Hara	EH	Very High	4610.38
11					*Ludwigia hyssopifolia* (G.Don) Exell	WP	Low	62.3
12					*Ludwigia perennis* L.	WP	Moderate	603.91

Sl.no	DIVISION	Class	Order	Family	Species	Habit*	Status**	Relative abundance (gm.M^{-2})
13	PHANEROGAMAE	DICOTYLEDONAE	Filicoidales	Molluginaceae	*Mollugo pentaphylla* L.	WP	Low	39.6
14			Umbellales	Apiaceae	*Centella asiatica* (L.) Urb.	WP	Low	22.03
15			Rubiales	Rubiaceae	*Oldenlandia brachypoda* DC.	WP	Moderate	407.3
16					*Oldenlandia corymbosa* L.	WP	Moderate	124.93
17					*Oldenlandia herbacea* (L.) Roxb	WP	Rare	5.10
18			Asterales	Asteraceae	*Eclipta prostrata* (L.) L.	WP	Rare	3.40
19					*Sphaeranthus africanus* L.	WP	Low	43.76
20			Gentianales	Menyanthaceae	*Nymphoides crystata* (Roxb.) Kuntze	AF	Moderate	856.52
21					*Nymphoides indica* (L.) Kuntze	AF	High	984.2
22			Polemoniales	Convolvulaceae	*Aniseia martinicensis* (Jacq.) Choisy	MA	Moderate	364.21
23					*Evolvulus alsinoides* (L.)L.	WP	Rare	22.65

Sl.no	DIVISION	Class	Order	Family	Species	Habit*	Status**	Relative abundance (gm.M^{-2})
24	PHANEROGAMAE	DICOTYLEDONAE	Polemoniales	Convolvulaceae	*Ipomoea aquatica* Forssk.	AF	High	3751.10
25					*Ipomoea carnea* Jacq.	AF	Moderate	1782.10
26					*Ipomoea pes-caprae* (L.) R.Br.	MA	Moderate	1879.29
27					*Merremia tridentata* (L.) Hallier f.	WP	Low	801.73
28			Personales	Plantaginaceae	*Bacopa monnieri* (L.) Wettst.	AF	High	1849.11
29					*Limnophila aquatica* (Roxb.) Alston	EH	Moderate	767.93
30					*Limnophila heterophylla* (Roxb.) Benth.	EH	Low	75.17
31					*Limnophila indica* (L.) Druce	EH	Rare	5.78
32					*Limnophila repens* (Benth.) Benth.	WP	Moderate	298.62
33				Linderniaceae	*Lindernia antipoda* (L.)Alston	WP	Low	125.37
34					*Lindernia hyssopioides* (L.) Haines	WP	Rare	2.00
35					*Lindernia rotundifolia* (L.) Alston	WP	Moderate	156.55
36					*Utricularia aurea* Lour.	SH	High	445.50

Sl.no	DIVISION	Class	Order	Family	Species	Habit*	Status**	Relative abundance ($gm.M^{-2}$)
37	PHANEROGAMAE	DICOTYLEDONAE	Personales	Lentibulariaceae	*Utriculria gibba* subsp. *exoleta* (R. Br.) P. Taylor	SH	Moderate	188.68
38					*Utricularia reticulata* Sm.	SH	High	910.11
39				Acanthaceae	*Acanthus ilicifolius* L.	MA	Moderate	5520.52
40					*Hygrophila auriculata* (Schumach.) Heine	WP	Moderate	809.71
41					*Hygrophila ringens* R. Br.ex Spreng	WP	Moderate	1310.76
42			Lamiales	Lamiaceae	*Clerodendrum inerme* (L.) Gaertn.	MA	Moderate	2350.37
43				Avicenniaceae	*Avicennia officinalis* L.	MA	Moderate	4383.22
44				Amaranthaceae	*Alternanthera philoxeroides* (Mart.) Griseb.	EH	High	3733.05
45					*Alternanthera tenella* Moq.	WP	High	2929.68
46			Curvembryae	Polygonaceae	*Persicaria pulchra (Blume) Sojak*	WP	Moderate	2267.22
47					*Persicaria glabra* (Willd.) M.Gomez	WP	Moderate	1061.02

Sl.no	DIVISION	Class	Order	Family	Species	Habit*	Status**	Relative abundance (gm.M^{-2})
48	PHANEROGAMAE	DICOTYLEDONAE	Ordines anomali	Ceratophyllaceae	*Ceratophyllum demersum* L.	SH	Moderate	97.2
49		MONOCOTYLEDONAE	Microspermae	Hydrocharitaceae	*Elodea canadensis* Michx.	SH	Moderate	998.64
50					*Hydrilla verticillata* (L.f.) Royle	SH	High	1209.04
51					*Vallisneria natans* (Lour.) H. Hara	MH	High	4264.19
52					*Najas graminea* Delile	MH	Moderate	594.36
53					*Najas indica* (Willd.) Cham	MH	Moderate	28.19
54			Coronariae	Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms	FF	Very High	11678.88
55					*Monochoria hastata* (L.) Solms	EH	Moderate	6063.80
56					*Monochoria vaginalis* (Burm.f.) C. Presl	EH	Moderate	1937.39
57			Nudiflorae	Araceae	*Pistia stratiotes* L.	FF	Low	1396.78
58					*Colocasia esculenta* (L.) Schott	WP	Rare	643.40
59					*Lemna perpusilla* Torr.	FF	Low	81.58

Sl.no	DIVISION	Class	Order	Family	Species	Habit*	Status**	Relative abundance (gm.M^{-2})
60	PHANEROGAMAE	MONOCOTYLEDONAE	Apocarpae	Aponogetonaceae	*Aponogeton natans* (L.) Engl. & K. Kraus. Jyothi. P.V. (2019). PhD Thesis. University of Calicut	AF	Moderate	30.48
61			Glumaceae	Cyperaceae	*Eriocaulon setaceum* L.	MH	Moderate	83.95
62					*Cyperus cephalotes* Vahl	EH	Rare	277.00
63					*Cyperus difformis* L.	WP	Low	573.10
64					*Cyperus dubius* Rottb.	WP	Low	411.81
65					*Cyperus javanicus* Houtt.	MA	Moderate	5509.70
66					*Cyperus haspan* L.	WP	Moderate	935.21
67					*Eleocharis dulcis* (Burm.f.) Trin. ex Hensch	EH	Moderate	580.07
68					*Fimbristylis quinquangularis* (Vahl) Kunth	MA	Rare	172.16
69					*Fuirena ciliaris* (L.) Roxb.	WP	Low	74.57

Sl.no	DIVISION	Class	Order	Family	Species	Habit*	Status**	Relative abundance ($gm.M^{-2}$)
70	PHANEROGAMAE	MONOCOTYLEDONAE	Glumaceae	Cyperaceae	*Schoenoplectiella articulata* (L.) Lye	EH	Moderate	2438.42
71					*Schoenoplectiella supina* (L.) Lye	EH	Moderate	3962.74
72				Poaceae	*Cynodon dactylon* (L.) Pers.	WP	Moderate	579.48
73					*Eragrostis atrovirens* (Desf.) Trin. ex Steud.	WP	Low	711.77
74					*Eragrostis gangetica* (Roxb.) Steud.	WP	Moderate	1260.80
75					*Hygroryza aristata* (Retz.) Nees ex Wight &Arn.	FF	Moderate	1267.65
76					*Hymenachne amplexicaulis* (Rudge) Nees	WP	Moderate	1307.24
77					*Leersia hexandra* Sw.	WP	Moderate	1077.56
78					*Paspalum distichum* L.	MA	Low	196.40
79					*Sacciolepis interupta* (Willd.) Stapf.	EH	Low	1310.99
80					*Sporobolus virginicus* (L.) Kunth	MA	Moderate	877.68

Sl.no	DIVISION	Class	Order	Family	Species	Habit*	Status**	Relative abundance ($gm.M^{-2}$)
81	PHANEROGAMAE	MONOCOTYLEDONAE	Glumaceae	Poaceae	*Oryza rufipogon* Griff.	WP	Low	74.80
82					*Oryza sativa* L.	WP	Low	524.76
83	CRYPTOGAMAE	CHAROPHYCEAE	Charales	Characeae	*Nitella mucronata* (A.Braun) Miq.	SH	Low	442.64
84		FILICOPSIDA	Pteridales	Pteridaceae	*Ceratopteris thalictroides* (L.) Brongn.	SH	Moderate	102.75
85			Marsileidae	Marsileaceae	*Marsilea quadrifolia* L.	AF	High	1554.78
86			Salviniidae	Salviniaceae	*Salvinia adnata* Desv.	FF	Very High	6730.28
87				Salviniaceae	*Azolla pinnata* R. Brown.	FF	Very High	2167.98

HABIT*: FF-Free floating; SH-Suspended hydrophytes; MH-Submerged hydrophytes; AF-Anchored floating; EH-Emergent hydrophytes; WP-Wetland plants; MA-Mangrove and associates

FREQUENCY STATUS** (Occurrence in number of samples)**: 1=Rare, 5 or <5=Low, 6 to 20 =Moderate, 21to 40=High, >40=Very high**

2.3.1 Detailed description of Macrophytes

Acanthus ilicifolius **L.**
Family**: Acanthaceae**
Sea holly/ 'Chakkaramulli'
Figure: **2.1**

Gregarious shrubs. Stilt root basal. Leaves simple, opposite-decussate, sinuately lobed, spine-tipped, petiole with01 a pair of basal spines. Flowers bluish-violet in terminal spike, sessile; bracts ovate, lanceolate, acute apex; bracteoles connate, persistent. Calyx lobes 4, mucronate, coriaceous. Corolla bluish purple, throat villous, upper lip obsolete, lower lip 3-lobed to entire. Stamens 4, attached to the throat of corolla tube, didynamous; exserted, anthers aggregated around the style, connectives thickly hairy, bi-lobed, one lobe sterile. Ovary oblong. Fruit capsule, ellipsoid to oblong. Seeds 4, compressed and orbicular.

Flowering and Fruiting: December – June. Common halophyte in backwaters and salt marshes.

Aeschynomene indica **L.**
Family**: *Leguminosae***
Sola pith plant/ 'Nellithali'
Figure**: 2.2**

Erect annual herb. Stem erect woody at the base. Leaves petiolate, compound, narrowly ovate stipule, leaflets 15-30 pairs, linear-oblong, tip minutely mucronate. Flowers 1-4 in an axillary raceme, papilionaceous, peduncles with minute tubercles; bracts ovate, acuminate; bracteoles ovate-lanceolate. Calyx glabrous, deeply 2-lipped. Corolla glabrous, pale yellow with purple streaks. Stamens in 2 bundles of 5 each. Ovary stipitate, ovules many. Pods borne on stalks, strap-shaped, flattened. Seeds oblong kidney-shaped black, glossy.

Flowering and Fruiting: August-December. Common in shallow water bodies, paddy fields and low marshy lands.

Alternanthera philoxeroides **(Mart.) Griseb.**

Family**: Amaranthaceae**

Alligator weed/ 'Vellamkanni'

Figure**:2.3**

Semi-aquatic perennial trailing herb with many erect branches from the prostrate stem; rooting from nodes; Stem hollow, longitudinally striate. Leaves opposite, linear-lanceolate, glabrous, apex acute, base obtuse, with a short petiole. Whitehead axillary pedunculate inflorescence; bracts and bracteoles subequal, ovate, glabrous, persistent. Perianth lobes 5, white, oblong- acute, compressed dorsally. Stamens 5, filaments united forming a tube, anthers unilocular. Ovary ovoid; style slender; stigma capitate.

Flowering and Fruiting: Almost throughout the year. Common in stagnant and slow-moving shallow water bodies. It invades over the mats of *Eichhornia crassipes, Salvinia adnata* and *Ipomoea aquatica*.

Alternanthera tenella **Moq.**

Family**: Amaranthaceae**

Sessile joy weed/ 'Kozhuppacheera, Ponamkannikkeera'

Figure: **2.4**

Widespread prostrate or procumbent perennial herb along the wet-grounds, branches purplish, rooting at nodes. Stem villous, not swollen. Leaves opposite, lanceolate, variable in shape and size, obtuse or acute at apex, cuneate at base. The older nodes bear white sessile flowers in an axillary spike. Bracts and bracteoles are ovate. Perianth lobes 5, white, ovate, acute. Stamens 3. The ovary is orbicular or ovoid; style short; stigma capitate. Fruit compressed utricle.

Flowering and Fruiting: Throughout the year except for monsoon. Common in paddy fields and wastelands associated with *Alternanthera philoxeroides*.

Aniseia martinicensis **(Jacq.) Choisy**

Family**: Convolvulaceae**

White jacket/ 'Venthiruthali'

Figure: **2.5**

Creeping and climbing herb. Stem twining. Leaves narrow, linear, base attenuate, apex emarginate with mucronate tip. Flowers solitary, axillary. Calyx lobes 5, foliaceous. Corolla white campanulate, both limb and tube silky pubescent. Stamens 5, included. Ovary glabrous, ovoid, bilocular, two ovules per locule; style filiform; stigma capitate. The fruit is a breaking capsule with four black seeds when mature.

Flowering and Fruiting: September-January. Common in the bank of rivers and canals.

Aponogeton natans **(L.) Engl. & K. Kraus**

Family**: Aponogetonaceae**

Drifting Sword Plant/

' Paruakizhangu'

Figure: **2.6**

They are anchored floating with usually floating and rarely submerged leaves. Submerged leaves petiolate, lanceolate, base cuneate, apex obtuse. Floating leaves long, oblong, base cordate, apex obtuse. Spike densely flowered, tips rising above the water surface, pink or purple tiny flowers. Perianth lobes 2, spathulate, petaloid, persistent. Stamens 6, filaments long. Ovary 3, oblong. Fruits follicles with eight seeds.

Flowering and Fruiting: September-December. Common in stagnant water bodies and paddy fields.

***Avicennia officinalis* L.**
Family**: Avicenniaceae**
Indian mangrove/ 'Uppatti'
Figure: **2.7**

Shrub or small tree; Pneumatophores straight, often forked with blunt tips. Leaves simple, opposite, decussate, elliptic-obovate, apex obtuse, coriaceous, silvery white pubescent beneath. Flowers yellow, terminal or axillary capitate cyme; Bracts small, sessile, round-ovate, pubescent; bracteoles ovate, apex obtuse; bracts and bracteoles persistent. Calyx lobes 4, pubescent, persistent, brownish-green. Corolla yellowish-brown, campanulate, four lobes, glabrous within, densely pubescent outside. Stamens 4 exerted. Ovary conic; style filiform. Fruit capsule, ovoid, compressed, yellowish-green, with a persistent stylar beak.

Flowering and Fruiting: April – November. Common along the bank of rivers and streams.

***Azolla pinnata* R. Brown**
Family**: Salviniaceae**
Mosquito fern
Figure: **2.8**

A small free-floating fern reaching a maximum length of 3 cm. Stem horizontal, alternately branched, bearing roots densely covered by long hairs, the whole plant appears trapezoid in outline. Leaves alternate, sessile, margin entire with transparent membranous border, overlapping towards the tip of branches, ovate, obtuse, each divided into two lobes, adaxial lobe thick green borne above water with two celled papillae arranged in regular rows, abaxial lobe one cell thick, colourless. Sporocarps are borne in pairs in the axils of first leaves of older branches.
Common in the paddy field.

Bacopa monnieri **(L.) Wettst.**
Family: **Plantaginaceae**
Water Hyssop/ 'Brahmi, Neerbrahmi'
Figure: **2.9**

Aquatic or amphibious, prostrate, semi-succulent herb. Stem creeping with ascending branches. Leaves thick, fleshy, succulent, shiny green, glabrous, sessile, opposite, decussate, ovate-oblong, base narrowed, rounded at apex. Flowers solitary, axillary, with 1 – 2 cm long pedicel, white to pink in colour with a green or black spot inside. Calyx lobes 5, unequal. Corolla bluish white, campanulate, 2-lipped, lobes 5. Stamens 4, didynamous. Ovary oblong-globose, style deflexed. Fruit globose capsule, seeds oblong.

Flowering and Fruiting: April-September. Common in marshy abandoned fields and margins of paddy fields.

Centella asiatica **(L.) Urb.**
Family**: Apiaceae**
Indian penny wort/ 'Kudakan'
Figure: **2.10**

Prostrate herb with a creeping stem. Roots at the node. Leaves reniform, cordate at base, dentate margin, long petiole, sheathing base. Flowers sessile, small, reddish-white, in a simple, axillary umbel. Calyx lobes 5, triangular. Corolla lobes 5, ovate, acute, purple. Stamens 5. Ovary 2-celled; style-2. Cremocarp with two laterally compressed mericarps.

*Flowering and Fruiting***:** Throughout the year. Common along river banks, paddy fields and streamsides.

Ceratophyllum demersum L.
Family: **Ceratophyllaceae**
Coontail / 'Kaimbayal'
Figure: **2.11**

Submerged rootless herb, 'bottle brush' like due to small internode towards the tip. Leaves in whorls at nodes, olive green, rigid, brittle, dichotomously forked 1 or 2 times, swollen in the middle, margins denticulate, apex acute. Flowers solitary, sessile. Male flowers: perianth segments 10, subequal, connate at the base, more than ten stamens, anthers long, oblong, connective prolonged at the tip into two spines and a central projection. Female flowers: perianth segments 10, ovary globular, long style.

Flowering and Fruiting: Throughout the year. Common in stagnant water bodies and slow running canals.

Ceratopteris thalictroides **(L.) Brongn.**
Family:**Pteridaceae**
Water sprite
Figure: **2.12**

Rooted emergent fern, emerging fertile branches green bearing forked leaf-like cylindrical stem, no flowers. Fronds arranged in a rosette, stipes terete, fleshy green, lamina dimorphous, sterile lamina bipinnatified, fertile lamina ovate, tripinnate. Sporangia in two rows on either side of veins on the lower surface of leaves. Mature parent plant submerged, young plantlets either floats or rooted in the mud depending on the water level.

Growing interspersed with other submerged plants, associated with *Salvinia, Alternanthera, Azolla* and *Limnophila*

Clerodendrum inerme (**L.*****)* Gaertn.**
Family**: Lamiaceae**
Wild jasmine/ ‘Puzhamulla’
Figure: **2.13**

Straggling evergreen shrub. Leaves elliptic-ovate to obovate, opposite, entire, petiolate, base acute, apex obtuse, subcoriaceous. Flowers white, axillary, trichotomous cyme, pedicel long; bracts minute, linear. Calyx cupular, minutely 5-toothed, persistent and slightly broader than the base of corolla-tube. Corolla white, hypocrateriform, five lobes, glabrous, obovate. Stamen 4, exserted, filaments pubescent, dark violet or purple, anthers yellow. Ovary oblong, 4-lobed, Drupe pyriform, pyrenes 4.

Flowering and Fruiting: January-April. Common along the banks of water bodies having saline intrusion.

***Colocasia esculenta* (L.) Schott**
Family**: Araceae**
Elephant ear, Taro/ ‘Kattuchembu’
Figure: **2.14**

Perennial herb with tuberous rhizomes and stolons. Leaves petiolate, oavte, peltate, base cordate, apex acute, margin entire, fleshy. Inflorescence spadix, spathes ovate-lanceolate, differentiated into a basal convolute green tube and upper lanceolate, yellow to orange caduceus limb. Flowers unisexual, female flowers at the base, nuters in the middle, followed by male flowers. Stamens united into a peltate mass. Ovary unilocular, ovules numerous, parietal placentation; style short; stigma discoid. Berry ovoid, enclosed in the persistent tube of the spathe

Flowering and Fruiting: Throughout the year. Common in marshy abandoned rice fields, margins of canals and rice fields.

***Cynodon dactylon* (L.) Pers.**

Family: **Poaceae**

Bermuda grass/ 'Karukapullu'

Figure: **2.15**

Slender, stoloniferous, creeping, rooting at the nodes, forming a dense mat. Stem slightly flattened often tinged purple in colour. Leaves linear, lanceolate, acuminate, glaucous, ligule membranous. Flowers in terminal spike, spikelets sessile, laterally compressed, single flowered, lower and upper glumes lanceolate, lemma boat-shaped, palea oblong. Stamens 3. Ovary oblong. Caryopsis linear.

Flowering and Fruiting: November-January. Common on the bunds of paddy fields.

***Cyperus cephalotes* Vahl**

Family: **Cyperaceae**

Flat sedge, Nut sedge

Figure: **2.16**

Erect, rhizomatous herb; rhizome creeping, with slender stolons, rooting at nodes, culm solitary or few together. Leaves linear-lanceolate, flat terrate and channelled, margin and mid rib serrate, both surface glabrous, acute apex. Inflorescence capitate, globose; spikelets compressed, rachis stout, glumes ovate, mucronate. Stamens 3, linear. Style long undivided, base ciliate; stigma 3. Nut ovoid, trigonous, brown, base corky white.

Flowering and Fruiting: August-November. Commonly growing on the decaying bed of

Salvinia and *Eichhornia*. Floating mass found in rivers, canals and paddy fields.

Cyperus difformis **L.**

Family: **Cyperaceae**

Small flowered nut sedge/ 'Thalekkattan'

Figure: **2.17**

Erect, slender, tufted, fleshy herb. Culms are tall with the trigonous stem. Leaves linear-lanceolate. Inflorescence terminal, globose dense, clusters of spikes. Glumes orbicular, apex rounded, margins white hyaline. Stamens 1-2. Stigma-3. Nuts elliptic, trigonous, pale brown.

Flowering: July – December. Common in wet areas and paddy fields.

Cyperus dubius **Rottb.**

Family: **Cyperaceae**

Figure: **2.18**

Erect tufted rhizomatous herb. Culms tall, with bulbous base, triquetrous, with membranous sheath. Leaves linear, acuminate apex, scabrid margin at the apex. Flowers in the hemispherical, globose, white head; bracts 3-5. Spikelets ovate-acute, turgid-flattened. Glumes 4-9, distichous, ovate, acute apex. Stamens 3, oblong anther. Stigma 3. Nut trigonous, oblong-ellipsoid.

Flowering and Fruiting: September-December. Common in sandy wastelands.

Cyperus haspan **L.**
Family: **Cyperaceae**
Sheathed flat sedge
Figure: **2.19**

Erect, rhizomatous, slender creeping rhizome. Culms soft, triquetrous. Leaves linear, glabrous, entire margin, apex acute, reduced to a lanceolate appendage of sheaths. Inflorescence terminal spike with a cluster of compressed spikelets. Glumes ovate-oblong, mucronate. Stamens 2-3, connective with bristles at the tip. Stigma 3. Nut trigonous, obovoid, pale brown, smooth.

Flowering and Fruiting: December – June. Common in wet areas and shallow watered rice fields. Frequently occurred on a floating mat of *Salvinia adnata*

Cyperus javanicus **Houtt.**
Family: **Cyperaceae**
Javanese flat sedge
Figure: **2.20**

Erect tufted herb with short rhizome. Culms trigonous, glaucous-green. Leaves linear, acuminate, coriaceous, glaucous-green, brown coloured basal sheath. Inflorescence compound. Bracts 5-7, leafy. Spikelet lanceolate, spicate, acute, straw coloured. Glumes distichous, ovate, apex acute, keel greenish, margin white hyaline, empty basal glumes. Stamens 3, Stigma 3. Nut obovate, trigonous.

Flowering and Fruiting: Throughout the year. Common in sandy areas.

***Eclipta prostrata* (L.) L.**

Family: **Asteraceae**

False daisy/ 'Kanjunni'

Figure: **2.21**

Diffuse ascending herb. Stems and leaves pubescent stem reddish. Leaves simple, opposite, sessile, oblong-lanceolate, base obtuse, serrate margin, acute apex. Inflorescences white hemispherical heads, axillary, solitary, heterogamous. Ray florets female, corolla strap-shaped, ligulate. Disc florets bisexual, corolla tubular. Anthers are sagittate at the base. Achene trigonous with a pappus of two small scales.

Flowering and Fruiting: June-October. Common on wet marshy places along paddy fields.

***Eichhornia crassipes* (Mart.) Solms**

Family: **Pontederiaceae**

Water hyacinth/'Kulavazha'

Figure: **2.22**

Free floating herb. Stem spongy and produces offsets for spreading. Leaves radical, rosulate, broadly ovate-rhomboid, base cunnate to round, apex obtuse, margin entire, swollen petiole, arranged in a whorl. Inflorescence terminal spike, covered by membranous sheath arise from the centre of the rosette. Flowers dense, blue or lilac with yellow blotches at the centre of corolla. Perianth lobes 3+3, obovate. Stamens 3+3, filaments long, dorsifixed anthers. Ovary 3-celled, trilocular, ovules many, style glabrous, stigma globose. Fruits capsule with numerous seeds.

Flowering and Fruiting: December-May. Common in canals, rivers, abandoned the field, shallow water and in cultivated rice fields during the offseason.

***Eleocharis dulcis* (Burm.f.) Trin. ex Hensch**

Family: **Cyperaceae**

Chinese water chestnut/ 'Neer chelli'

Figure: **2.23**

Erect, tufted, annual herb with deep stout rhizome, long stolons. Culms tufted, terete, fluted, shining green. Leaves reduced to membranous sheaths, purplish. Inflorescence terminal with single spikelet. Spikelet cylindrical, terete, densely flowered, rachilla straight. Glumes obovate, obtuse. Stamens 3, linear, apiculate. Hypogynous bristles 6 –7, much exceeding style base, styles bifid; stigma 2. Nuts smooth, orbicular, obovoid, biconvex.

Flowering and Fruiting: April – August. Common in paddy fields associated with *Nymphaea nouchali* and *Leersia hexandra.* Sometimes form a monospecific community in abandoned fields.

***Elodea canadensis* Michx.**

Family: **Hydrocharitaceae**

Pond weed

Figure: **2.24**

Submerged, bushy, aquatic perennial herb. Roots unbranched, thread-like. Stem branched out between 20 and 30 cm in length, joints brittle. Leaves oblong-linear, in whorls of three, overlapping, dark green, transluscent, minutely toothed, non-waxy, rigid. Flowers, dioecious, greenish-white, appear on the surface of the water with a long slender stalk, sheathing, two-lobed spathe. Perianth lobes 3, free. Male flowers with nine stamens. Female flowers with three fused carpels. Fruit ovoid capsule, many seeds.

Flowering and Fruiting: July-September. Common in paddy fields associated with Hydrilla verticillata.

Eragrostis atrovirens **(Desf.) Trin. ex Steud.**

Family: **Poaceae**

Wiry love grass

Figure: **2.25**

Perennial, tolerate salinity. Culms tufted, erect or geniculate at base, nodes glabrous. Leaves linear, lanceolate, base round, glaucous, ligule truncate, membranous, leaf blade flat or involute, adaxial side scabrous, abaxial side glabrous. Spikelet ovate, 10-25 flowered. Lower and upper glume ovate-lanceolate. Lemma ovate, acute. Paleas elliptic-lanceolate. Stamens 3. Ovary oblong; stigma long. Grains ellipsoid.

Flowering and Fruiting: Through the year. Common in wetlands, banks of canals and backwaters.

Eragrostis gangetica **(Roxb.) Steud**.

Family: **Poaceae**

Slime flower love grass

Figure: **2.26**

Annual herb. Culms erect, tufted, nodes glabrous. Leaves lanceolate, base round, apex acuminate, glaucous; ligule truncate, membranous, fimbriate. Panicle grey. Spikelets oblong, breaking up at maturity from the base upwards, grey, 6-17 flowered; lower glume ovate-lanceolate, upper glumes lanceolate; lemma ovate; palea elliptic-lanceolate, two scabrid keels. Stamens 3, anthers violet with a white connective. Stigma white.

Flowering and Fruiting: June-December. Common in margins wetlands and streams.

Eriocaulon setaceum **L.**
Family: **Cyperaceae**
Figure: **2.27**

Submerged aquatic herbs; stem elongate, spongy, densely clothed with numerous leaves. Leaves filiform, oblong-lanceolate, apex acuminate, semi-translucent with a median nerve, fenestrate. Heads hemispherical to conical, grey. Receptacle is conical to columnar, densely pilose. Involucral bracts are shorter than capitulum width, obovate-oblong, obtuse, firm with scarious margins, glabrous, slightly downturned at maturity. Floral bracts obovate-cuneate, obtuse, acute white- papillose on the centre back. Flowers 3-merous, enclosed within bracts. Male flowers turbinate; calyx lobes connate into spathe, oblong, concave, white papillae near the rounded tip; corolla lobes ovate, hairy, within the calyx; anthers 6, oblong. Female flowers born on a short stipe, calyx lobes 2, free, oblong, sparsely white-papillose; corolla lobes spathulate, hyaline, white- papillose at the tip, glands poorly developed; ovary ovoid; style 3-fid.

Flowering and Fruiting: August-December. Common in paddy fields and sides of stagnant water bodies.

Evolvulus alsinoides **(L.) L.**
Family**: Convolvulaceae**
Dwarf morning glory/
‘Chumadukodi or Vishnukranthi’
Figure: **2.28**

Small, prostrate, branched, spreading, hairy herb. Stem not twining. Leaves lanceolate to ovate, base acute, apex subacute, densely clothed with adpressed, white, silky hairs on both sides. Flowers pale blue, axillary, solitary or paired; bracts linear. Calyx lobes lanceolate, silky hairy. Corolla rotate, sub-entire, blue. Ovules 2 in each cell; style 2, each longitudinally bifid. Fruit (capsule) round 4 seeded.

Flowering and Fruiting: August-December. Common in open wet areas.

Fimbristylis quinquangularis **(Vahl) Kunth**

Family**: Cyperaceae**

Hoorah grass/ Mungai

Figure: **2.29**

Erect, tufted, non-rhizomatic annual herb. Leaves equitant, linear, laterally flattened margin scabrid, ligule absent. The inflorescence is a branched spike pale to dark brown. Erect annual herb Stem weak, 4 – 5 angled upwards, 15 – 75 cm tall, leaves narrow 2- 3 mm wide, sheath inflated, acuminate at apex. Umbel decompound; glumes broadly ovate, pale or dark brown. Spikelets brownish ellipsoid. Nuts pale brown, obovate, trigonous, densely verruculose.

Flowering and Fruiting: July – October. Common in paddy field and other seasonally moist areas, associated with *Cyperus* sp. *Monochoria vaginalis* and *Ludwigia adscendens.*

Fuirena ciliaris **(L.) Roxb.**

Family: **Cyperaceae**

Figure: **2.30**

Erect, tufted, non-rhizomatic annual herb. Culms tall, slender, angular, pubescent. Leaves linear, lanceolate, round base, acute apex, sheath and lamina pubescent, reduced basal leaves; ligule short membranous, hairy; Inflorescence terminal glomerulous clusters of spikelets with short pubescent peduncles; bracts leaflike. Spikelets ovate, squarrose, pubescent. Glumes are pubescent, oblong-ovate. Stamens 3. Stigma 3, papillose. Nuts triquetrous, obovoid, sides shiny wrinkled yellow to dark brown.

Flowering and Fruiting: Throughout the year. The interspersed community found in rice fields and seasonally moist areas.

***Hydrilla verticillata* (L.f.) Royle**

Family: **Hydrocharitaceae**

Water thyme

Figure: **2.31**

Submerged, aquatic perennial herb. Stem slender, highly branched, distant basal nodes, upper closer ones. Leaves in a whorl around the stem, with 3-8 leaves per whorl, linear, margin serrulate, membranous. Flowers solitary, axillary, unisexual, enclosed in the spathe. Male flowers: minute, solitary in muricate sessile spathe; calyx lobes 3, white, ovate, reflexed; corolla lobes 3, spathulate, white; stamens 3, reniform. Female flowers: solitary in sessile spathe, long, tubular; calyx lobes three ovate, white; corolla lobes three oblong; ovary 1-celled, ovules many; style 2-3, linear; stigma fimbricate fruit smooth, subulate with persistent style.

Flowering and Fruiting: November –May. Common in stagnant water bodies.

***Hygrophila auriculata* (Schumach.) Heine**

Family**: Acanthaceae**

Long leaved Barleria/ 'Vayal chulli'

Figure: **2.32**

Erect armed subshrubby herb. Stem purplish, with 7-8 leaves and 5-6 sharp, stout spines at a node. Leaves sub-sessile, whorled, lanceolate, base cuneate, margin undulate, apex acute, pubescent. Juvenile plants are devoid of spines. Flowers in axillary whorls, sessile, foliaceous bract and bracteoles. Calyx lobes 4, unequal, lanceolate. Corolla lobes 5, bluish purple. Stamens 4, didynamous. Ovary oblong; style ciliate. Fruit linear-oblong septicidal capsule.

Flowering and Fruiting: November – March. Common in bunds of paddy fields, non-cultivated rice fields with low water level and marshy places.

Hygrophila ringens **(L.) R. Br.ex Spreng**

Family: **Acanthaceae**

Erect hygrophila/ 'Nir-Schulli'

Figure: **2.33**

Erect herb found on wet grounds in groups. Stem glabrous, quadrangular, swollen node, profusely branched. Leaves opposite, linear-lanceolate, midrib ciliate, base attenuate, apex acute, margin crenulate. Flowers dense axillary whorls, purple, subsessile; bracts scalelike, lanceolate; bracteoles long, linear. Calyx lobes 5, unequal, connate half way down. Corolla 2-lipped, upper lip 2-lobed, lower 3-lobed, deflexed, pinkish violet. Stamens 4, exserted, filament pairs united at base, anthers oblong, unequal. Capsules linear-oblong, longer than the calyx lobes.

Flowering and Fruiting: Throughout the year. Common along the margins of paddy fields, canals, streams, rivers and in abandoned fields with the low water level.

Hygroryza aristata **(Retz.) Nees ex Wight & Arn.**

Family: **Poaceae**

Bengal wild rice/ 'Nirvallipullu'

Figure: **2.34**

Aquatic glabrous floating herb. Culms long, floating, spongy below, capillary roots arising from nodes. Leaves are simple, ovate-oblong, base subcordate, apex acute, glaucous beneath, sheath long, inflated, spongy and forming floats. Panicle long, few spikelets, long pedicel. Lemma lanceolate, acuminate, awns scabrid. Palea elliptic-lanceolate, awnless, keels ciliate. Stamens 6. Grains narrowly oblong. Shoots are growing from the water edge to the middle of the water bodies forming dense floating mats.

Flowering and fruiting: November-February. Found in stagnant water bodies and rice fields.

***Hymenachne amplexicaulis* (Rudge) Nees**

Family: **Poaceae**

Bamboo grass, Trumpet grass

Figure: **2.35**

Perennial grass. Culms long, creeping, rooting at nodes, nodes glabrous. Leaves linear- lanceolate, base rounded, apex acuminate; ligules membranous, truncate. Spikelets elliptic- lanceolate. Lower glumes ovate, acuminate; upper glumes lanceolate, acuminate. Lower florets empty, upper bisexual. First lemma lanceolate, aristate; second lemma oblong, acuminate, coriaceous. Palea small, elliptic, coriaceous, 2-keeled. Stamens 3. Ovary oblong.

Flowering and Fruiting: January-October. Common in stagnant water bodies.

***Ipomoea aquatica* Forssk.**

Family: **Convolvulaceae**

Water spinach, Water morning glory/ 'Kozhuppa'

Figure: **2.36**

Trailing and floating aquatic herb spreading over water surface forming sudd. Stem glabrous, hollow, thick and spongy, rooted at nodes. Leaves alternate, oblong-lanceolate, triangular, entire, apex acute, base hastate. Flowers pinkish white, solitary or few in cyme. Corolla 5 lobes, funnel form. Stamens 5, included, filaments villous at base. Ovary 2-celled, ovules 4 in each cell; style filiform. Capsule globose.

Flowering and Fruiting: September – February. Common in canals and paddy fields forming a mat connecting the canals like a bridge when fully spread.

***Ipomoea carnea* Jacq.**
Family: **Convolvulaceae**
Pink morning glory/ 'Neyveli katta'
Figure: **2.37**

Perennial erect shrub found on the margins of rice fields and canals with woody stem, height ranging from 1.5 to 3 m. Stem fistulose at maturity. Leaves simple, broadly ovate, base cordate, apex acuminate, glabrous. Flowers in axillary cymes or subterminal, pink coloured, bracts deciduous. Calyx lobes 5, sub-equal, sub-orbicular, glabrous. Corolla funnel shape, pink coloured, Capsule ovoid, with mucronate tip, persistent calyx lobes embrace the fruit. Seeds ovoid densely covered with brown hair.

Flowering and Fruiting: Throughout the year. Common in wet lowlands.

***Ipomoea pes-caprae* (L.) R.Br.**
Family: **Convolvulaceae**
God's foot creeper/
'Kuthirakulamban or
Adumbuvalli'
Figure: **2.38**

Stout creeper. Leaves shallowly bi-lobbed, broadly orbicular, base truncate, with long petiole. Flowers in axillary cyme. Calyx lobes 5, acuminate, ovate, unequal, accrescent in fruit. Corolla pink, funnelshaped, 5-lobed, limb spreading, plicate. Stamens 5, included, filaments unequal. Ovary 2 celled, ovules 4 in each cell; style long, pilose. Capsule sub-globose, glabrous, 4-valved.

Flowering and Fruiting: October-March. Common along river banks.

Leersia hexandra **Sw.**
Family**: Poaceae**
Southern cut grass, Swamp rice grass
Figure: **2.39**

Aquatic perennial grass. Culms long, erect or trailing, with hairy nodes. Leaves linear-lanceolate, rounded base, acuminate apex, sheath long, ligule membranous. Panicle is flaccid. Spikelet laterally compressed, oblong, 1-flowered. Glumes reduced, 2-lobed rim, entire. Lemma coriaceous, obliquely oblong, keels ciliate. Palea linear-oblong, coriaceous. Stamens 6. Ovary elliptic; style 2, free. Grains oblong, compressed.

Flowering and Fruiting: Throughout the year. Common in fallow fields and wetlands; floating over weeds in canals and streams.

Lemna perpusilla **Torr.**
Family: Araceae
Duck weed/ 'Payal'
Figure: **2.40**

Small free floating herb. Fronds cohering in groups, ovate to oblong, base obtuse, apex rounded, upper side convex with 2-apical papilla, lower side flat, pale green. Flowers unisexual; staminate flowers 2, anthers 2-thecous; pistilate flower1, pistil long. Seeds 1 per fruit, brownish.

Flowering and Fruiting: August-January. Common in paddy fields, stagnant water and slow running streams forming a green floating mat on the water surface.

Limnophila aquatica **(Roxb.) Alston**
Family**: Plantaginaceae**
Giant ambulia
Figure**: 2.41**

Emergent aquatic herb with basal part submerged. Leaves heterophyllous; submerged leaves dissected, compound, pinnate with lobes divided into capillary or linear flattened segments; aerial leaves sessile, opposite, glabrous, ovate-lanceolate, base round, margin serrulate, apex acute. Flowers in a terminal raceme, white, pedicel slender, glandular, pubescent. Calyx lobes equal, ovate-lanceolate, acuminate. Corolla villous within at throat, limb sub-equally 5-lobed, white or pale blue, lobes of upper lip orbicular with a purple blotch at centre. Stamens 4. Capsule globose.

Flowering and Fruiting: July-November. Present in flooded rice fields, shallow ponds and running streams.

Limnophila heterophylla **(Roxb.) Benth.**
Family**: Plantaginaceae**
marshweed/ 'Manganari'
Figure: **2.42**

Emergent annual herb**.** Leaves heterophyllous; aerial leaves sessile, glabrous, opposite, elliptic, apex subacute, margin serrulate, submerged leaves multifid. Flowers solitary, sessile or with small pedicel on upper axils. Calyx 5 lobes, ovate-lanceolate, glabrous. Corolla pale pink, throat hairy, upper lip 2-lobed, lower lip 3-lobed.Stamens 4, didynamous, included. Capsule ellipsoid, style deflexed at the tip.

Flowering and Fruiting: August-December. Common in regularly cultivated rice fields. It forms a monospecific community or may grow in association with *Ceratopteris thalictroides* and *Nymphaea pubescens.*

Limnophila indica **(L.) Druce**
Family: **Plantaginaceae**
Indian marshweed/ 'Manganari'
Figure: **2.43**

Amphibious herb. Leaves dimorphic; submerged leaves dissected, aerial leaves, sub-sessile, whorled, dissected, linear- lanceolate, cuneate base, serrulate margin, acute apex. Flowers, axillary, solitary. Calyx 5lobes, membranous. Corolla tube white with the yellow mouth having purple shade, lobes orbicular. Stamens 4. Ovary ellipsoid.

Flowering and Fruiting: September-December. Common on wet fields and river banks.

Limnophila repens **(Benth.) Benth.**
Family: **Plantaginaceae**
Creeping marshweed/ 'Manganari'
Figure: **2.44**

Erect or procumbent herb, aromatic. Leaves opposite, oblong, base attenuate, margin serrate, apex acute, glabrous, punctuate on both surface, sub-sessile. Flowers solitary or axillary raceme, sub-sessile. Calyx 5 lobes, hirsute, lanceolate, with striations. Corolla pinkish-violet, with a purple stripe, throat pubescent. Stamens 4, didynamous, included. Stigma spathulate. Capsule ellipsoid.

Flowering and Fruiting: September- December. Common in wet paddy fields and banks of streams.

Lindernia antipoda **(L.) Alston**
Family: **Linderniaceae**
Sparrow false pimpernel
Figure: **2.45**

Prostrate, decumbent annual herb spreading below, rooting at nodes. Leaves sub-sessile, opposite, elliptic-obovate, lanceolate, base cuneate, margin serrate, apex obtuse, glabrous. Flowers solitary, axillary or in a terminal raceme, leafy bracts. Calyx clefted at the base, lanceolate, margin scarious. Corolla bilipped, bluish with the yellow mouth. Stamens 2 fertile, two staminodes. Capsule oblong-elliptic, valvular dehiscence, seeds numerous.

Flowering and Fruiting: August-November. Common along the banks of canals, rice fields and other wet areas during monsoon.

Lindernia hyssopioides **(L.) Haines**
Family: **Linderniaceae**
Figure: **2.46**

Slender, erect herb. Stem quadrangular, diffusely branched. Leaves sessile, linear-lanceolate, basal leaves ovate, base cuneate, apex acute. Flowers solitary, axillary, bracteate. Calyx deeply five-lobed, linear, lanceolate, glabrous. Corolla lilac, bilipped, upper lip 2-lobed at apex, dark blue blotches on the lower lip. Stamens 2, inserted at the middle of corolla tube; staminodes 2-fid, with hairy basal appendages. Capsule ovoid-ellipsoid.

Flowering and Fruiting: September-November. Common in wetlands and paddy fields.

***Lindernia rotundifolia* (L.) Alston**
Family: **Linderniaceae**
Lindernia variegated
Figure: **2.47**

Erect or diffuse herb. Rooting at lower nodes. Leaves ovate, apex oblong, rounded base, margin crenate. Axillary, solitary flowers, slender petiole. Calyx 5-lobes, lanceolate with deeply segmented. Corolla 5-lobes, bilipped, lobes orbicular, white with blue blotches at the mouth. Stamens 2, staminodes 2, glandular. Stigma 2-lamellate. Capsule sub-globose, smaller than calyx.

Flowering and Fruiting: September- November. Common in wet lowlands during monsoon.

***Ludwigia adscendens* (L.) H. Hara.**
Family: **Onagraceae**
Water primerose/ 'Nircharambu'
Figure: **2.48**

Floating plant with spongy white aerophores at nodes. Stem branched, brownish red. Leaves alternate, obovate or oblanceolate, margin entire, base attenuate, apex obtuse, glossy lower surface. Flowers solitary, axillary. Calyx tube narrow, 5-lobes, pubescent, persistent. Corolla 5 lobes, obovate, emarginate at apex, cream coloured with yellow blotch inside. Stamens 10, unequal. Ovary 5-locular, many ovules, hairy style, globose stigma. Capsule with long stalk, terete, 10-lobed.

Flowering and Fruiting: September – May. Common in abandoned fields, paddy fields and stagnant water bodies. Floating interspersed on *Salvinia, Utricularia* and *Eichhornia.*

Ludwigia hyssopifolia **(G.Don) Exell**

Family: **Onagraceae**

Water prime rose

Figure: **2.49**

Semi-aquatic herb. Stem erect, angled. Leaves lanceolate, base cuneate, apex acuminate, membranous, glabrous. Flowers axillary, solitary. Calyx tube narrow, lanceolate, 4-lobes, persistent. Corolla 4, obovate, yellow. Stamens 8 with unequal filaments. Ovary 4-celled, many ovules; stigma 4-lobed. Capsule linear, 8-ribbed. Seeds dimorphic.

Flowering and Fruiting: September-December. Common in marshy places and wet paddy fields.

Ludwigia perennis **L.**

Family: **Onagraceae**

Perennial water prime rose, Paddy clove/ 'Carambu'

Figure: **2.50**

Erect herb growing in semi-aquatic conditions. Stem brownish, profusely branched. Leaves elliptic-lanceolate, base attenuate, apex acute, undulate. Flowers axillary, solitary, sessile, 4-merous. Calyx lobes 4, tube long, adnate to ovary, ovate, acuminate. Corolla lobes 4, yellow, elliptic. Stamens 4 with short filaments. Ovary 4-celled, long, linear. Capsule oblong with persistent calyx lobes.

Flowering and Fruiting: All seasons. Common in banks of the marshy area, bunds of paddy fields and canals interspersed with *Alternanthera tenella* and *Ludwigia adscendens.*

***Marsilea quadrifolia* L.**

Family: **Marsileaceae**

Water clover, Water 'Naalilakodian'

Figure: **2.51**

Rhizome long creeping, branched, green, covered by thin hairs, roots arising from nodes. Stipe glabrous, terete. Leaves 4, sessile, obovate, margin entire, base cuneate, arranged like cloverleaf model at the tip of the stipe. Sporocarp born on nodes in the cluster, adnate to peduncle laterally, bean-shaped, hard, densely hairy in young, sparsely when mature, microsporangia and megasporangia enclosed in the same sporocarp.

Common in paddy fields and semi-aquatic places.

***Melochia corchorifolia* L.**

Family: **Malvaceae**

Chocolate weed, Wire bush

Figure: **2.52**

Erect, branched herb. Yong stem, petiole, bract, calyx lobes stellate hairy with mixed hairs. Leaves ovate-oblong, attenuate at the base, serrate margin, acute apex, hairy on both sides. Flowers terminal capitate cyme. Bracts linear, ciliate margin. Calyx 5 lobes, campanulate, lanceolate, ciliate. Corolla pinkish violet, obovate, retuse at the apex. Stamens 5, filaments united at the base. Ovary 5 celled, two ovules each, style 5. Capsule sub-globose, 5-valved.

Flowering and Fruiting: Through the year. Common weed on wastelands and wet fields.

Merremia tridentata **(L.) Hallier f.**

Family**: Convolvulaceae**

Merremia vine/ 'Tala-neli, Prasarini'

Figure: **2.53**

Trailing herb with long slender branches. Leaves linear-lanceolate, auriculate base, acute apex, mucronate, sub-sessile. Flowers axillary cyme. Calyx 5-lobes, sub-equal, lanceolate, acuminate. Corolla campanulate, cream coloured with purple at the centre, 5-lobes, spreaded. Stamens 5, hairy, filaments sub-equal. Ovary 2-celled, ovules-4; style filiform; stigma bifid. Capsule sub-globose. Seeds glabrous.

Flowering and Fruiting: September- January. Common hedges of water bodies.

Mollugo pentaphylla **L.**

Family: **Molluginaceae**

Carpet weed/ 'Parpakakapullu'

Figure: **2.54**

Ascending herb. Stem less than a foot tall, branches slender, glabrous. Leaves, whorled or opposite, unequal, oblong-lanceolate, base attenuate, apex obtuse. Flowers in axillary or terminal cyme with very slender and short stalks. Perianth lobes 5, elliptic-oblong, obtuse, green with a white margin, accrescent in fruit. Ovary 3-5 celled, ovoid; many ovules; style 3-5. Capsule spherical, membranous. Seeds many, reniform, covered with raised tubercular points.

Flowering and Fruiting: July-October. Fairly common in river beds, wastelands and sandy soil.

***Monochoria hastata* (L.) Solms**

Family: **Pontederiaceae**

Arrow leaf pond weed

Figure: **2.55**

Erect emergent rhizomatous herb with a robust stem. Leaves hastate, sagittate, with spongy petiole, sheathing leaf base. Flowers with long pedicel, on racemose inflorescence, spathulate, with blue flowers. Complicated spathe below raceme. Perianth campanulate, lobes 6, oblong. Stamens 6, unequal. Carpels 3; stigma 2-lobed. Fruit an oblong loculicidal capsule.

Flowering and Fruiting: September- January. Common in rice fields in summer, along ditches, in shallow pools, on canal banks, and particularly in flooded rice fields.

***Monochoria vaginalis* (Burm.f.) C. Presl**

Family: **Pontederiaceae**

Pickerel Weed/ 'Karimkoovalum or Neelolppalam'

Figure: **2.56**

Emergent semi-aquatic herb. Leaves obovate, base cordate, apex acuminate, long sheathing petiole. Inflorescence terminal raceme. Flowers bracteate, regular. Perianth blue, campanulate, lobes 3+3, deeply lobed, oblong. Stamens 6 with unequal filaments. Ovary 3-locular, many ovules per locule; stigma 3-lobed. Capsule oblong, glandular. Seeds many, oblong, ribbed.

Flowering and Fruiting: August – January. Common in paddy fields in the offseason along with *Nymphaea* sp., *Limnophila* sp. and *Utricularia* sp.

Myriophyllum oliganthum **(Wight & Arn.) F.Muell.**

Family: **Halorrhagidaceae**

Water milfoil

Figure: **2.57**

Glabrous aquatic herb with floating stems. Floating leaves linear-serrate, upper ones alternate- decussate, lower ones whorled, pectinately pinnatifid, lobes filiform. Flowers small, bisexual or unisexual, axillary. Male flowers pedicellate or sessile; calyx lobes 2-4, linear; corolla 2-4, rose in colour; stamens 4, pistillode 4. Female flowers sessile; calyx adnate to ovary, four furrowed; corolla lobes 0. In bisexual flowers calyx lobes rudimentary, adnate to ovary; corolla lobes 4, yellow, oblanceolate; stamens 4; ovary four celled, ovule one each, pendulous; style 4; stigma plumose. Drupe of 4 mericarps.

Flowering and Fruiting: August-December. Common in stagnant water bodies.

Najas graminea **Delile**

Family: **Hydrocharitaceae**

Rice field water nymph

Figure: **2.58**

Rooted submerged herb. Monoecious, appearing feather like due to closely packed leaves. Stem long, branched, long internodes, without spines. Leaves whorled, translucent, acicular, margin with 55-60 spiny teeth, sheath long, deeply auriculate, serrulate with 3 - 14 spines on each side. Flowers 1-2 per axil. Male flowers on upper axil, naked, spathe absent; perianth lobes long, oblong, hyaline; anther 4-celled. Female flowers naked, spathe absent, sub-sessile, perianth lobes appressed to ovary; ovary elliptic. Fruit ellipsoid.

Flowering and Fruiting: August – December. Common in freshwater ponds and wastewater ditches.

***Najas indica* (Willd.) Cham.** Family: **Hydrocharitaceae Guppy grass**
Figure: **2.59**

Plant monoecious. Stem long, with long internodes. Leaves acicular, up to 20 triangular spines in the margin; sheath obscurely auricled, margin entire, apex obtuse. Male flower: enclosed by a membranous spathe, with spiny apex, stamen 1, with sessile anthers. Female flower: surrounded by a membranous sheath; ovary 1-carpel, ellipsoid; style short; stigma 2, linear; ovule solitary. Fruit nut, enclosed in membranous coat, trigonous.

Flowering and Fruiting: September-December. Stagnant water bodies.

***Nelumbo nucifera* Gaertn.**
Family: **Nelumbonaceae**
Indian lotus/ 'Thamara'
Figure: **2.60**

Bottom rooted floating-leaved rhizomatous herb. Stems dimorphic; slender horizontal vegetative stolon or rhizome. Leaves alternate, petioles up to 2 m long, spiny, lamina when immature floating, cup-like and emergent when mature, peltate, reniform, orbicular, 10 - 60 cm in diameter, glabrous, glaucous. Flowers pinkish white, emergent, fragrant. Perianth lobes 12 - 30, free; outer 2 - 5 persistent, ovate, greenish white, sepaloid; inner petaloid, white to pink, elliptic, obtuse. Stamens numerous, filaments up to 1 cm long, connectives are projecting into hood like appendages. Spongy, obconical receptacles. Carpels many, free, oblong; stigma peltate. Fruit nut-like.

Flowering and Fruiting: February-December. Common in freshwater bodies and flooded low lands. It is often cultivated for beautiful flowers, edible rhizomes, nuts and honey.

Nitella mucronata **(A.Braun) Miq.**
Family: **Characeae**

Pointed stonewort

Figure: **2.61**

Structurally complex perennial monoecious macroalga resembling musk grass (Chara). Dark green; Slender branches and branchlets. Branchlets occur in whorls at regular intervals along branches, bearing antheridia and oogonia. Fertile branchlets divided 2-3 times, sterile branchlets 1-2. Dactyls 2 (rarely 3) celled, mucronate, with acute end-cells. Gametangia conjoined; oogonia solitary, absent from the lowest branchlet nodes — Oospores dark brown, with reticulate membrane and prominent ridges.
Common in canals.

Nymphaea nouchali **Burm. f.**
Family: **Nymphaeaceae**
Indian water lily/ 'Citambel'
Figure: **2.62**

Floating leaved rooted, stoloniferous herb. Leaves are forming rosette over water surface, orbicular, glabrous, margin entire, base cordate with deep sinus, reddish purple on the lower surface. Flowers white. Calyx 4 lobes, triangular-ovate. Corolla lobes many, arising from below receptacle. Stamens many, yellow, petaloid, attached on the upper edge of receptacle, with a distal sterile appendage. Carpels many, connate, embedded in receptacle, ovary many-celled, many ovules; stigma sessile. Fruit: fleshy berry, enclosed by persistent calyx. Seeds many, ellipsoid.

Flowering and Fruiting: Throughout the year. Common in flooded paddy fields associated with *Nymphaea pubescens, Ceratopteris thalictroides* and *Limnophila aquatica*

Nymphaea pubescens **Willd.**
Family**: Nymphaeaceae**
Hairy water lily/ 'Ambel'
Figure**: 2.63**

Floating leaved rooted, stoloniferous herb. Leaves ovate or reniform, deep sinus, margin dentate, glabrous and dark green above, purple green and pubescent below. Flowers fragrant. Calyx lobes 4, ovate-lanceolate, obtuse apex, puberulous and green outside, white inside. Corolla lobes many, white, linear-lanceolate, obtuse apex. Stamens many, yellow, without sterile appendages. Ovary 10-18 loculate; stigmatic appendages many, oblong, inflexed, yellow. Fruit: fleshy berry. Seeds many, ellipsoid, with aril.

Flowering and Fruiting: August-December. Common in flooded paddy fields and stagnant water bodies.

Nymphoides crystata **(Roxb.) Kuntze**
Family: **Menyanthaceae**
Crested floating heart

Figure: **2.64**

Rhizomatous herb. Primary fertile shoots many, uniphyllous, arising from axils of scales on the rhizome. Secondary shoots zig-zag, sympodial, many-jointed, each joint bearing a single floating leaf. Leaves fertile, floating, ovate-orbicular, base deeply cordate, gland-dotted below, membranous. Flowers bisexual, female in an umbellate cluster at the junction of the branch and petiole. Calyx lobes five, narrowly lanceolate. Corolla lobes five with flexuous membranous wings on the margin, white with a yellow throat. Stamens five. Ovary bottle-shaped with five, minute orbicular, disc glands at the base; Stigma 2-lobed. Capsule oblong. Seeds discoid.

Flowering and Fruiting: September- February. Common in flooded lowlands.

Nymphoides indica **(L.) Kuntze**
Family: Menyanthaceae
Water snow flake/ 'Nedel-ambel'
Figure: **2.65**

Floating leaved rhizomatous herbs. Primary fertile branches many, petiole-like and uniphyllous; secondary branches sympodial, zig-zag, multi-jointed, trailing on the water surface, rooting nodes. Leaves thick, fleshy, entire, cauline, floating, ovate-orbicular, base cordate, glossy green above, pale, gland dotted below, fertile. Flowers bisexual, distylous, umbel, arise from the junction of petiole and branches. Calyx 5 lobes, oblong, green with hyaline margin. Corolla white with yellow throat, corolla lobes oblong, acute, densely covered with long white hairs within. Stamens 6-8, dimorphic, adnate to corolla tube, filaments yellow. Bottle shaped ovary, stigma 4-8 lobed. Capsule indehiscent.

Flowering and Fruiting: September – April. Common in shallow water bodies and flooded paddy fields associated with *Limnophila heterophylla*, *Ceratopteris thalictroides* and *Utricularia aurea*, often competes with *Salvinia adnata* and *Pistia stratiotes.*

Oldenlandia brachypoda **DC.**
Family: **Rubiaceae**
Red rice
Figure: **2.66**

Diffusely branched prostrate herb. Stem terete to slightly flattened, glabrous. Leaves sub-sessile, linear, narrowly elliptic, base acute, margin revolute, apex acute, membranous, adaxially glabrous, stipules fused to petiole base, glabrous, truncate to broadly triangular. Flowers axillary, solitary or in pairs, sessile or with short pedicel, ebracteate. Calyx cup-shaped, persistent, lobes 4, triangular, glabrous. Corolla white, lobes 4, rotate, glabrous at the throat, lobes triangular. Stamens 4, exserted. Style exserted, stigma papillate. Fruit capsular, membranous to papery, compressed globose to sub-globose, loculicidally dehiscent.

Flowering and fruiting. February–November. Common in low wet land, paddy fields, ridges of farmlands with stem floating on water.

Oldenlandia corymbosa **L.**

Family**: Rubiaceae**

Diamond flower, Wild chayroot/

'Parppatakappullu'

Figure: **2.67**

Diffuse or spreading prostrate herb. Stem angular, purple coloured. Leaves sessile, linear- lanceolate, base attenuate, acute apex, adaxially glabrous, abaxially scabrescent, opposite, margin recurved; stipules small, membranous, truncate, sheathing, glabrous adaxially. Flowers 2-6 in corymb, 4-merous, bracts filiform, at the base of pedicels. Calyx- sparsely pubescent, tube minute, ovoid, lobes 4. Corolla white, slender, tubular, with the hairy throat, lobes 4, oblong, obtuse. Stamens- 4, filament short, included; stigma bifid, hairy. Fruit capsules sub-globose, loculicidal, didymous, top not protruded beyond calyx, glabrous. Seeds minute, trigonous.

Flowering and Fruiting: August-November. Common in moist low lands.

Oldenlandia herbacea **(L.) Roxb**

Family: **Rubiaceae**

Slender diamond flower/
'Nonganampullu'

Figure: **2.68**

Erect much branched glabrous bushy herb. Stem 4 angled, winged along with angles. Leaves are simple, opposite, sessile, linear-lanceolate, acute apex, glabrous, with recurved margins, lower border than upper ones. Flowers small, solitary or 2 axillary, peduncle filiform. Calyx funnel shaped, lobes triangular. Corolla tube slender, wider on mouth, white, 5-minute lobes. Stamens 4, included. Stigma bifid. Capsule sub-globose, loculicidal. Seeds minute, ellipsoid.

Flowering and Fruiting: October – December.

***Oryza rufipogon* Griff.**

Family: **Poaceae**

Brown beared rice, Red rice/ 'Varinellu'

Figure: **2.69**

Annual herb. Culms erect, tufted, nodes glabrous. Leaves linear, lanceolate, acuminate apex, rounded base, keeled sheath, ligule ovate, membranous, truncate. Spikelet reddish brown, compressed, deciduous; lemma long awned, ovate, laterally compressed; palea oblong. Stamens 6, anthers yellow; stigma cream coloured. Grains elliptic. Similar to rice and grows along with it and can be differentiated by its long awns and compressed spikelets. The grains are with a long tail called awns at the apex about 10 to 20 times longer than the size of the grain.

Flowering and Fruiting: September-March. Common along the margins of stagnant water bodies and paddy fields. Growing interspersed with rice strands in paddy fields.

***Oryza sativa* L.**

Family: **Poaceae**

Paddy/ 'Nellu'

Figure: **2.70**

Annual herb. Culms erect, rooting at lower nodes, nodes glabrous. Leaves linear, apex acuminate, sheath ciliate on margin; ligule membranous. Spikelet are oblong, deciduous, and shortly awned. Glumes reduced. First lemma oblong-lanceolate; second lemma fertile, oblong, granulate. Palea oblong-lanceolate, acuminate. Grains oblong enclosed with lemma and palea.

Flowering and Fruiting: August-May. Cultivated in paddy fields.

***Paspalum distichum* L.**

Family: **Poaceae**

Knot grass, Water finger-grass/ 'Kulavaragu'

Figure: **2.71**

Trailing grass often found floating on water. Culms are creeping, rooting at nodes, nodes glabrous. Leaves linear-lanceolate, base cordate, apex acuminate, ligules ovate, membranous. Inflorescence racemes in 2, pink feathery. Spikelets in pairs, ovate-elliptic, acute; lower glumes absent; upper glumes elliptic-lanceolate, glabrous. Lower florets barren, upper bisexual. First lemma lanceolate, upper ones ovate-oblong. Palea ovate-oblong, 2-keeled. Stamens 3, anthers pale violet. Ovary oblong; style 2; stigma pink, feathery.

Flowering and Fruiting: April-December. Common in paddy field bund, banks of canals and margins of abandoned fields. They are associated with *Cyperus* sp. and *Leersia hexandra*. Large patches were observed in offseason in cultivated paddy fields.

***Persicaria glabra* (Willd.) M.Gomez**

Family: **Polygonaceae**

Dense flower knot weed/

'Chuvanna- modela-muccu, Kozhivalan'

Figure: **2.72**

Stout aquatic herbs. Leaves lanceolate, base cuneate, apex acuminate. Inflorescence terminal paniculate spike. Bracts oblong, triangular, margin scarious. Perianth lobes 5, campanulate, rose coloured, oblong. Stamens 5. Ovary trigonous, 1-celled; style two armed; stigma capitate. Nut biconvex, included in perianth lobes.

Flowering and Fruiting: November-March. Common in marshy places, banks of water bodies.

Persicaria pulchra (Blume) Sojak

Family: **Polygonaceae**

Hairy knot weed/ 'Velutta-modela-muccu'

Figure: **2.73**

Stout semi-aquatic or rooted floating herb. Stem glabrous. Leaves sub-sessile, alternate, lanceolate, base acute, apex acuminate, glabrous except margins and midrib. Paniculate terminal spike. Flowers white, bracts fimbriate, ciliate along margins, truncate. Perianth lobes 5, white, oblong. Stamens 5. Ovary trigonous, 1-celled, ovules solitary; style-3; stigma capitate. Fruit trigonous nutlets included.

Flowering and Fruiting: October-March. Common in banks of streams, rivers, canals, abandoned fields and marshy areas. It is associated with *Salvinia adnata, Leersia hexandra* and other aquatic grasses.

Pistia stratiotes **L.**

Family: **Araceae**

Nile cabbage, Water lettuce/ 'Kudappayal'

Figure: **2.74**

Free-floating stoloniferous herb, resembling cabbage-like leaves. Stem with short internodes. Leaves sessile, forming a rosette, smaller towards the centre, obovate, apex retuse, base subcuneate, margin undulate, pubescent on both sides. Flowers in a spadix, with short peduncle, spathe small, oblong with a constriction in the middle, lower half sub-convolute, upper half spreading. Male flowers in a whorl of few stamens beneath the apex of spadix; few neutrals are forming a ring below male flowers; single female flower. Perianth 0. Ovary 1-celled, obliquely adnate to spadix. Stigma discoid; many ovules on parietal placentation. Berry ovoid; many-seeded capsules crowned by persistent style.

Flowering and Fruiting: March-October. Common in canals, paddy field and ponds; growing interspersed in paddy fields and competing with *Salvinia, Lemna* and *Azolla.*

Rotala indica **(Willd.)Koehne**
Family: **Lythraceae**

Indian tooth cup

Figure: **2.75**

Amphibious herb. Stem erect, rooting at nodes, quadrangular. Leaves decussate, sessile, sub-orbicular, base cuneate, apex acute, margin cartilaginous. Bracts dimorphic; foliaceous on major branches; smaller, elliptic on flowering branches. Bracteoles are lanceolate. Flowers solitary, sessile, axillary. Calyx tube pink, campanulate, lobes 4, triangular. Corolla lobes 4, pink, elliptic. Stamens 4, filaments attached at the middle of calyx tube. Ovary is ellipsoidal; stigma capitate. Capsule 2-valved, ellipsoid.

Flowering and Fruiting: November-April. Common in moist rice fields.

Rotala macrandra **Koehne**
Family**: Lythraceae**

Giant red rotala

Figure: **2.76**

Aquatic heterophyllous herb. Creeping stem, rooting below, branches decumbent; aerial stem pink. Leaves 2 forms; submerged in whorls of 3 in the beginning, lanceolate, decussate later on. Aerial leaves sessile, decussate, ovate, cordate base, rounded apex, fleshy, red. Flowers in terminal branched, bracteates spike. Bracts cordate; bracteoles linear. Calyx tube campanulate, four lobes, appendages absent, pink. Corolla lobes 4, obovate, rose in colour. Stamens 4, exserted. Ovary 4 locular, ovules many per locule; stigma capitate, wider than style. Capsule globose, 4-valved.

Flowering and Fruiting: September-January. Common in flooded paddy fields and stagnant water bodies.

***Rotala malampuzhensis* R. V. Nair ex C.D.K.Cook**
Family**: Lythraceae**
'Malampuzharotala'
Figure: **2.77**

Marshy wetland herb. Stem creeping, rooting below, reddish. Leaves opposite, decussate, sessile, lanceolate. Bracts foliaceous; bracteoles capillary. Flowers solitary, axillary, sessile. Calyx tube campanulate, lobes 3, red in colour, ovate-acute, three appendages. Corolla red, lobes 3, small. Stamens 3. Nectar scales 3, linear, alternating with stamens. Ovary globose; short style; capitate stigma. Capsule globose, red, beyond calyx tube.

Flowering and Fruiting: July-October. Common in flooded paddy fields.

***Sacciolepis interrupta* (Willd.) Stapf.**
Family: **Poaceae**
'Polla kala'
Figure: **2.78**

An emergent hydrophytic herb. Culms erect, creeping, spongy, nodes glabrous, rooting at nodes below. Leaves linear, base rounded, apex acuminate; ligule ovate, membranous. Panicle interrupted. Spikelets ovate-lanceolate; lower glumes oblong, upper glumes lanceolate. Lower florets male, upper bisexual, first lemma same as upper glume. Palea elliptic, 2-keeled, hyaline; second lemma ovate-oblong. Stamens 3, violet coloured anthers. Stigma pink in colour.

Flowering and Fruiting: Throughout the year. Common in stagnant water and marshy fields.

Salvinia adnata **Desv.**

Family: **Salviniaceae**

Karibaweed/ 'Africanpayal'

Figure: **2.79**

Free floating, covering water surface in canals and other aquatic water bodies. Stem spongy, terete, branched with nodes and internodes. Leaves 2 types: submerged leaves blackish brown, root-like, with septate hairs; normal leaves born in two opposite pairs at nodes, erect, floating, sessile, oblong, entire, lower surface glabrous, upper surface pubescent. Sporocarp born in a cluster on submerged leaves, arranged in two rows, common in the old plant, ovoid, apiculate, sessile, densely haired; mega-sporocarp and micro-sporocarp present separately.

Very aggressive floating weed in the paddy fields, canals and other water bodies. Most dominant over other floating plants like *Lemna, Azolla* and *Pistia*. It has two life forms; mat forms having a dense cover and open water forms having long internodes, thin and flat small leaves.

Schoenoplectiella articulata **(L.) Lye**

Family: **Cyperaceae**

Bulrush/ 'Chelli'

Figure: **2.80**

Erect, tufted sedge. Culms cylindrical, hollow, septate, glabrous, green. Leaves well developed when young, reduced to 1 or 2 sheaths at the base on maturity. Sheath cylindrical, mouth truncate. Inflorescence pseudolateral head, located midway position of the culm bearing lateral spikelets in a dense cluster. Spikelets cylindrical, oblong-acute, sessile, wingless rachilla, persistent. Glumes ovate-acute, shortly keeled. Stamens 3, anthers oblong. Style long; stigma 3. Achemes ovate, elliptic, trigonous, black, smooth.

Flowering and Fruiting: September-March. Common in abandoned drained fields associated with *Eleocharis dulcis, Fimbristylis quinquangularis* and *Monochoria vaginalis.*

Schoenoplectiella supina **(L.) Lye**
Family: **Cyperaceae**
Bulrush
Figure: **2.81**

Erect non-rhizomatous herb. Culms tufted, non-septate, solid. Leaves reduced to sheath without blade; sheaths 2, membranous, mouth truncate. Inflorescence pseudolateral head, born above the middle of culm; bracts 1-2, lower one is exceeding the inflorescence. Spikelet straw coloured, rachilla persistent, without a wing. Glumes ovate-acute, margin hyaline, keeled. Stamens 3, connective having bristles at the top. Stigma 3, as long as style. Nuts trigonous. Obovoid, wrinkled transversely.

Flowering and Fruiting: September-December. Common in rice fields.

Sphaeranthus africanus **L.**
Family: **Asteraceae**
African globe thistle/ 'Vella adakkamaniyan'
Figure: **2.82**

A semi-aquatic aromatic herb grows along with the wet areas of bunds. Stem branched, winged, wings denticulate. Leaves obovate, base attenuates, margin serrulate, apex acute, both surface pubescent, sessile. Inflorescence compound head, terminal; peduncle stout. Flowers greenish white. Corolla lower half swollen, upper part spreading.

Flowering and Fruiting: November-April. Common in paddy fields in offseason.

Sporobolus virginicus **(L.) Kunth**

Family: **Poaceae**

Salt water couch

Figure: **2.83**

Perennial grass. Culms stoloniferous, creeping by long slender rhizomes, nodes glabrous. Leaves are lanceolate, rounded base with acuminate apex. Panicles narrow, appressed to the rachis. Spikelets are lanceolate. Glumes and lemma are more or less equal, both lanceolate; palea elliptic, delicate. Stamens 3, anthers brownish. Stigma white.

Flowering and Fruiting: July- November. Common in wet saline soil.

Utricularia aurea **Lour.**

Family: **Lentibulariaceae**

Golden bladder wort

Figure: **2.84**

Suspended aquatic herb common in rice fields. Rhizoids absent. Stolon branched, floating below the surface of the water. Foliar organ dissected into capillary segments, bladders many, ovoid, on secondary or tertiary segments, stalked, mouth lateral, oblique. Flowers yellow in racemes, arising at intervals on the stolon, projecting above the water surface, peduncles and pedicels stout. Calyx lobes sub-equal, ovate, larger. Corolla bilipped, yellow, upper lip erect, smaller than lower, sub-orbicular, obtuse at apex; lower lip obovate, throat spurred. Stamens 2. Ovary ovoid; stigma 2-lipped.

Flowering and Fruiting: May-August. Common in paddy fields, stagnant water bodies and slow running waters associated with *Nymphoides indica* and *Salvinia adnata*.

***Utriculria gibba* sub sp. *exoleta* (R. Br.) P. Taylor**

Family: **Lentibulariaceae**

Huped bladderwort

Figure: **2.85**

Suspended aquatic herb. Stolon branched, filiform. Foliar organ dissected three times dichotomously, segments capillary, trap few, reniform, lateral, on all segments, mouth lateral. Flowers in receme, 1-3 flowered, bracts basifixed. Calyx lobe sub-equal, ovate. Corolla bilipped, yellow, upper lip larger than lower, sub-orbicular, apex rounded; lower lip conical, apex obtuse. Stamens 2, inserted at base of the corolla, anthers dorsifixed. Ovary globose; style short; stigma 2-labiate. Seeds thickly lenticular with a relatively broad wing surrounding the seed.

Flowering and Fruiting: October-March. Common in shallow, stagnant water bodies and slow running water.

***Utricularia reticulata* Sm.**

Family: **Lentibulariaceae**

Net veined bladder/

'Nelli poo, Krishnapoovu'

Figure: **2.86**

Weed of rice fields. Stolon branched. Foliar organ linear, attenuate at base, obtuse at apex. Bladder many, sub-globose, appendages 2, subulate. Raceme twining; bracts ovate, basifixed, acute apex; bracteoles subulate. Flowers blue coloured; pedicel narrowly winged, erect, deflexed in fruit. Calyx lobes sub-equal, lanceolate, acuminate apex. Corolla blue; upper lip sub-orbicular, white-streaked, rounded, notched, slightly 3-lobed; lower lip obovate, apex rounded, throat hairy, gibbous at base, truncate, notched; spur subulate, conical, curved. Stamens 2, inserted at the base of the corolla. Ovary ovoid; style short; stigma 2-lipped, truncate at apex. Capsule ovoid, compressed.

Flowering and Fruiting: August-December. Common in paddy fields.

Vallisneria natans **(Lour.) H. Hara**
Family: **Hydrocharitaceae**

Eel grass
Figure: **2.87**

Submerged herb. Leaves radical, linear, flat, base narrow, minutely toothed margin, obtuse apex. Flowers dioecious. Male flowers many, break off and rise to the water surface at anthesis; spathe oblong; calyx lobes 3, ovate; corolla lobes absent; stamens 3. Female flowers long-peduncled, spirally coiled after fertilisation; spathe oblong, covering ovary; calyx lobes 3, oblong; corolla lobes 3, small; staminodes; ovary linear; style 3, 2-lobed, hairy. Fruit long, linear. Seeds numerous.

Flowering and Fruiting: November-March. Common in stagnant water bodies.

2.4. DISCUSSION

Aquatic vascular plants (macrophytes) are essential elements of the wetland ecosystem and diverse assemblage pattern can enhance habitat heterogeneity (Keddy, 2000; Mitsch and Gosselink, 2000; Cronk and Fennessy, 2001); imperative for primary productivity and nutrient cycling (Peakall and Burger, 2003). The functions served by aquatic plants are extensive and impressive. They harbour aquatic insects that serve as the foodstuff for fish, habitually providing a launching space from the water to the air and offer hiding place, nurseries and spawning areas for zooplankton, amphibians and fishes (Mitsch and Gosselink, 2000; Heegaard *et al*., 2001). Also, offer oxygen for those who live in and above the waterline and aiding water purification. Many macrophytes have quite beautiful flowers attracted by the tourists providing aesthetic value. Aquatic plants are essential to the proper maintenance and function of a healthy and attractive wetland.

Aquatic macrophytes identified in *Kole* wetland of Ponnani, Thrissur offers a diversity of microhabitat for different flora and fauna due to the variety of physiognomic forms which results in niche diversification. Abundant macrophyte species excluding cultivated species *Oryza sativa* were *Ludwigia adscendens*, *Alternanthera philoxeroides*, *Eichhornia crassipes*, *Salvinia adnata* and *Azolla pinnata*. Paddy cultivation is very common in *Kole* wetlands from September to April. Along with paddy, many paddy associates were also noticed. Wetland species were dominated in Ponnani *Kole* wetland ecosystem, and the families Poaceae and Cyperaceae were outstanding with regard to the number of species. Among the listed plants 28 species are used in systems of treatments like Ayurveda, Folk, Sidha and Unani (Udayan and Balachandran, 2009; Jyothi and Sureshkumar, 2014b).

Sujana and Sivaperuman (2008) identified 140 species of aquatic macrophytes from *Kole* wetlands of Thrissur including the macrophytes seen in raised bunds. Present study limited exclusively to the aquatic macrophytes excluding all the edge species. Almost 352 aquatic plants were listed by Cook (1996) from Kerala. Sunil (2000) while studying the flora of Alappuzha district observed almost 200 species of aquatic and semi-aquatic plants. Joseph (2002b) studied the aquatic flora of Kerala by concentrating on the inland wetlands of Malabar region and described 241 species of angiosperms belonging to 42 families under three groups; the first group in running water, second in stagnant water bodies and third in marshy areas.

Ghosh (2010) noted that wetland plant diversity of West Bengal is richest in India, represented by almost 380 aquatic species belonging to 176 genera and 81 families. Centre for Environment and Development (CED, 2003) listed 717 angiosperms and eight pteridophytes under 81 families from the major wetlands of Kerala. They extended the study in Vembanad *Kole* and recorded a total of 347 plants. Ninety-one species of aquatic macrophytes under 35 families were recorded from Salim Ali Bird sanctuary Thattekad, grouped under three growth forms like free floating, submerged and marshy vegetation (Seema, 2002). Poaceae was represented with a maximum number of species followed by Cyperaceae in Thattekad (Seema, 2002) and Pocharam lake in Telangana (Swamy *et al.,* 2016); similar observation was made in Ponnani *Kole* during the current study. Among the observed aquatic plants wetland species were most prominent in Ponnani *Kole*, whereas both wetland and emergent species were equally dominant in Pocharam lake. Sylas *et al.* (2004) studied the aquatic macrophytes of Kuttanad wetland ecosystem and found *Salvinia adnata, Cyperus compressus, Eichhornia crassipes, Alternanthera philoxeroides* and *Nymphaea pubescens* were most dominant and widely distributed. These plants were also noticed in Ponnani *Kole* land ecosystem as dominant vegetation except *Cyperus compressus*. According to Sujana and Sivaperuman (2008) species composition of wetland flora in the cultivated and uncultivated area of *Kole* land is same except in number and ability to resist herbicides. The same pattern of occurrence was observed in Ponnani *Kole* lands. Jayson and Sivaperuman (2005) reported 182 species of birds, 13 species of fishes from the Thrissur *Kole* wetlands, the platform for feeding, roosting and the breeding process by migratory and resident birds. Eighty species of economically important macrophytes including 34 medicinal plant species (Sujana and Sivaperuman, 2007); 243 hydrophytes and wetland-dependent plants under 56 families (Unnikrishnan, 2008) were reported during the floristic survey in Vembanad *Kole* ecosystem. Aiswarya *et al.* (2010) reported 32 plant species from Anachal wetland ecosystem and the area represents unique yet fragile vegetation of coastal ecosystems in Kerala. Paul and George (2010) studied the riverine flora of Pamba river basin and reported 410 angiosperms, three gymnosperms and 20 pteridophytes, of which Poaceae was recorded as dominant family. Vijayakumar (2006) studied the mangrove ecosystems and reported six species of mangroves from Panangadu estuary in Kadalundy, Kerala where *Avicennia officinalis* and *Acanthus ilicifolius* were the dominating macrophyte species. Jayson and Sivaperuman (2001) studied the mangrove ecosystem in Kochi and found that mangroves and mangrove associates serve as feeding, roosting, and breeding grounds for several migratory birds. Balachandran *et al.* (2005) noticed the interaction between waterfowl and aquatic vegetation and found that *Cyperus, Hydrilla* and *Nymphaea* were the common aquatic plants fed by birds in Chilika lake. Deepa and George (2017) studied the avian fauna of Pokkali wetland ecosystem in Kerala and observed 30 trans-continental migrants and five local migrant species. Three near threatened species; Spot-billed Pelican (*Pelecanus philippensis*), Darter (*Anhinga melanogaster*) and Oriental White Ibis (*Threskiornis melanocephalus*) were recorded.

The present study showed that mangrove and associates like *Aniseia martinicensis, Ipomoea pes- caprae, Acanthus ilicifolius, Clerodendrum inerme, Avicennia officinalis, Cyperus javanicus*, *Fimbristylis quinquangularis* and *Paspalum distichum* were common in the area of saline intrusion. These mangrove species offer meandering ground for faunal species including trans-national migratory birds. *Salvinia adnata, Azolla pinnata, Marsilea quadrifolia* and *Ceratopteris thalictroides* were the pteridophytes observed in all seasons. *S. adnata* formed thick mats over the water surface during monsoon and grown interspersed in paddy fields during cultivation. The same observation was also found in Kuttanad wetland ecosystem (Sylas, 2010). *Ceratopteris thalictroides* was very common during the off-season in rice fields (Sunil, 2000), but in the present study, it was common during post-monsoon and pre-monsoon in rice fields and abandoned fields. *Nymphaea nouchali* and *N. pubescens* were distributed widely in the study area in all seasons, while *Nelumbo nucifera* was observed in pre-monsoon. Sylas (2010) reported that *Nymphaea nouchali* and *N. pubescens* were distributed widely in the offseason in the paddy fields and its removal causes huge economic loss to farmers in Kuttanad wetland ecosystem. Different species of macrophytes form the floristic spectrum of Ponnani *Kole* land by providing ecological, economic and medicinal significance. Conservation and management of this ecosystem wealth should be initiated for maintaining the balance of this unique ecosystem.

2.5 CONCLUSION

The present study envisages to list out the aquatic macrophytes of a typical tropical wetland ecosystem. Macrophytes in the study area cover a taxonomically highly diverse group of plants. Their functions in wetland ecosystems impact many processes such as nutrient cycling and food web dynamics. Providing such an essential role in the wetland ecosystem, macrophytes may also be used as a management tool, taking into account its biodiversity restitution and human economic awareness. A better perceptive of the species specificity and the significance of diversity, in the fulfilment of ecosystem functions, will both enhance our knowledge of the role of macrophytes in a wetland ecosystem and lead to better guidance of restitution efforts. The database developed through the present investigation can serve as a initial document for the impact assessment of the zone and also for the policy decisions for the management and conservation of wetlands in general and the aquatic flora of this fragile ecosystem in particular. The principal menace to aquatic ecosystems arises from the cultivation of surrounding land in addition to the lack of awareness concerning the importance of wetland ecosystems among the local population. Detailed knowledge concerning the floristic composition, ecology and environmental factors that influence vegetation types, provide a strong basis to research and helps in the improvement of conservation and management practices in relation to the vegetation and biodiversity of wetland ecosystems.

Chapter-3

SEASONAL VARIABILITY IN PHYSIOGNOMIC ASSEMBLAGE PATTERN OF MACROPHYTE IN PONNANI *KOLE* LANDS

ABSTRACT

Ponnani *Kole* wetlands, the northward extension of Vembanad *Kole* Ramsar site in Kerala, is a place of outstanding biodiversity which supports a spectacular contemplation of individual species and serves as habitat for several endemic species. Aquatic macrophytes play a significant role in the freshwater ecosystem by enhancing biodiversity, providing clear water state, stabilising bottom sediments and, offering shelter and food for a multitude of aquatic organisms. The distribution, abundance and community structure of macrophytes in aquatic systems are highly seasonal. This chapter intends to explain the seasonal variation in diversity and distribution pattern of plant communities in Ponnani *Kole* wetlands. A total of 81 plant species were recorded from the five selected sites and categorised into seven major physiognomic forms. Variation in mean biomass, evenness ($1\text{-}\lambda$) and average taxonomic distinctness (AvTD; $\Delta+$) of aquatic macrophytes was not significant ($p>0.05$) during monsoon, post-monsoon and pre-monsoon seasons. However, the number of species in the macrophyte assemblage in post-monsoon and monsoon showed significant variation ($p=0.000$, $F=9.19$) from that of pre-monsoon. Diversity was found to be higher in post-monsoon due to the increase in the number of species of with the availability of water and nutrient runoff from catchment areas, whereas a decrease in diversity was observed in pre-monsoon owing to the scarcity of water. The results reported here are from competition performed across a gradient of light availability by free-floating and submerged growth forms in monsoon. The resulting shading by a canopy of free-floating forms like *Eichhornia* and *Salvinia* flushed from nearby water sources in the monsoon appears to reduce light levels below the submerged and suspended forms. Significant variation in taxonomic distinctness (VarTD, **$\Lambda+$)** was observed between three different seasons ($F= 4.64$; $p=0.012$). Lower VarTD (177.43) was observed in pre-monsoon due to the survival of only drought tolerant species. However, in post-

monsoon higher VarTD (330.27) was observed because of the occurrence of 56 species with an unequal predominance of all taxa, viz. class, order and family of macrophytes. Even though the bio-climatic condition of the region was found to be fluctuating with seasons, the range of variability seemed to be within the tolerable limit of macrophytes the fluctuations play a significant role in the determination of community structure of macrophytes.

3.1 INTRODUCTION

Wetlands are resilient ecosystems as they exhibit the uniqueness of both aquatic and terrestrial systems by providing a high level of strength in physical and chemical conditions (Ripken, 2009). They support a spectacular contemplation of individual species as well as the diversity of species and act as critical genetic reservoirs. They also offer excellent habitats for migratory avian fauna and nurture a broad spectrum of animal forms and microorganisms. Wetlands not only support large biological diversity but also provide a wide range of ecosystem goods and services (Wetlands Rules, 2010). Wetlands are a relatively stable freshwater ecosystem which supplies structural heterogeneity conferred by macrophytes. Even though they are the most productive and stimulating ecosystems, get shattered all over the world under certain conditions. Because of the growing population and increasing food demand, an increase in food production in the coming decades is expected to exert added pressure on wetland ecosystems and freshwater resources (Zingstra and Wiseman, 2003). As India is a signatory to the Ramsar Convention on wetlands, the country should endeavour to conserve the biodiversity and ecological nature of *Kole* wetland ecosystem. The *Kole* lands of Kerala one of the important rice fields meeting 40% of Kerala's rice requirement reclaimed from lake area by building temporary earthen bunds and cultivation of rice were done by innovating farmers during the summer period from December to May (Johnkutty and Venugopal, 1993). Safeguarding the *Kole* wetlands is essential for the conservation of the migratory and resident birds in which the majority of them act as bio-control agents in reducing the pest species that affect the paddy cultivation. Kuruvilla (2016) reported more than 180 species of water birds like pelicans, ducks, geese, swans, cranes, herons, storks and cormorants following the Central Asian Flyway using wetlands of Kerala as a stopover during trans-continental migration. Many of these species are now threatened due to the destruction and degradation of the wetland ecosystem in this region.

Macrophytes are an important part of aquatic ecosystems and are used extensively in the Water Framework Directive (WFD) to set up ecological worth. Macrophytes exert signal effects by participating in the construction of different patches on different scales (O'Hare *et al*., 2006; Kuczynska-Kippen, 2007) and are well-matched as indicators of ecological integrity in wetlands (Cronk and Fennessy, 2001; DeKeyser *et al*., 2003). Macrophytes are the major primary producers in such shallow wetland ecosystems (Schneider *et al*., 2012). They interact directly and indirectly with higher trophic levels by providing food and habitat (Holmes, 1999), through their impact on sediment composition, thereby influencing physical characteristics (Wetzel, 2001; Maltchik *et al*., 2007; Kleeberg *et al*., 2010). Wetland vegetation is known as important wetland regulators as they remove pollutants and excess mineral nutrients from the water (Romero *et al*., 1999). However, aquatic plants are still regarded as a menace and a nuisance because of the unawareness of their great potential and economic value. Aquatic plants are more productive than conventional terrestrial crops.

The *Kole* wetland discussed in this study faces threats like land reclamation for agriculture purpose and discharge of industrial effluents, agrochemicals and sewage. Construction of bunds in the main channels affects the water flow patterns as well as hinders the migration and breeding of many species. Therefore rational usage, periodic monitoring, proper management and stringent conservation strategies of the resources of the wetland under the present study are much solicited. This chapter intends to explain the seasonal variation in diversity and the distribution pattern of plant communities in Ponnani *Kole* lands.

3.2 MATERIALS AND METHODS

In the current study, five representative stations were sampled to assess the floral composition and seasonal variation in their distribution (Table 3.1). Plant species recorded during the study were categorized into seven physiognomic forms, such as free-floating, suspended hydrophytes, submerged hydrophytes, anchored floating, emergent hydrophytes, wetland plants and mangrove and associates as described in chapter 1.5.4.2.

Table 3.1 Geographic positions of selected stations in the Ponnani *Kole* wetland to study the seasonal variation

No	Stations	Average water depth (mm) (Table S2)		
		Post-monsoon	Pre-monsoon	Monsoon
1	Mukolamtazhath	791.25	260	1502.5
2	Aynichira	700	251.25	890
3	Kottamukku	335	388.75	368.75
4	Naranipuzha	525	472.5	775
5	Vadakkekkottol	460	148.75	558.75

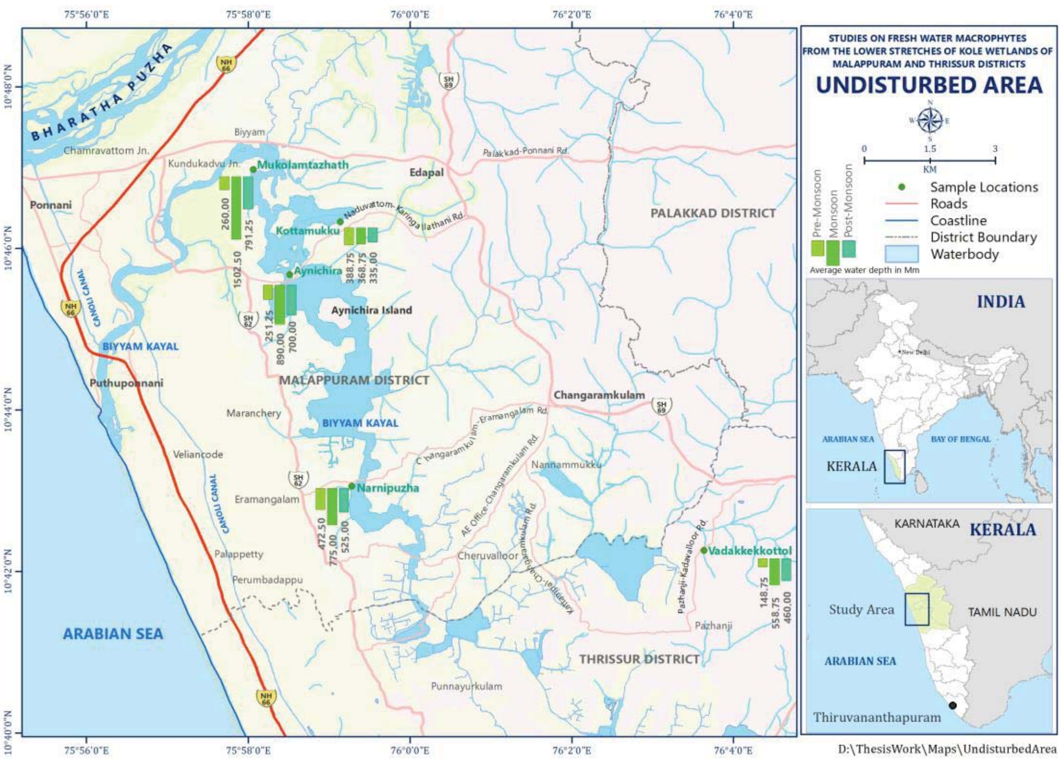

Figure 3.1 Location of the five study stations in the Ponnani *Kole* wetland

3.2.1 Field Observations

Vegetation survey and dry weight biomass determination of macrophytes were conducted in five stations for two years (2014 to 2016) in three different seasons, the monsoon (MON) or rainy season generally from June to September, post-monsoon (POM) from October to February and the pre-monsoon (PRM) or dry season from

March to June. Sampling was done as described in chapter 1.5.4.2. A total of 120 samples were collected and analysed during the study period. Primary examination of data was done with the samples collected from six different seasons corresponding to two years, and the results were analysed. No significant variation ($p>0.05$) was observed within the samples collected during a specific season from different stations. Therefore, the data collected from various stations in seasons are pooled and presented.

3.2.2 Data Analysis

To provide information on diversity and community structure of macrophytes in the study area the indices, viz. Species number (S), Abundance (Biomass; N), Shannon-Wiener diversity index (SDI - H'), Simpson evenness (SEI - 1-ƛ), Average taxonomic distinctness (AvTD - $\Delta+$) and Variation in taxonomic distinctness (VarTD - $\Lambda+$) were worked out; funnel plot and k dominance plot were constructed, as described in chapter 1; section 1.5.5. Differences in the mean diversity indices and mean biomass of various growth forms between seasons in the selected area were compared using ANOVA and further by Duncan's multiple range test (Snedecor and Cochran, 1969). The detailed result of one-way ANONA was given in the table S4.

3.3 RESULTS

3.3.1 Occurrence and abundance of Macrophytes

Eighty-one species of aquatic macrophytes belonging to 54 genera and 31 families were recognized from the wetlands of the survey site (Table S3). The dominant families are Cyperaceae and Poaceae represented by eleven species each. Followed by Convolvulaceae and Hydrocharitaceae represented by five species each and Plantaginaceae by four. Three species each represented the family Lythraceae, Onagraceae, Rubiaceae, Lentibulariaceae and Pontederiaceae. Two species each represented the family Nymphaeaceae, Asteraceae, Menyanthaceae, Acanthaceae, Amaranthaceae, Polygonaceae and Salviniaceae. Nelumbonaceae, Malvaceae, Leguminosae, Molluginaceae, Apiaceae, Verbenaceae, Avicenniaceae, Ceratophyllaceae, Araceae, Aponogetonaceae, Characeae, Pteridaceae and Marsileaceae were represented by single species each.

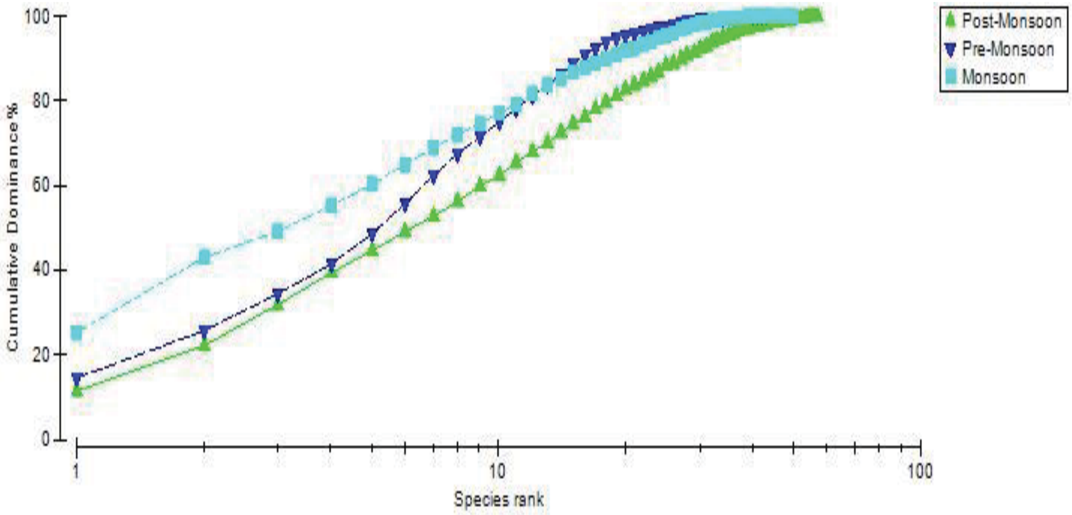

Figure 3.2. The cumulative frequency of abundance (or k-dominance plots) of species in three seasons

The K-dominance plot, where percentage cumulative dominance values are plotted against log species rank (Lambshead *et al*., 1983) clearly shows the variation in the pattern of diversity of aquatic macrophytes during three different seasons in the study area. The curve for the frequency of abundance of macrophytes during the post-monsoon season was below that of monsoon and pre-monsoon seasons (Figure 3.2) indicating higher species diversity in most of the sampling stations during post-monsoon than monsoon and pre-monsoon. During pre-monsoon period the curve rises rapidly and reached above the curves of monsoon and post-monsoon (Figure 3.2), which, shows that in many stations, the diversity of macrophytes were lower when compared to other seasons, with many stations have few numbers of species ie. 90% of the stations have less than 20 species. During monsoon season, high rainfall may have hindered the diversity of the aquatic macrophytes in many stations as shown in figure 3.2 that 80% of the stations have less than ten species.

3.3.2 Species Richness (S)

Macrophyte species composition showed significant variation ($p<0.05$) between different seasons in Ponnani *Kole* lands. A higher number of species of macrophytes was observed in the post-monsoon (56) and monsoon (49), however only the lower number of species was recorded during pre-monsoon (43). The result of ANOVA and post hoc analysis revealed that there is no significant variation in the number of species in the macrophyte assemblage in post-monsoon and monsoon. However, a significant difference (F= 9.19; p=0.000) could be observed between pre-monsoon and the other two seasons (Table 3.2). Wetland plants showed a maximum number of species followed by emergent and anchored floating during the study period. *Nymphaea nouchali, N. pubescence, Ludwigia adscendens, L. perennis, Oldenlandia corymbosa, Nymphoides indica, Ipomoea aquatica, Bacopa monnieri, Limnophila aquatica, Utricularia aurea, Hygrophila ringens, Alternanthera tenella, Hydrilla verticillata, Vallisneria natans Eichhornia crassipes, Najas indica, Marsilea quadrifolia, Salvinia adnata* and *Azolla pinnata* were present in all the three seasons in the study period (Table S3). *Nymphaea nouchali, N. pubescence, Nymphoides indica, Ipomoea aquatica, Bacopa monnieri* and *Marsilea quadrifolia* were observed to be the anchored floating species occurred throughout the year. *Ludwigia adscendens* and *Limnophila aquatica* were two species of emergent hydrophytes observed in all the three seasons. Among wetland plants, *Ludwigia perennis, Oldenlandia corymbosa, Hygrophila ringens* and *Alternanthera tenella*; free-floating hydrophytes *Eichhornia crassipes, Salvinia adnata* and *Azolla pinnata* were found throughout the year. *Utricularia aurea* and *Hydrilla verticillata* are suspended hydrophytes observed in all the three seasons, similarly submerged hydrophytes *Najas indica* and *Vallisneria natans* were also noticed in all the three seasons, but *Eriocaulon setaceum* observed only in post-monsoon. During the study, *Hydrilla verticillata* was the most dominant suspended hydrophyte observed throughout the year (Table S3).

Mollugo pentaphylla, Oldenlandia herbacea and *Eragrostis atrovirens* (wetland plants); *Nelumbo nucifera* and *Aponogeton natans* (anchored floating hydrophytes); *Avicennia officinalis* and *Cyperus javanicus* (mangrove and associates); *Elodea canadensis* and *Ceratopteris thalictroides* (suspended hydrophytes); *Cyperus cephalotes* (emergent hydrophyte) were observed only during the pre-monsoon. Among wetland plants, *Rotala indica, Ludwigia hyssopifolia, Sphaeranthus africanus, Cyperus dubius, Hymenachne amplexicaulis* and *Oryza sativa* were observed only in the post-monsoon. Similarly, *Clerodendrum inerme, Fimbristylis miliacea* and *Paspalum distichum* were the mangrove and associate noticed only in the post-monsoon. *Ipomoea carnea* (anchored floating hydrophyte) *Eriocaulon setaceum* (submerged hydrophyte) and *Nitella mucronata* (suspended hydrophyte) were present during the post-monsoon season. *Melochia corchorifolia, Rotala malampuzhensis, Oldenlandia brachypoda, Eclipta prostrata, Evolvulus alsinoides, Merremia tridentata* and *Lindernia hyssopioides* were the wetland plants observed only in the monsoon (Table S3).

3.3.3 Biomass of Macrophytes (N)

No significant variation (F= 0.86; p=0.424) was observed in the mean biomass of macrophytes during the three different seasons in various sites of the study area (Table 3.2). The highest biomass of macrophytes was recorded during the monsoon season (407.43) and the lowest during the pre-monsoon season (337.10). *Eichhornia crassipes,* a free-floating hydrophyte was the most dominant species in the monsoon and *Nymphaea nouchali,* an anchored hydrophyte dominated during pre-monsoon. Amongst emergent hydrophytes, *Schoenoplectiella supina* was the most dominant in post-monsoon whereas among suspended hydrophytes *Hydrilla verticillata* was noticed to be the most dominant species during monsoon season. *Vallisneria natans* was observed to be the most dominant among submerged hydrophytes during pre-monsoon. *Alternanthera tenella* was dominant among wetland plants in post-monsoon. *Avicennia officinalis* was the most dominant mangrove in pre-monsoon.

3.3.4 Shannon-Wiener Diversity Index (H')

The result of this investigation revealed that species diversity is a useful parameter for comparing the community structure in different seasons. The seasonal variation in requirements of the diverse growth forms may cause the variation in the species diversity. A significant variation (F=4.14; p=0.018) was observed in the mean diversity of macrophytes during the three different seasons in various sites (Table 3.2). Among 81 species, only 19 species are common in all the three seasons in the study area, and the others are specific to different seasons (Table S3). The highest diversity of macrophytes was recorded during post-monsoon (H'=1.54), represented by 56 species and the lowest during pre-monsoon (H'=1.07) represented by only 43 species. During monsoon, a medium diversity was (H'=1.23) observed with a representation of 49 species. A negative relation was observed between macrophyte density and pre-monsoon season as most of the macrophytes cannot flourish in the dry season due to water scarcity. However, in other seasons, an adequate environment might be prevailed for supporting the growth of most of the species and hence higher diversity observed.

3.3.5 Simpson's Evenness Index; SEI (1-ƛ)

The number of individuals of various species in the assemblage (evenness) is very important for maintaining significant functions and services in the wetland ecosystem. The results of ANOVA and post hoc analysis showed that there is no significant (F= 2.16; p=0.119) variation among the SEI (1-ƛ) in the macrophyte assemblages during different seasons (Table 3.2). Among three seasons post-monsoon showed higher evenness (0.52) in the distribution of macrophytes than pre-monsoon (0.41) and monsoon (0.45). Increase in SEI (1-ƛ) was noted in post-monsoon because of the occurrence of 56 species with an unequal predominance of all taxa, viz. class, order and family of macrophytes. This is due to the flourishing of members of taxonomically closer groups like Rubiales, Gentianales, Polemoniales and Personales; similarly Curvembryae, Microspermae and Coronariae and also many members of Glumaceae in all the three seasons.

3.3.6 The average taxonomic distinctness (AvTD; Δ+)

The average taxonomic distinctness (AvTD; Δ+) of the community of macrophytes in three seasons are provided in Table 3.2. The mean AvTD does not vary significantly (F=0.45; p=0.638) between three different seasons. Higher AvTD represents a widespread distribution of species within species-rich zones. AvTD is responsive to the taxonomic relatedness of species. Here also post-monsoon has higher AvTD (79.77) and pre-monsoon has lower (75.74) AvTD. In the study area, 43 species observed in pre-monsoon under 34 genera and 24 families, while 56 species found in post-monsoon are under 40 genera and 24 families; 49 species under 37 genera and 23 families were established in monsoon. This is because the ecosystem supports the growth of the members of all the species.

3.3.7 Variation in taxonomic distinctness (VarTD; Λ+)

Variation in taxonomic distinctness (VarTD; **Λ+**) of the macrophyte assemblages in different seasons in the study site are listed in Table 3.2. Significant (F= 4.64; p=0.012) variation in VarTD was observed between three different seasons. Lower VarTD was observed in pre-monsoon (177.43) due to the survival of drought-tolerant species. However, in post-monsoon higher VarTD (330.27) was observed because of the occurrence of 56 species with an unequal predominance of all taxa, viz. class, order and family of macrophytes. VarTD has the potential to differentiate the taxonomic structure resulting in assemblages with some genera becoming highly species-rich while a range of other taxa is represented by only one species. In Ponnani *Kole* lands, during post-monsoon, the study area was occupied by genera like *Rotala, Ludwigia*, *Limnophila Utricularia* and *Cyperus* which are highly species-rich and other higher taxa like *Eleocharis*, *Fimbristylis, Fuirena*, *Hygroryza, Hymenachne, Sacciolepis*, *Paspalum* and *Sporobolus* were represented by one species each. Similarly in monsoon *Utricularia* is represented by many species whereas *Cyperus, Schoenoplectiella, Cynodon, Eragrostis, Hygroryza, Leersia*, *Sacciolepis* and *Oryza* are higher taxa represented by one species.

Table 3.2. Diversity indices of macrophytes worked out for different seasons in Ponnani *Kole* wetlands and results of their comparison

Diversity indices	Post-monsoon	Pre-monsoon	Monsoon	F	P
Species Richness (S)	5.43^{b}	3.55^{a}	4.63^{b}	9.19*	0.000
Biomass of Macrophytes (N)	398.73^{a}	337.10^{a}	407.43^{a}	0.86	0.424
Shannon Diversity H'(log_2)	1.54^{b}	1.07^{a}	1.23^{ab}	4.14*	0.018
Simpson's Evenness (1-ƛ)	0.52^{a}	0.41^{a}	0.45^{a}	2.16	0.119
Average Taxonomic Distinctness (AvTD; Δ+)	79.77^{a}	75.74^{a}	78.98^{a}	0.45	0.638
Variation in Taxonomic Distinctness (VarTD, **Λ**+)	330.27^{b}	177.43^{a}	267.59^{ab}	4.64*	0.012

*Significant (P<0.05). Values with the same superscript in a row do not vary significantly (>0.05)

Simulation test to check the deviation of AvTD of macrophyte assemblages in different seasons concerning the global mean using funnel plot showed that the AvTD in pre-monsoon (75.74) is above 95% confidence level of the global mean. Mean AvTD of macrophytes in post-monsoon (79.77) and monsoon (78.98) are very close to the expected value simulated from the whole assemblage (Figure 3.3).

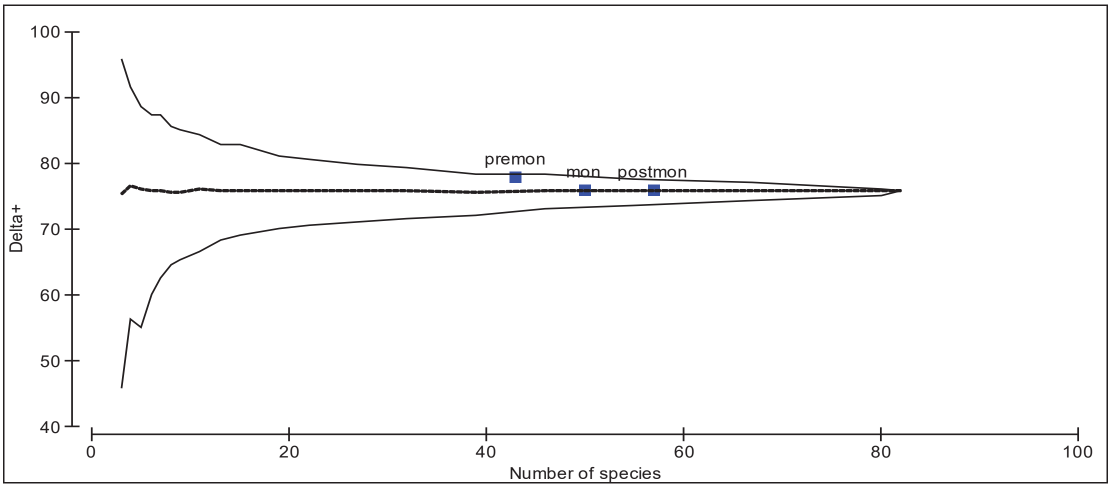

Figure 3.3. Average Taxonomic Distinctness (Δ+) of macrophytes worked out for different seasons in the study area

Funnel plots were developed to configure the ordination of VarTD (Λ+) of macrophyte assemblages in three different seasons to bring out its variability concerning global mean. It clearly showed that VarTD of the assemblages in post-monsoon (330.27), pre-monsoon (177.43) and monsoon (267.59) falls within a 95% confidence limit of the global mean (Figure 3.4). The result also indicates that VarTD was higher than the normal mean in all seasons. This shows an equal dominance of all macrophyte species belonging to various higher taxa viz. class, order, and family in all seasons in the study area.

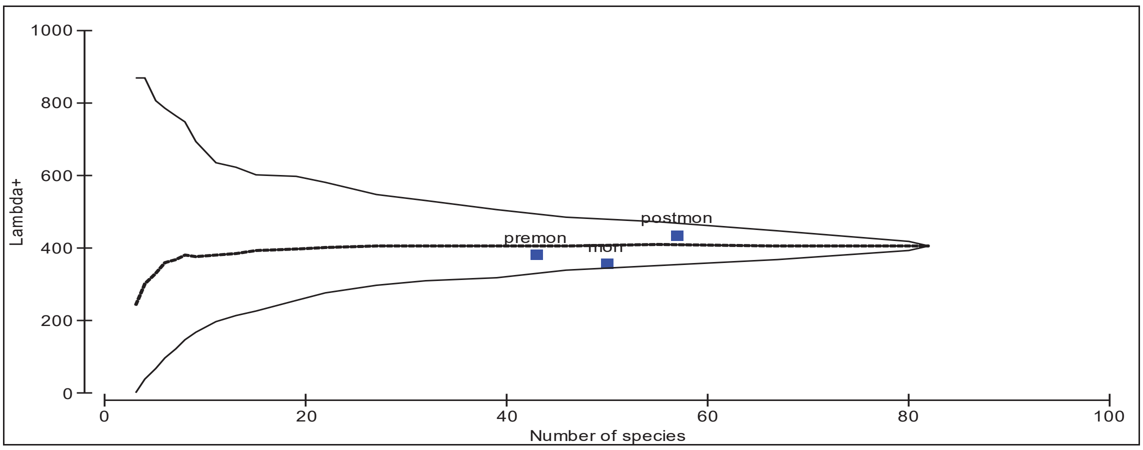

Figure 3.4. Variation in Taxonomic Distinctness (Λ+) of macrophytes worked out for different seasons in the study area.

3.3.8 Distribution of different physiognomic forms of aquatic macrophytes in three different seasons

Table 3.3. Distribution of different physiognomic forms of aquatic macrophytes during three different seasons in the study area

Physiognomic forms	Post-monsoon	Pre-monsoon	Monsoon	F	P
Free floating	94.44^{ab}	19.25^{a}	135.55^{b}	3.69*	0.028
Submerged	8.81^{a}	54.18^{b}	0.21^{a}	6.17*	0.003
Suspended	17.10^{a}	7.01^{a}	18.29 ^{a}	0.74	0.479
Anchored	68.76^{a}	116.75^{a}	132.21^{a}	1.10	0.335
Emergent	81.58^{a}	39.92^{a}	35.08^{a}	1.31	0.275
Wetland plants	102.29^{a}	54.73^{a}	85.17^{a}	1.67	0.193
Mangrove and associates	25.70^{ab}	45.22^{b}	0.94^{a}	2.34	0.101

*Significant (P<0.05). Values with the same superscript in a row do not vary significantly (>0.05)

The results of ANOVA and post hoc analysis (Table 3.3) showed significant ($p<0.05$) variation in the free-floating ($F= 3.69$; $p=0.028$) and submerged ($F=6.17$; $p=0.003$) macrophyte community assemblage during different seasons. In free-floating forms mean deviation was observed higher in monsoon (135.55) and lower in pre-monsoon (19.25). This may be due to the flushing of free-floating forms like *Eichhornia crassipes* and *Salvinia adnata* from nearby water resources. Mean deviation for submerged forms was observed higher in pre-monsoon (54.18) and lower in monsoon (0.21). *Vallisneria natans, Najas graminea* were more abundant in pre-monsoon whereas *Najas indica* and *Eriocaulon setaceum* were more in post-monsoon. The occurrence of submerged forms in monsoon was negligible. This may be due to the obstruction of available light by the augmentation of free-floating forms above the submerged ones. All other physiognomic forms like suspended, anchored, emergent, wetland and mangrove were not showing significant variation seasonally. In suspended forms mean deviation was observed higher in monsoon (18.29) and lower in pre-monsoon (7.01); similarly in anchored forms also higher mean deviation was observed in monsoon (132.21) and lower in post-monsoon (68.76). However, a higher deviation was observed in post-monsoon (81.58) and lower in monsoon (35.08) in emergent forms. Wetland plants have a higher mean deviation in their assemblage pattern in post-monsoon (102.29) and lower in pre-monsoon (54.73) during the study period whereas mangrove and associates show higher deviation during pre-monsoon (45.22) and lower in monsoon (0.94).

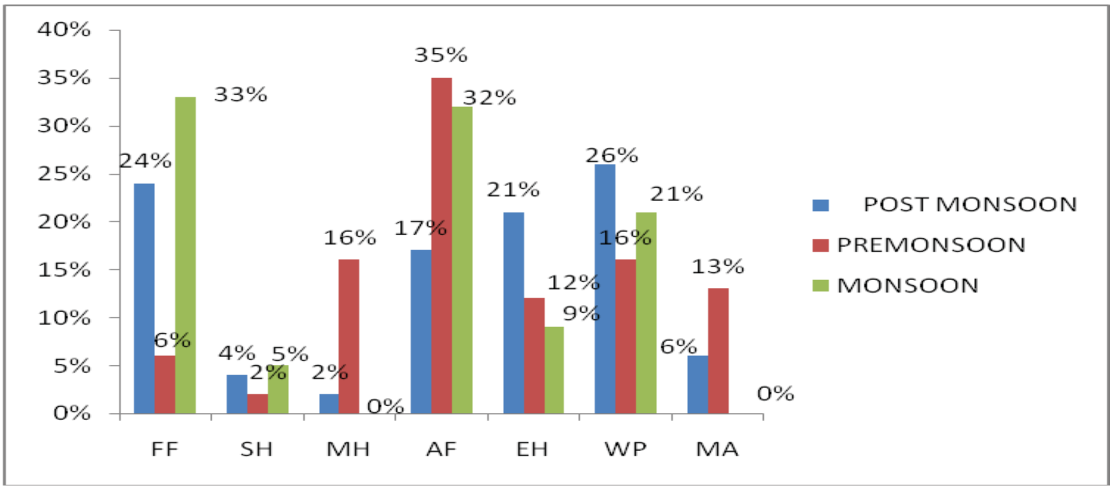

Figure 3.5 Percentage occurrences of Macrophytes of different physiognomic forms during various seasons in the study area**.**

Habit: FF-Free floating; SH-Suspended hydrophytes; MH-Submerged hydrophytes; AF-Anchored floating; EH-Emergent hydrophytes; WP-Wetland plants; MA-Mangrove and associates

Seasonal variation in the percentage of occurrence of different physiognomic forms is presented in Figure 3.5). In pre-monsoon, the dominant macrophytes include anchored floating forms like *Nymphaea pubescence, Nelumbo nucifera, Nymphoides indica, Ipomoea aquatica, Bacopa monnieri, Aponogeton natans* and *Marsilea quadrifolia* constituted about 35% of the total biomass. In the monsoon free-floating forms (33%) like *Eichhornia crassipes, Hygroryza aristata, Salvinia adnata* and *Azolla pinnata* and anchored floating forms (32%) like *Nymphaea nouchali, N. pubescence, Nymphoides crystata, N. indica, Ipomoea aquatica, Bacopa monnieri Marsilea* and *quadrifolia* were dominated. In post-monsoon, wetland plants (26%) and free floating forms (24%) were the dominant groups. *Aeschynomene indica, Rotala indica, R. macrandra, Ludwigia hyssopifolia, L. perennis, Centella asiatica, Oldenlandia corymbosa, Sphaeranthus africanus, Limnophila repens, Lindernia antipoda, Hygrophila ringens, H. auriculata, Alternanthera tenella, Persicaria* *pulchra, P. glabra, Cyperus difformis, C. haspan, C. dubius, Fuirena ciliaris, Hymenachne amplexicaulis, Oryza rufipogon* and *O. sativa* were wetland plants observed in post-monsoon whereas *Eichhornia crassipes, Lemna perpusilla, Hygroryza aristata, Salvinia adnata* and *Azolla pinnata* were the free floating forms present in post-monsoon. During monsoon season submerged macrophytes and mangrove associates were absent in the study area.

3.4 DISCUSSION

The year-round occurrence of the genera indicates their ability to adapt to diverse conditions. Higher abundance of *Eichhornia crassipes*, the free-floating macrophyte observed during the monsoon season may be due to ingression through the inflowing water from nearby rivers into the *Kole* land. Its current dominance may be endorsed to its invasive nature and also to its inclination for eutrophication during monsoon, similar to Oxbow Lake ecosystem in Ganga River Basin (Ghosh and Biswas, 2015). Ricciardi (2001) reported that some invaders could alter habitat conditions in favour of other invaders, creating a positive feedback system and leading to an accumulation of other non-indigenous/introduced species. This is true with our *Kole* land ecosystem where positive facilitative interactions between *A. philoxeroides* and other invasives like *Eichhornia crassipes* (Wundrow *et al.*, 2012) have also been observed. The year-round growth of the *Hydrilla* indicates its ability to adapt to various conditions (Ida and Kensa, 2016). Suspended hydrophytes provide erosion stabilisation (Gurnell *et al.*, 2006), water retention, facilitate nutrient cycling, and habitat to associated faunal communities (de Groot *et al.*, 2002; Duarte 2000).

Rai and Sharma (1991) reported the seasonal changes of macrophyte communities in tropical wetland ecosystems. In seasonally flooded areas during pre-monsoon water dried and substrate get exposed, allowing the germination of buried seeds of perennial emergent plants. After the onset of monsoon, with the rise in water level, the mud-flat species vanished leaving only the emergent ones (Jha, 2004). This is true in the case of emergent forms like *Alternanthera philoxeroides*, *Schoenoplectiella articulata* and *Sacciolepis interupta*. The submerged species quickly reappeared due to the germination of seeds in the standing water. Submerged aquatic vegetation is an important component in the ecosystem of coastal estuarine and inland waters (Orth and Moore, 1983) by providing food and shelter for fish, shellfish and invertebrates and produce oxygen. According to Clayton and Edwards (2006), submerged aquatic plants are environmental indicators of ecological condition in New Zealand lakes. During the growing season, submerged aquatic vegetation retains nitrogen and phosphorous removing excess nutrients and preventing the growth of algae in the water (Deepa, 2015). In our study area *Vallisneria natans* and *Najas graminea* have maximum biomass in pre-monsoon where as in post-monsoon *N. indica* and *Eriocaulon setaceum* have maximum biomass. The emergent plants increase in density and become dominant during the monsoon; however, with the decrease of water level in post-monsoon this community becomes senescent (Jha, 2004). This is true with the abundance of *Ludwigia adscendens, Alternanthera philoxeroides, Schoenoplectiella articulata* and *Sacciolepis interupta* in our study site. During post-monsoon season emergent plants have maximum biomass, but at the arrival of pre-monsoon, there will be a break in shoot growth, fuelled by photosynthesis and translocation of carbohydrates and other nutrients stored in their rhizomes (Bernard, 1998). This is true with *Alternanthera philoxeroides*, fast-growing plant in this wetland ecosystem generally poses troubles in paddy fields and chokes irrigation canals.

A. philoxeroides is regarded as one of the worst weeds of the world because of its invasive nature, fast spreading ability, high tolerance to environmental fluctuations and a wide range of adaptive potential (Chatterjee and Dewanji, 2012) and has unfavourable economic and ecological impacts. *A. philoxeroides* causing a serious threat to native plant diversity (Julien *et al*., 1995) by limiting the growth of other allied species in its close vicinity. JinCheng and Qiang (2006) reported a decrease in the species composition and diversity of the community with mounting dominance of *A. philoxeroides*. The same situation is present in the study areas of Ponnani *Kole* lands where a strong competitive interaction between native vegetation and *A. philoxeroides* is observed. Keller *et al*. (2018) observed the troublesome made by *A. philoxeroides* in Wular Lake leading to declining in human welfare.

The variation in the biomass of macrophytes along the hydrological phases occurred differentially between the wetland systems. According to Maltchik *et al*. (2007), biomass was lower in flooded periods and was higher in the period even without the surface water (Schott *et al.*, 2005). According to Neiff (1975) maximum biomass of some macrophyte species occurred over the flood period, other species showed high biomass values at low water level. Higher biomass in the flooded period was observed for some species like *Ipomoea aquatica, Hygrophila ringens, Alternanthera philoxeroides, Hydrilla verticillata* and *Eichhornia crassipes*, *Salvinia adnata* in our study area. Similarly, *Nymphaea nouchali, Nymphoides indica, Bacopa monnieri* and *Vallisneria natans,* showed higher biomass at low water level. According to Pettit *et al*. (2012), aquatic macrophyte biomass was highest at the beginning of the dry season and declined as the dry season progressed. This is agreed with *Nymphaea pubescence*, *Limnophila aquatica, Lindernia antipoda, Alternanthera tenella, Monochoria hastata*, *Najas indica* and *Sporobolus virginicus* in our study site. Remaining macrophytes like *Azolla pinnata* and *Rotala macrandra* were flushed out by the first wet-season flows, although they were quickly re-established later during the wet season.

Maltchik *et al*. (2007) noticed the biomass peak of free-floating plant *Eichhornia azurea* during the flood phase and the biomass peak of *Eleocharis interstincta* during the drawdown phase. This is agreed with the free-floating species like *Eichhornia crassipes* and *Salvinia adnata* in the area of study. Ghosh and Biswas (2015) reported the lowest diversity indices during monsoon as compared to the other two seasons of the year including the community as a whole in the oxbow lake. This is true with Ponnani *Kole* lands, where lowest diversity indices were observed during monsoon and pre-monsoon compared to post-monsoon of the year for all growth forms.

Similarly, maximum diversity was found during post-monsoon (H'=1.54), and this may be due to the synchronised development of different species and variation in species composition. The abundant growth of various macrophytes in post-monsoon may be attributed to the availability of water along with nutrient leach from sediments of wetland and favourable environmental conditions. During the pre-monsoon, diversity of macrophytes was found to decrease (H'=1.07), represented by only 43 species. This may be due to the scarcity of water, depletion of nutrients, entry of saline water, rise in atmospheric and water temperature. The decrease in diversity in pre-monsoon may also be due to the loss of different growth forms except for wetland plants and mangrove associates as a result of the decrease in water level. The comparable diversity in all the three seasons indicates the stable and balanced nature of the habitat.

The evenness index provides information on the species distribution and indicates whether the high diversity of plant community is due to the presence of many species with different abundance or due to the smaller number of species with a more homogeneous distribution (Chrisoula *et al*., 2011). This is true in our case due to the similar distribution and equal contribution of species in this ecosystem with, 56 species under 40 genera and 24 families in post-monsoon, 43 species under 34 genera and 24 families in pre-monsoon and 49 genera under 37 species and 23 families in monsoon. Maximum diversity and uniform distribution of species in the assemblages were found during the post-monsoon season as it is the active growth period of macrophytes. Similarly, the Simpson evenness index shows even distribution of macrophytes in post-monsoon (0.52) (Table 3.2). This is true with the wetlands in Cooch Behar District, West Bengal (Goswami *et al*., 2010). Ponnani *Kole* lands provide a good habitat for many aquatic macrophytes which are an inevitable part of this sole ecosystem. Environmental factors including the water chemistry, nutrient status and absence of the natural enemy can control the excess growth of these macrophytes (Wassen *et al*., 2002; Rickey and Anderson, 2004). The balanced incidence of many species provides efficient ecosystem services and high carrying capacity.

AvTD is sensitive to the taxonomic relatedness of species. Both species richness and taxonomic extent are significant attributes of biodiversity that should be given equal weight for monitoring and maintenance of the ecosystem. This indicates that uniform distribution of species exists in all the three seasons in the study site. According to Leonard *et al*. (2006), the benefit of taxonomic distinctness is the unevenness in biodiversity due to environmental factors falling within a predictable range, based on the probability of random selection from a local pool.

VarTD reveals the differences in the taxonomic structure of different assemblages when some of the genera become highly species-rich while a range of other taxa is represented only by one species (Clarke and Warwick, 2001a). This is true in our study area where the genera like *Ludwigia*, *Limnophila* and *Utricularia* occurred with high species richness while other higher taxa like *Eriocaulon, Eleocharis*, *Fimbristylis, Fuirena, Hygroryza, Paspalum, Hymenachne, Sacciolepis* and *Sporobolus* were represented only by one species in post-monsoon.

Submersed aquatic macrophyte communities, may often be limited by the availability of light, due to shading and dwindling by water (Spence, 1972; 1975). Thus, they offer a valuable opportunity to appraise competition across a light gradient along with free-floating hydrophytes. The results reported here are from competition performed in monsoon across a gradient of light availability by free-floating and submerged growth forms. Shade due to the canopy of free-floating forms like *Eichhornia* and *Salvinia* appears to reduce light levels below the submerged and suspended forms during monsoon season. Other competition studies with submerged aquatic plants have concerned shading as an important mechanism determining the upshot of competitive interactions (Spencer and Ksander, 2000; Barrat-Segretain, 2004). Herb and Stefan (2006) studied the competitive interaction between different species of aquatic macrophytes and found that invasive species can hold back the growth of native ones over a wide range of environmental conditions. This is agreed with the over dominance of invasive species like *Ipomoea carnea*, *Alternanthera philoxeroides*, *Eichhornia crassipes* and *Salvinia adnata* in the study area.

Wetland plants were more frequent in post-monsoon, however, anchored floating plants in pre-monsoon and free-floating and anchored floating in monsoon. A difference in vegetation patterns in response to different ecological conditions in monsoon was conducive for the plant species to grow and propagate and they exhibit seasonal boom of plant biomass. The entire biomass dies during the post-monsoon due to the unfavourable ambience and decomposition that enrich the soil and water of wetlands. Rai (1980) reported that in wetlands of north Bihar in India, the percentage of occurrence of anchored floating species attains the highest value in monsoon and lowest in post-monsoon, whereas the submerged species have the highest frequency in post-monsoon and lowest in monsoon. The occurrence of free-floating forms maximum in monsoon and minimum in pre-monsoon; suspended hydrophytes present in the almost same frequency in post-monsoon and monsoon but minimum in pre-monsoon; submerged hydrophytes are maximum in pre-monsoon and absent in monsoon. This may be due to the development of free-floating and anchored floating forms over the submerged ones in monsoon preventing the availability of light for their survival;

anchored floating forms flourish well in both monsoon and pre-monsoon; emergent forms and wetland plants show maximum occurrence in post-monsoon but emergent forms are minimum in monsoon and wet landforms in pre-monsoon. Mangrove and associates observed maximum in pre-monsoon and absent in monsoon due to the decrease in salinity of water in monsoon.

3.5 CONCLUSION

Detailed knowledge about the floristic composition, ecology and seasonal factors that influence types of vegetation, offer a strong base for research and helps in the improvement of conservation and management practices in relation to vegetation and biodiversity of wetland ecosystems. So by this study, we can underscore the detail changes of macrophytes composition in a seasonal frame and also we can correlate these studies in depicting the pollution status of a water body. Prevention of eradicating vegetation and protection of biological diversity and veracity are necessary activities to maintain and improve the resilience of wetland ecosystems so that they provide valuable services under changing climatic conditions (Kusler *et al*., 1999). The greatest threat to aquatic ecosystems arises from the cultivation in surrounding land and lack of knowledge on the significance of wetland ecosystems among the local population. Sustainable wetland utilisation can be achieved through empowering local communities as primary users and preservers by providing technical support which can be accomplished through the support of government agencies. Wetland ecosystem functions provide goods and services to society and the benefits resulting from wetlands can be cherished with different qualitative and quantitative appraisal methods. Decision supporting tools should be developed for strategy makers that can assist exploration of land-use and disturbance scenarios along with tools that can assess multiple ecosystem services such as biodiversity, food security, water resources, and trade-offs between these services.

Chapter- 4

PATTERNS OF VEGETATION DYNAMICS ACROSS MILD DISTURBANCE GRADIENT IN PONNANI *KOLE* WETLAND ECOSYSTEM

ABSTRACT

The chapter describes the community assemblage pattern of macrophytes and their variations within and among areas affected by environmental disturbances in Ponnani *Kole* wetland system. The macrophyte community structures in the study site were characterised with reference to areas of saline intrusion, intense agricultural activities and sewage disposal. *Sphaeranthus africanus* and *Colocasia esculenta* were specific to sewage; *Rotala indica*, *Oldenlandia corymbosa*, *Limnophila heterophylla* and *Eriocaulon setaceum* were specific to agriculture; while *Acanthus ilicifolius* and *Cyperus dubius* were specific to areas of saline intrusion. Mean diversity did not vary significantly among the different zones of disturbance except saline intruded areas. Taxonomically, similar species flourished well in all regions of the study except in the saline intrusion area. In undisturbed areas, considered as control, the occurrence of all macrophytes was observed in equal proportions with the exception of mangroves and suspended hydrophytes. However, in sewage disposal areas, the occurrence of 44 species was observed with an unequal predominance of all taxa, viz. class, order and family of macrophytes. The execution of assessment supporting tools to aid strategy and policymakers to investigate land-use options and disturbance scenarios along with ecological mechanisms assessing multiple ecosystem services will see Ponnani *Kole* wetland become established as a macrophyte dominated ecological regime which can be further developed as a conservation and educational site for tropical aquatic macrophytes.

4.1 INTRODUCTION

Kole wetlands are vital ecosystems which provide agricultural produce, fish, fuel, fibre, fodder, and a host of other day-to-day necessities for thousands of inhabitants in its vicinity. Wetlands are also defined as important repositories of aquatic biodiversity in general and particular for algal flora, macrophytic flora, avianfauna and ichthyofauna. Benefits of wetlands are categorised into provisioning (agricultural produce), regulating (biogeochemical cycles and micro-climatic conditions), supporting (soil formation and biodiversity) and cultural (aesthetics, recreational and spiritual activities) services (MEA, 2005). These services ensue from the intact ecosystem functions and depend largely upon the complex biodiversity of this ecosystem. Macrophyte dominated wetlands are highly valued for bird watching, boating and other leisurely activities (Weller and Spatcher, 1965). The fabulous potential of this wetland ecosystem for securing aquatic biodiversity, improving moisture regimes, replenishing aquifers and emergent eco-tourism sites has remained abhorrently under-tapped and demands immediate attention.

Aquatic macrophytes play an important role in freshwaters by promoting a clear water state through reduced nutrient availability thus reducing competition with algae, stabilisation of bottom sediments, and enhancing biodiversity by offering shelter and substrate, and providing food for herbivorous waterfowl (Engelhardt and Ritchie, 2002). Aquatic macrophytes in tropical regions constitute the largest single form of biomass on freshwater ecosystems (Chandra and Kulshreshtha, 2004). Despite this, when growing in suitable habitats, several species such as *Ipomoea carnea, Salvinia molesta* and *Eichhornia crassipes* are considered aquatic weeds due to their rapid colonisation and adverse effects upon aquatic diversity and ecosystem functioning (Camargo *et al*., 2003). The function of macrophytes in these ecosystems is related to their structural attributes like species composition, distribution, abundance and diversity which, in turn, depend on substrate composition, disturbance, competitive interactions and quality of water and sediment nutrients (Cronk and Fennessey, 2001; Wetzel, 2001; Capers, 2003; Pankhurst, 2005; Feldmann, 2012; Tamire and Mengistou, 2012). The role of certain macrophytes like *Eichhornia crassipes* and *Alternanthera philoxeroides* has also been demonstrated to be vital in the removal of heavy metals such as Copper (Cu^{2+}), Cadmium (Cd^{2+}), Nickel (Ni^{2+}), Lead (Pb^{2+}) and Zinc (Zn^{2+}) within wetland systems (Southichak *et al*., 2006). This chapter describes the baseline community assemblage pattern of macrophytes and their variation within and among areas of environmental disturbance in Ponnani *Kole* land ecosystem. Strict conservation and management actions should be implemented to control human-led activities in this *Kole* wetland ensuring sustainable development and utilisation. To secure long term conservation objectives, the initial step is to assess the baseline diversity of natural resources in the study area and to identify potential factors which could cause a decline in habitat quality and species population. It is anticipated that the research findings will provide an insight for the development of a site-specific and appropriate conservation policy for the aquatic macrophytes of this subtle ecosystem and also for the creation of an ideal *in situ* conservation and educational location for tropical aquatic macrophytes.

4.2 MATERIALS AND METHODS

4.2.1 Site Description

Nine stations were selected with different disturbances regimes: two saline intrusion sites (**Porangue and Cheerppu)**, three stations in the areas of agricultural activity (**Kalachal, Uppungalkadav, Muchikadavu)** and two stations (**Kummipalam, Thuyyam)** in sewage disposal regions representing anthropogenic disturbance and two undisturbed sites (**Naranipuzha, Mukolamtazhath)** selected as control stations (Figure 4.1 and Table 4.1). A detailed description of these sites is provided in Chapter 1, General introduction; Section 1.5.3.

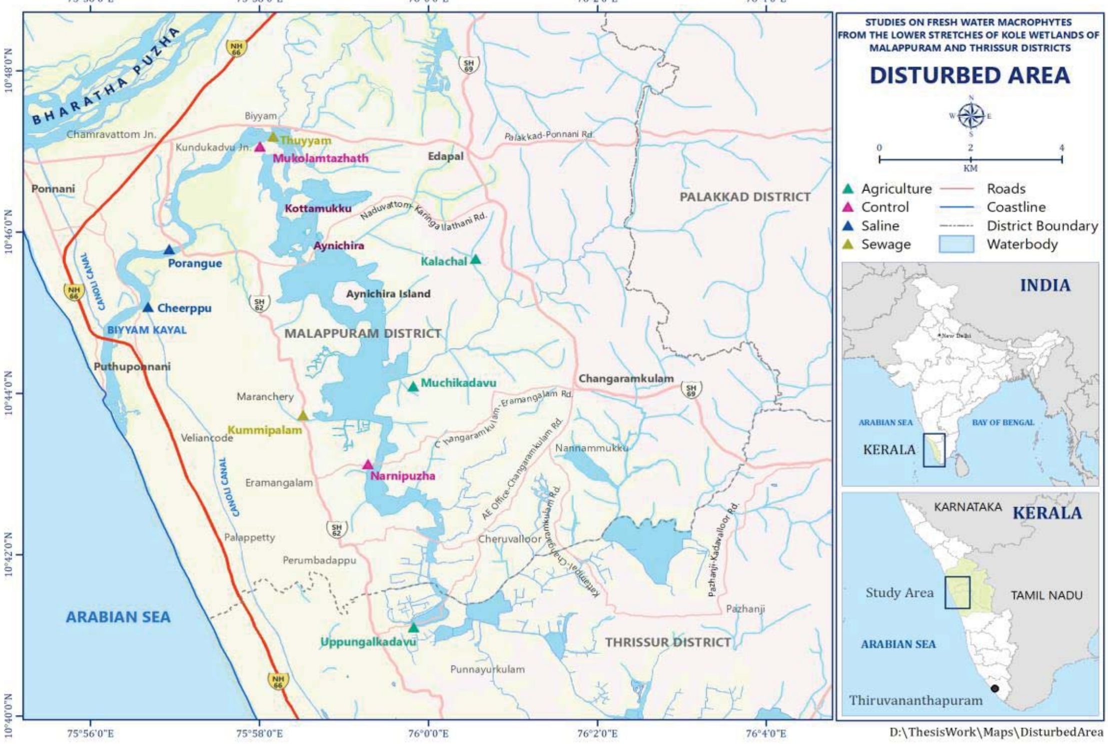

Figure 4.1 Location of the nine study stations selected for the study in the Ponnani *Kole* wetland.

Table 4.1 Geographic positions of the stations, in the Ponnani *Kole* wetland, selected for the study.

Stations	Zones	Average Depth (mm) (Table S7)
Porangue	Saline	266.7
Cheerppu	Saline	34.04
Kalachal	Agriculture	442.1
Uppungalkadav	Agriculture	485.8
Muchikadavu	Agriculture	697.5
Kummipalam	Sewage	320.8
Thuyyam	Sewage	663.3
Naranipuzha	Control	590.8
Mukolamtazhath	Control	851.3

a. Area of saline intrusion

The stations in the area of saline intrusion are located where coir retting was practised (Areas for retting are almost devoid of higher aquatic life because of anoxic condition). The area was dominated by salt-tolerant plants (*Avicennia officinalis, Clerodendrum inerme Acanthus ilicifolius*, *Ipomoea pes-caprae* and *Cyperus dubius*). During monsoon, floating macrophytes like *Eichhornia, Pistia* and *Salvinia* are flushed to this area by water currents.

b. Area of agricultural activities

Rice cultivation is practised in this area whereby earthen bunds and dams are constructed to improve agricultural crop yields. Reclamation activities using unauthorised encroachment of wetland areas for constructing housing and buildings have started on one side of the paddy fields. During periods of flooding typical suspended, submerged and anchored floating hydrophytes were present but during pre-monsoon wetland plants alone were noticed. Cattle grazing and duck farming were also taking place at these stations. Infrastructure development in the form of roads and other lines of communication fragmented the contiguity of the wetland. This *Kole* land is also an attractive site for many wetland birds as it supports good nesting habitats with aquatic and marginal flora. Migratory birds visit the stations in post-monsoon times and use this aquatic ecosystem as a stop-over or transit area because of easy food availability. *Salvinia adnata, Ludwigia adscendens, Nymphaea pubescens, Azolla pinnata* and *Nymphaea nouchali* were abundant in agricultural fields. Three stations were selected in agricultural areas to cover the larger extent of agriculture fields in the study site.

c. Area of sewage disposal activities

An area with domestic sewage disposal and water contaminated with oil discharge from vehicles were noticed. *Eichhornia, Pistia* and *Salvinia* were the characteristic plants of this region. This may be due to the leaching of nutrients from the disposed sewage, which is diluted to a level of low impact. The bank of the water body is contaminated with solid wastes such as disposed of utensils and containers, rags and domestic refuse.

d. Control Site

A typical wetland ecosystem having different species of macrophytes is selected as control sites. Suspended hydrophytes like *Utricularia* and *Hydrilla,* similarly anchored floating like *Nymphoides* were very common in this area. The area is devoid of any Anthropogenic activities and saline intrusion. Water in this area is clear and having a good number of fishes and other organisms. The area is a spot for fishing and collection of freshwater mussels. People were commonly using this area for drawing water for domestic purpose.

4.2.2 Vegetation Surveys

Vegetation surveys were conducted at nine study stations over two years, covering three different seasons pre-monsoon, monsoon and post-monsoon for three different disturbance zones and control as described in Chapter 1; section 1.5.4.2. A total of 216 samples were collected in which 48 samples each from areas of control, saline intrusion and sewage disposal and 72 samples from the area of agriculture activity. Biomass of each species from various samples with respect to control and different disturbance zones were worked out to determine relative abundance (as dry mass per square meter (gm. M^{-2}) and diversity indices. Furthermore, all the identified macrophytes were categorised into seven physiognomic forms as described in Chapter 1; section 1.5.4.2.

4.2.3 Diversity Measurements & Statistical Analyses

To provide information on the community structure of the study area the diversity indices, viz. Species number (S), Abundance (M), Shannon-Wiener Diversity Index (SDI - H') and Simpson's Evenness Index (SEI - 1-λ) were calculated from the biomass of each species collected from stations and Average Taxonomic Distinctness (AvTD - Δ+) and Variation in Taxonomic Distinctness (VarTD - Λ+) from the presence or absence data using Primer 6.0 software (Clarke and Warwick 1998). Preliminary analysis of biomass of macrophytes data showed no significant variation in the macrophyte community composition within the different disturbance zones; hence the data were pooled per disturbance zone. Differences between the mean diversity indices recorded from areas of three disturbances and control were compared using ANOVA's with Duncan's multiple range post-hoc analysis (Snedecor and Cochran, 1969) in the statistical package SPSS 17.0. The k-dominance plot and funnel plots were constructed as described in chapter 1.5.5. To examine spatial patterns in macrophyte assemblages in four different zones the Bray-Curtis dissimilarity metrics of biomass was evaluated using non-metric multidimensional scaling (NMDS) as described in Chapter 1; section 1.5.5 for representing their similarity/dissimilarity in assemblage pattern (Clarke 1993).

4.3 RESULTS

4.3.1 Distribution pattern of macrophytes in different zones of disturbance

Community structure of aquatic macrophytes in different regions of mild disturbances in Ponnani *Kole* wetlands showed significant variation (Table 4.2). Seventy-six species of aquatic macrophytes from 51 genera and 29 families were recorded from the study area. *Sphaeranthus africanus* and *Colocasia esculenta* were specific to the sewage zones; *Aeschynomene indica, Myriophyllum oliganthum, Rotala indica, R. malampuzhensis*, *Centella asiatica, Oldenlandia corymbosa, Limnophila heterophylla, L. indica, L. repens, Aponogeton natans, Najas graminea, N.indica, Eriocaulon setaceum* and *Oryza rufipogon* were specific to the intensive agriculture areas; while *Ipomoea pes-caprae, Acanthus ilicifolius, Avicennia officinalis, Clerodendrum inerme* and *Cyperus dubius* were specific to saline area. *Nymphoides indica, Merremia tridentata, Utricularia reticulata, Alternanthera philoxeroides, Schoenoplectiella articulata*, *Schoenoplectiella supina*, *Cynodon dactylon, Monochoria hastata* and *Leersia hexandra* showed wider ecological tolerances and were observed in all the study zones.

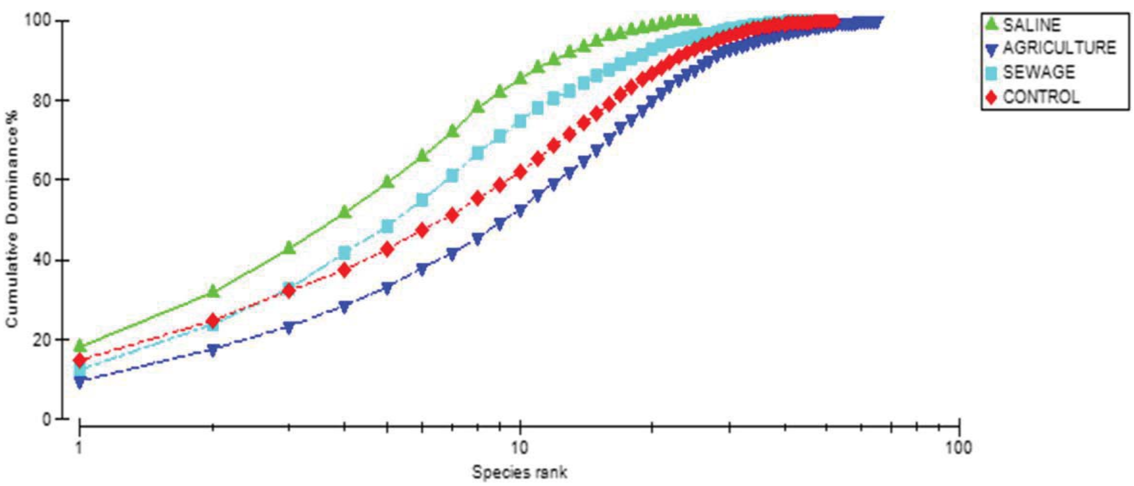

Figure 4. 2: Dominance plot of the macrophytes recorded from different disturbance zones of Ponnani *Kole* wetland

The K-dominance plot clearly shows the diversity pattern in the four different zones where percentage cumulative dominance values are plotted against log species rank (Platt *et al.*, 1984). The curve for the saline zone rises rapidly and lies above the curves of sewage, control and agriculture zones because only a few species were recorded from this zone (Figure 4.2). The upper most curve representing macrophytes of saline zone corresponded to least diversity and dominated by only a few species. However, the curves representing agriculture fields, sewage and control zones lie on the lower side, extending further and rising slowly because of the occurrence of a large number of species with the dominance of many species (Figure 4.2).

4.3.2 Variation in diversity indices of macrophytes composition in different disturbances

Various diversity indices, Species Richness (S), Biomass (N), Shannon Diversity Index (SDI,H'), Simpsons Evenness Index (SEI, 1-λ), Average Taxonomic Distinctiveness (AvTD, Δ+) and Variation in Taxonomic Distinctiveness (VarTD, Δ), worked from the basic data collected from different zones are presented in the Table 4.2 and Table S5.

Table 4.2. Diversity indices of aquatic macrophytes and results of ANOVA and post-hoc analysis for different study zones within Ponnani *Kole* wetlands

DIVERSITY INDICES	SALINE	AGRICULTURE	SEWAGE	CONTROL	F	P
Species Richness (S)	1.67^{a}	4.90^{b}	4.13^{b}	4.27^{b}	25.35	0.000
Biomass (M)	627.98^{c}	269.57^{a}	472.21^{b}	405.96^{b}	10.08	0.000
Shannon Diversity Index (H'(log_2))	0.378^{a}	1.295^{b}	1.114^{b}	1.214^{b}	17.61	0.000
Simpson's evenness index (1-λ)	0.160^{a}	0.462^{b}	0.412^{b}	0.435^{b}	15.36	0.000
Average taxonomic distinctiveness (AvTD; Δ+)	30.77^{a}	76.51^{b}	73.74^{b}	74.51^{b}	33.36	0.000
Variation in taxonomic distinctness (VarTD, Λ+)	40.24^{a}	246.04^{b}	379.40^{c}	193.43^{b}	19.83	0.000

Values with the same superscript in a row do not vary significantly

4.3.3 Number of Species (S)

Macrophyte species composition showed significant variation ($P<0.05$) in different areas in Ponnani *Kole* lands. A higher number of species of macrophytes were observed in the areas of agricultural activities (64), and sewage disposal (44); however, area of saline intrusion (25) and undisturbed area (control; 39) showed a lower number of species. The result of ANOVA and post hoc analysis showed that there is no significant ($p>0.05$) variation in the number of species in the macrophyte assemblage in control, sewage and agriculture areas, however a significant variation ($p<0.05$) could be observed between the area of saline intrusion and other disturbances. No significant variation ($p=0.068$) (Table S6) was observed in the macrophyte species richness between the control (4.27), sewage disposal (4.13) and intensive agricultural areas (4.90). However, a significant variation ($F=25.35$ $p=0.000$) in macrophyte species richness was observed between the area of saline intrusion (1.67) and the other three study zones. Higher species richness in the zones of agricultural activity and sewage disposal is a consequence of the development of species that are not typical for that specific ecosystem. Wetland species like *Cyperus difformis, Cyperus haspan, Cynodon dactylon, Eragrostis atrovirens, Eragrostis gangetica, Hymenachne amplexicaulis , Leersia hexandra, Oryza rufipogon, Oryza sativa* with a wide ecological scale were observed in these regions. Hence provisions for periodical clearing and regeneration as well as higher nutrient inputs may be the cause of species-rich assemblage in areas of agricultural activity and sewage disposal. With respect to species composition, the cultivated field system was different from other systems. The dynamics of species composition were closely related to the cultivation practices which form two distinct ecological conditions, the off-season and cultivation period.

4.3.4 Biomass of Macrophytes (N)

The highest biomass of macrophytes was recorded in the area of saline intrusion with a mean value of 627.98 g.m^{2,} and the lowest value (269.57 g.m^{2}) was observed in the agricultural area. This is because salt tolerant species observed in the saline area are large shrubs with pneumatophores whereas plants in the agricultural fields are small herbaceous ones. Field cleaning before farming, growth of saplings and the competition among the species reduced the biomass of plants in the agricultural field. Biomass of aquatic macrophytes was higher in sewage discarding area with a mean value (472.21 g.m^2) when compared to the undisturbed area (405.96 g.m^2). This is due to the overgrowth of certain species viz. *Salvinia adnata, Pistia stratiotes, Eichhornia crassipes, Vallisneria natans, Persicaria pulchra , Ipomoea carnea* and *I. aquatica*. Oversize of *Pistia stratiotes* and *Eichhornia crassipes* were also observed from this area.

4.3.5 Shannon-Wiener Diversity Index (H')

In Ponnani *Kole* wetlands, the agricultural area (H'=1.295) showed the highest SDI whereas lower SDI was observed in saline areas (H'=0.378) (Table 4.2). In the control area (H'=1.214) and sewage disposal (H'=1.114) area, higher SDI was observed which infer the occurrence of optimal environmental conditions supporting the growth of many macrophyte species. Mean SDI showed no significant variation (p=0.228) between the intensive agriculture, sewage disposal and control areas indicating a uniform macrophyte assemblage (Table S6). However, mean SDI was significantly lower (F = 17.61; p=0.000) in the saline intrusion areas when compared to the other three study areas (Table 4.2).

A strong negative relationship was observed between macrophyte diversity and salinity as most of the macrophytes cannot thrive in the regions of saline intrusion due to narrow salt tolerance. However, in other regions tolerable environment might be prevailed for supporting the growth of most of the species and hence higher diversity observed. Among 76 species, 26 species are common in the study area, and others are specific to the habitats with environmental disturbances. *Sphaeranthus africanus* and *Colocasia esculenta* are specific to sewage area, *Aeschynomene indica, Myriophyllum oliganthum, Rotala indica, Rotala malampuzhensis*, *Centella asiatica, Oldenlandia corymbosa, Limnophila heterophylla, L indica, L repens, Aponogeton natans, Najas graminea, Najas indica, Eriocaulon setaceum* and *Oryza rufipogon* are specific to agriculture area. Similarly saline tolerant species *Ipomoea pes-caprae, Acanthus ilicifolius, Clerodendrum inerme, Cyperus dubius* are specific to saline area in the study site. However, mean diversity was not varying significantly (P>0.05) in study area except salinity intruded area.

4.3.6 Simpson's Evenness (1-λ)

Simpson's evenness (1-λ) of species assemblage of macrophytes recorded from different regions of disturbances of the study area showed variation similar to Shannon diversity index (Table. 4.2). Higher evenness was observed in the control and agricultural zones and lower in the areas of saline intrusion. Simpson's evenness index (SEI, 1-λ) was high in the control (0.44), intensive agricultural (0.46) and sewage disposal zones (0.41) compared to the areas of saline intrusion (0.16) (Table 4.2). The results of ANOVA and post hoc analysis showed that there are no significant ($p>0.05$) variation among the evenness in the macrophyte assemblages in control, sewage and agriculture areas, however, a significant variation ($p<0.05$) could be noticed between these regions and the areas of saline intrusion. An even distribution of macrophytes in control, intensive agricultural and sewage disposal areas and dominance of specific saline tolerant species in saline intrusion zones were observed. Similar to SDI no significant variation was observed in SEI between the control, sewage disposal and intensive agriculture areas ($p=0.353$) (Table S6). However, mean SEI was significantly lower in the saline (0.160) intrusion areas when compared to the other three study areas ($F=15.36$; $p=0.000$) (Table 4.2). The results showed an even distribution of macrophytes in undisturbed ($F=0.435$) and agricultural areas ($F=0.462$) and dominance of specific saline tolerant species like *Acanthus ilicifolius, Ipomoea pes-caprae, Clerodendrum inerme, Avicennia officinalis* and *Cyperus dubius* in saline area. The number of individuals of various species in the assemblage (evenness) is very important for maintaining significant functions and services in the wetland ecosystem.

4.3.7 Average Taxonomic Distinctness (Δ+)

The mean values of average taxonomic distinctness (AvTD; Δ+) of the community of macrophytes in different regions of disturbances are shown in Table 4.2. Significantly ($p<0.05$) lower AvTD of the macrophyte assemblages was observed in the saline area when compared to other three regions of study, where the AvTD does not vary significantly between them (Table 4.2). Higher AvTD indicates a widespread distribution of species within species-rich zones. AvTD is sensitive to the taxonomic relatedness of species. In the study area, 25 species observed in the saline area are under 20 genera and 10 families, while 64 species found in the area of agricultural activities are under 43 genera and 26 families; 44 species under 34 genera and 20families were established in the sewage area, and 39 species were observed in the control area under 29 genera and 18 families. The intensive agricultural area had the highest mean value of AvTD (76.51) and highest number of families when compared to sewage disposal and control areas. In the area of saline intrusion, which had the lowest mean value of AvTD (30.77), all species belong to only ten families. Significantly, lower AvTD was also observed in saline (30.77) areas when compared to the other three regions of study (F = 33.35; p=0.000) and did not vary significantly (p= 0.627) (Table S6) between intensive agriculture (76.51), sewage disposal (73.74) and control sites (74.51) (Table 4.2).

4.3.8 Variation in Taxonomic Distinctness (Λ+)

Variation in taxonomic distinctness (VarTD, **Λ+**) of the macrophyte assemblages in different areas of disturbances are listed in Table 4.2. Lower VarTD was observed in the area of saline intrusion (40.24) due to the exclusive establishment of saline tolerant species. These species are limited to few closely related families like Menyanthaceae, Convolvulaceae, Lentibulariaceae Verbenaceae, Avicenniaceae, Amaranthaceae, Pontederiaceae, Cyperaceae and Poaceae. However, in the area of sewage disposal, higher VarTD (379.40) was observed because of the occurrence of 45 species with an unequal predominance of all taxa, viz. class, order and family of macrophytes. VarTD has the potential to distinguish differences in taxonomic structure resulting in assemblages with some genera becoming highly species-rich while only one species represent a range of other taxa. In Ponnani *Kole* lands the area of sewage disposal has genera like *Ludwigia, Nymphoides, Ipomoea* and *Utricularia* which are highly species-rich and other higher taxa like *Eleocharis*, *Cynodon*, *Eragrostis*, *Leersia*, *Paspalum, Sporobolus* and *Oryza* were represented by only one species. Similarly in the area of agricultural activities *Rotala*, *Ludwigia*, *Limnophila* and *Utricularia* are some genera represented by many species whereas *Eragrostis*, *Hygroryza*, *Hymenachne*, *Leersia* and *Sporobolus* are higher taxa represented by one species.

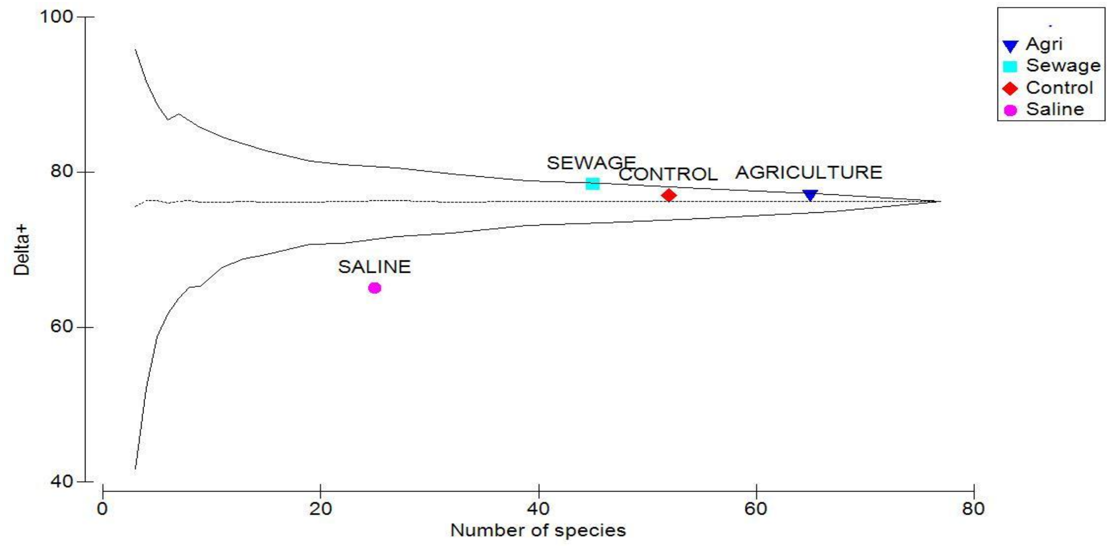

Figure 4.3: Average Taxonomic Distinctness (Δ+) for the four different study areas within Ponnani *Kole* wetlands.

Simulation tests to check the deviation of AvTD recorded from the global mean using funnel plots showed that the AvTD in saline intrusion areas was well below the 95% confidence level of the global mean (Fig.4.3). Mean AvTD values in the area of intensive agricultural activities (76.51) and the control area (74.51) was very close to the expected range simulated from the global assemblage, while AvTD in sewage disposal area (73.74) fell below the 95% confidence level (Figure.4.3).

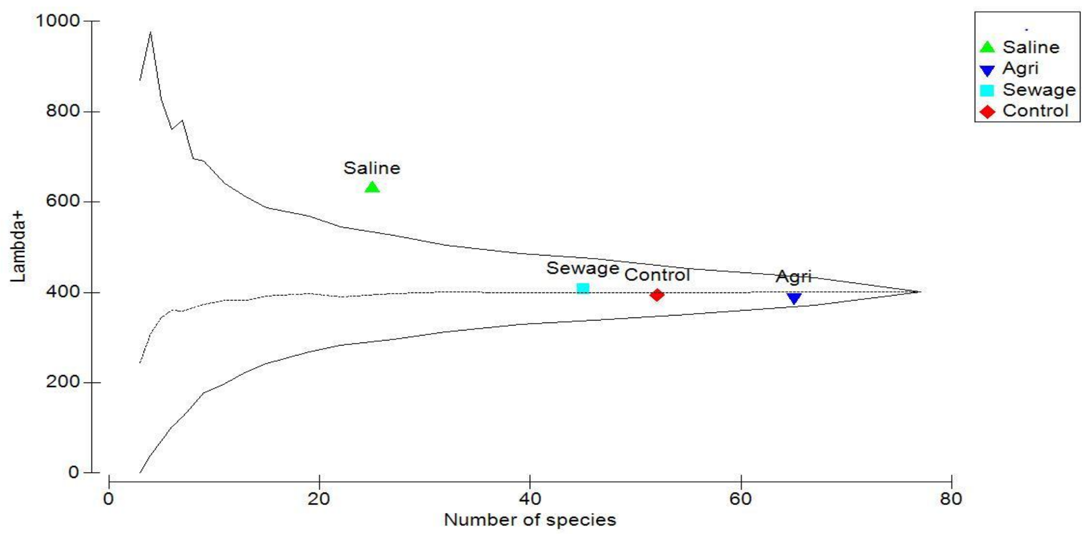

Figure 4.4: Variation in Taxonomic Distinctness (Λ+) for the four different study area within Ponnani *Kole* wetlands.

VarTD values for intensive agriculture (246.04), sewage disposal (379.40) and control (193.43) were observed within the 95% confidence limit of the global mean for all the sites with values for saline intrusion (40.24) shown above the global mean limits (Fig.4.4). The result shows an equal dominance of all macrophyte species belonging to various higher taxa in all zones of study except that of the saline intrusion areas.

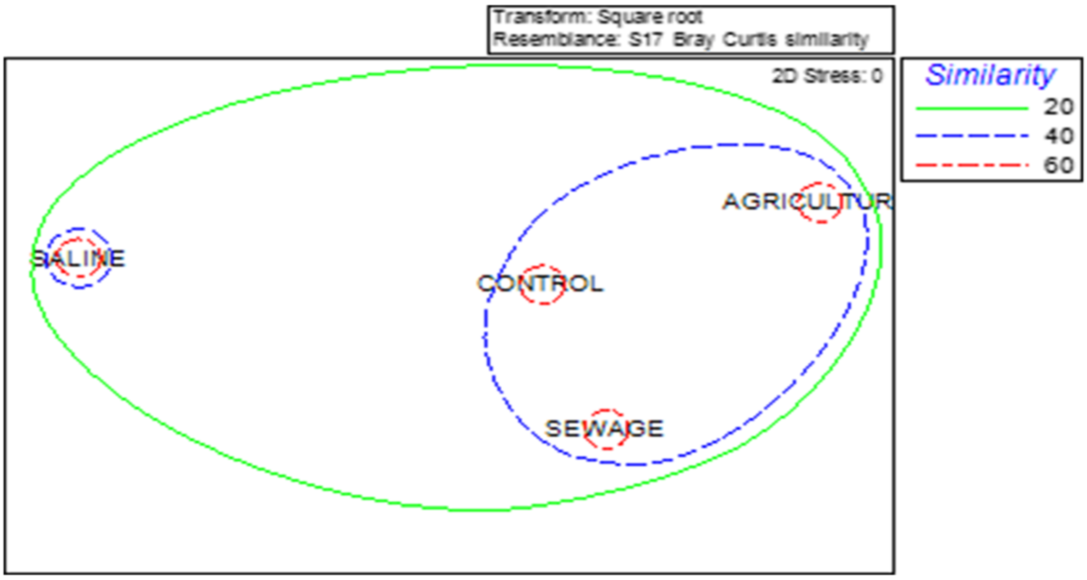

Figure 4.5: Non-metric Multidimensional Scaling plot of macrophyte assemblage in four different zones within Ponnani *Kole* wetlands.

Macrophytes assemblages within the four different zones showed 60% similarity (Figure 4.5). However, between the sewage, agriculture and control zones macrophyte assemblages showed 40% similarity. Only 20% similarity was observed between the macrophyte assemblages of saline zones with all other studied areas (Fig.4.5).

4.3.9 Distribution of different physiognomic forms of macrophytes in different disturbance zones

Macrophytes recorded from the different zones of Ponnani *Kole* wetland were categorised based on their habits, and the results are presented in Table 4.3. In the area of saline intrusion, the dominant macrophytes include mangroves and its associates, like *Ipomoea pes-caprae, Acanthus ilicifolius, Clerodendrum inerme, Avicennia officinalis* and *Cyperus javanicus*, which constituted about 58% of the total biomass (Table 4.3). In the areas of intense agricultural activity, anchored floating macrophytes like *Nymphaea nouchali, N. pubescence, Nymphoides crystata, Marsilea quadrifolia,* (30.37%) and wetland plants like *Aeschynomene indica, Hygrophila auriculata, Alternanthera tenella* and *Eragrostis gangetica* (23.54%) were dominated. In the sewage disposal area, anchored floating (30.83%) and free-floating plants (30.36%) were the dominant groups with free floating plants like *Salvinia adnata, Eichhornia crassipes, Pistia stratiotes, Lemna perpusilla* and *Salvinia adnata* were very recurrent. In the control area, wetland plants (28.06%) and anchored floating (28.61%) were the dominant group. *Rotala macrandra, Ludwigia perennis, Oldenlandia brachypoda Merremia tridentata, Alternanthera tenella, Persicaria pulchra P. glabra, Cyperus difformis, Eragrostis gangetica, Hymenachne amplexicaulis, Leersia hexandra* and *Cynodon dactylon* were the wetland plants observed in the undisturbed area whereas *Nymphaea nouchali, N. pubescence, Nymphoides indica, Ipomoea aquatica, Bacopa monnieri* and *Marsilea quadrifolia* were the anchored freshwater species observed for the control sites.

Table 4.3: Percentage occurrence of aquatic macrophytes of different habits in different zones of ecological disturbances in Ponnani *Kole* wetlands

Habit	Disturbance Zones			
	Saline	Agriculture	Sewage	Control
Free floating	9.00	18.67	30.36	14.27
Suspended hydrophytes	1.00	9.20	2.15	2.61
Submerged hydrophytes	Nil	5.07	6.43	5.56
Anchored floating	Nil	30.37	30.83	28.61
Emergent hydrophytes	21.00	9.39	14.04	12.29
Wetland plants	11.00	23.54	15.27	28.06
Mangrove and its associates	58.00	3.75	0.92	8.59

4.4 DISCUSSION

Changes in land use patterns within the Ponnani *Kole* wetland ecosystem, due to the agriculture activities, disposal of sewage and saline intrusion resulted in alterations to the hydrology and sediment chemistry, in turn, lead to the changes in the local plant community. The number of individuals of various species in the assemblage (evenness) is significant for maintaining significant functions and services such as soil stability, nutrient and water availability in wetland ecosystems (Eviner and Chapin 2001). Higher species richness in the zones of agricultural activity and sewage disposal is a direct consequence of increased nutrient loading resulting in the development of species which are not typical of the Ponnani *Kole* wetland ecosystem. Periodic clearing of wetlands and application of higher nutrient load as chemical fertilizers in the area of agricultural activities may provide an equal chance for the sprouting of different species and promoting their growth (Verhoeven and Setter 2010). Hence, provisions for clearing and high nutrient input may be the reason for species-rich assemblages in areas of agricultural activity. According to Hrivnak (2009), species richness increases with decreasing water depth, and that is caused by the presence of true aquatic plants and wet meadow species in shallow water, representing appropriate conditions for all species. This is true with areas of agricultural activity in our study site. Sewage disposal areas also seemed to support the luxurious growth of many species of macrophytes. Disturbed sites with very high nutrient loading (70 µg 1^{-1}) are characterized by low vascular plant richness and by the presence of filamentous algae (Thiebaut and Muller 1998). In this study, the sewage disposal may be within the carrying capacity of the wetland system, as the sewage is properly decomposed to release nutrients slowly. Therefore this region may be a sink for sewage from nearby areas. However, reclamation and reduction in the extent of the wetland area could seriously hinder the ecosystems equilibrium. Reddy and De Busk (1985) suggested that some macrophytes grow naturally in water bodies with mild pollution from urban areas and utilise these nutrients to produce large amounts of biomass. This is true in the sewage disposal area were higher biomass compared to the control sites was observed. Area of saline intrusion accommodate only few saline tolerant species like *Acanthus ilicifolius, Ipomoea pes-caprae, Clerodendrum inerme, Avicennia officinalis* and *Cyperus dubius*. Under specific environmental conditions, there is a possibility of low species richness because only a few species can tolerate the conditions prevailing in that environment (Grime, 1973).

The high biomass of macrophytes in saline areas was attributed to the large mangrove shrubs with pneumatophores, whereas small and herbaceous wetland plants, suspended hydrophytes and emergent hydrophytes were common in the agricultural fields. Nielsen *et al.* (2003) suggested that rising salinity in aquatic habitats unfavourably affects many freshwater macrophytes due to their intolerance of salt. This may be the reason for the predominance of specific saline tolerant macrophytes in saline intrusion areas of the study site. Hart *et al*. (2003) suggested that aquatic plants exhibit many sub-lethal responses to increased salinity including loss of vigour and reduced species diversity. Many of the macrophytes cannot thrive in the region of saline intrusion due to narrow salt tolerances and thus, a decrease in macrophyte diversity observed. Lee Foote *et al*. (1996) suggested that in fertilised waters *Eichhornia* sp. may double its size every two weeks and in highly polluted areas it is capable of taking up and sequestering unwanted nutrients and heavy metals in the water column. According to Victor *et al*. (2016), *Pistia stratiotes* and *Eichhornia crassipes* were proved to be mercury and chromium accumulators and utilised for the removal of the heavy metals from the polluted water bodies.

Certainly, biodiversity decreases on a global scale as an effect of human activity, mild influxes of nutrients leads to the enhanced biomass production intolerant species. However, in local scale, as inferred from the present study, higher diversity was observed in the area of agricultural activities. This is in agreement with the studies of aquatic ecosystems in an agricultural landscape in West Poland (Goldyn, 2010). The loss of biodiversity can have important consequences that include reduced ecosystem function and resilience, as well as the loss of genetic diversity (Walker *et al.*, 1999; Folke *et al*., 2004). Shimoda (2003) revealed high plant diversity in paddy fields compared with vegetation in an abandoned field. This is true with our study area where nutrient-rich and herbicide free agricultural fields promote an increase in plant diversity compared to other zones. Overall floristic composition and species richness associated with agriculture area has received little attention. In this context plant diversity of an area is not merely a measure of a number of species occurring, but also reflects the dependence of indigenous communities on that plant resource (Jain, 2000). The examined species richness is the simplest form of diversity in communities with high species number. High species diversity indicates a high complexity of organization of the community which is often associated with high stability. In aquatic vegetation, mono-dominant zones are observed frequently (Papastergiadou *et al*., 2008) however; periodical clearing of agricultural fields will reduce the chance of mono-species domination. Hence, the similarity observed for species richness, and Shannon diversity index in the current study area can be due to the consistent dominance of several species across the disturbance gradient. According to Kipriyanova *et al*., (2007) diversity of macrophytes in non-riverine wetlands is negatively associated with salinity.

This is agreed with Ponnani *Kole* showing a negative relationship between macrophytes and salinity.

Sewage from the household area can supply adequate quantities of these limiting nutrients. In this regard plants with high rates of net productivity and higher nutrient uptake are preferred in wetlands subject to sewage inputs. The anthropogenic impact on diversity was meagre when compared to environmental impacts, and wetland system has some corrective mechanisms for stabilization. Wetlands contribute 20-25% to the total methane emissions to the atmosphere, but they also sequester large amounts of carbon in their soils (Mitsch *et al*., 2013). The presence of species unique to different agricultural areas was considered the factor is contributing much to the high species diversity. The presence of remnant species from the original vegetation was also significant in contributing to diversity. Human activities such as watering, ploughing, weeding and livestock grazing prevented paddy vegetation from making the succession to homogenous land. Thus multiple plant species coexisted in an agricultural area, and many of these species were essential for subsistence livelihoods.

Study on the vegetation of Eagle Lake in northwest Iowa suggest that greater the environmental stress the higher the average Simpson's index (Currier *et al*., 1975). The low value of $1-\lambda$, indicating the uneven distribution of species assemblage in the saline area in the present study is a result of the removal of freshwater species. The balanced occurrence of many species perform ecosystem services effectively, and hence the carrying capacity may be high. At the community level, the species differed in their response to the changes brought about in the habitat by the succession and cause changes in the relative abundance, community composition and species diversity (Elmberg *et al*., 1993). Anthropogenic activities such as agricultural practices and use of wetlands as sewage area may influence the line of succession which in turn alters the richness, evenness and abundance of plant species in the study area. The prevalence of certain species in an area might be due to environmental or human-induced initial conditions that favoured the growth and development of these species. This could be a reasonable explanation to the dominance of *Colocasia esculenta* in the sewage area of the study site. This is true in the wetlands in Kumasi Metropolis in Ghana (Campion and Odametey, 2012). Maintaining biodiversity is essential for productive agriculture, and ecologically sustainable agriculture (Pimentel *et al*., 1992). Communities with low evenness are less diverse when compared to those with higher species richness and biomass (Khan, 2013) and this is true in the area of saline intrusion in our study site.

The effect of anthropogenic disturbances may result not only in the reduction in species richness but also in the spread of species across the higher taxa. Both species richness and taxonomic spread are important attributes of biodiversity that should be given equal weight for environmental monitoring and conservation purpose. Taxonomic relatedness indices were suggested to be more sensitive than species richness to intrinsic differences among habitat types, and thereby to be more amenable to detecting degradation due to anthropogenic effects (Clarke and Warwick 1998). Taxonomically dissimilar or not closely related species are flourished well in all region of study except in saline intrusion where only saline tolerant species were established. It is based on the instinctive principle that an assemblage of distantly related species is more diverse than the assemblage of closely related species (Warwick and Clarke, 2001). According to Leonard *et al*. (2006), the advantage of taxonomic distinctness is that variability in biodiversity due to natural environmental factors generally falls within an expected range, based on the probability from a random selection from a regional pool. Anthropogenic influences alter this pattern such that biodiversity falls below the predicted range. This is true in saline intrusion area of the study site. Unlike species richness, AvTD does not appear to be strongly dependent on habitat type, having a different number of species but centrally placed distinctness.

Under the framework proposed by Clarke and Warwick (1998, 2001a), variability in taxonomic distinctness due to natural environmental factors generally falls within a specific range, based on the anticipation from a random selection from a regional species pool. Furthermore, as anthropogenic influences may alter this pattern, taxonomic distinctness measures are functional to differentiate between natural and impacted sites.

However, the present findings are important to assess the anthropogenic effects on biodiversity although the index of taxonomic distinctness (AvTD and VarTD) has been suggested to be less sensitive than species richness to differences in habitat types, and thereby be more agreeable for detecting actual degradation due to anthropogenic effects (Warwick and Clarke 1995, 1998). Since the taxonomic spread is more directly related to functional diversity than species richness, these novel measures might be more important when considering the conservation of ecosystem functioning. Heino *et al*. (2005) opined that taxonomic distinctness also varies along natural gradients and it is unlikely that a site can be determined to be degraded or not degraded based only on a measure of taxonomic distinctness. However, the present findings are of importance to the assessment of anthropogenic effects on biodiversity. The AvTD in intensive agriculture, sewage disposal and control areas do not show much variability when compared to each other but did vary when compared to saline intrusion areas. This indicates the uniform distribution of species in all study zones except saline intrusion areas. When considering the parameters describing the assemblages in relation to disturbance, the taxonomic distinctiveness approach was found to be particularly suitable for macrophytes, for which the less-disturbed study zones (intensive agriculture, sewage disposal and control) were characterised by species belonging to wide taxonomic groups and hence higher taxonomic distinctness.

Furthermore, functional groups of macrophytes were more evenly distributed within these zones. Increased anthropogenic influences could alter this pattern in the future resulting in biodiversity falling below the predicted range. Although AvTD has the ability to discriminate properly between polluted and non-polluted areas, in those of low number of species, the results of this study demonstrated that its power of discrimination decreases when the number of species increases (Fig.4.3) which makes us to think that the index is not able to show correlations within pollution areas where richness depends on other factors. VarTD has the potential to distinguish differences in taxonomic structure resulting in assemblages of some genera becoming highly species-rich while other groups are represented by only a few species.

In the sewage disposal areas, the dominance of genera like *Ludwigia, Nymphoides, Ipomoea* and *Utricularia* which are highly species-rich was observed alongside other higher taxa like *Eleocharis*, *Cynodon*, *Eragrostis*, *Leersia*, *Paspalum, Sporobolus* and *Oryza* which were represented by only one species each.

Similarly, in the intensive agricultural activities area *Rotala*, *Ludwigia*, *Limnophila* and *Utricularia* are some genera represented by many species whereas genera like *Eragrostis*, *Hygroryza*, *Hymenachne*, *Leersia* and *Sporobolus* were represented by one species each. Clarke and Warwick (2001a) hypothesised that under anthropogenic disturbances perturbed communities have reduced taxonomic distinctness, being composed on average of more closely related species than unperturbed communities, which tend to have more taxonomically distant species resulting in greater taxonomic distinctness. This is true with the saline intrusion area where species from related families like Lentibulariaceae, Acanthaceae, Verbenaceae and Avicenniaceae, as well as, Poaceae and Cyperaceae represented the area. This observation is confirmed by the results obtained in the NMDS and dominance plots of the species assemblage of aquatic macrophytes recorded from the four zones of the study area. It is further inferred that the impact of anthropogenic disturbance is not contributing significantly to the biodiversity variability of aquatic macrophytes in the Ponnani *Kole* wetland region. However the geoclimatic attributes contribute significantly to the diversity and assemblage pattern of aquatic macrophytes of the region. The similarity of agriculture and sewage disposal zones to the control and difference in saline intruding area with other zones obtained in the NMDS plot further confirms the above inference. Land use variables are less influential on diversity compared to the geo-climatic gradients at the eco- regional scale as seen in this study and this is supported by the findings of Davies *et al*. (2006), who found the land use had weak explanatory power at the scale of biogeographic regions but had a stronger role at the global scale.

The analysis of diversity, Simpson's evenness and Shannon diversity index, in the four study areas, exhibited the same pattern. These results are in accordance with the Intermediate Disturbance Hypothesis (IDH) proposed by Connell (1978) which states that intermediate levels of disturbance embrace maximise species diversity because competitively dominant species exclude minor species at lower disturbance levels. In the same way, a high limitation level leads to local disappearance of species. The IDH has important practical implications for the maintenance of biodiversity (Townsend *et al.*, 1997) as it highlights environmental conditions that favour the coexistence of numerous species with a large set of bio/ecological profiles and consequently may host diversified communities. Intensive agricultural areas using the optimal level of nutrients harbour an appreciable abundance of typical aquatic plants and maintain their community structure and distribution. Mangroves were limited in areas with an agricultural activity which may be due to the absence of saline intrusion or periodic clearing of agricultural fields before farming. In aquatic plants, intense competition may be expected between species of similar habit occupying a similar area of the wetland. The spread of wetland species is typical of synanthropization, as observed in other wetland systems (Faliniski 2000). In spite of evident similarities, these species may vary significantly when facing interference competition (Gettys *et al*., 2009). The occurrence of typical wetland species indicates that the Ponnani *Kole* wetland is experiencing minimum anthropogenic disturbances.

4.5 CONCLUSION

The observed disturbances indicated that the future growth of agriculture and other human led activities will augment the rate of species loss by typical aquatic plants susceptible to slight disorders in this wetland system. This phenomenon could accordingly alter the functional status and community structure of macrophytes in this unique wetland. Sustainable wetland utilization, fit for purpose, can be achieved through empowering local communities as primary users and preservers,while technical support should come from government and educational agencies. It involves various operational methods including the upkeep of the wetland as an aqua-park, fish reserve, centre for culture augmentation and repository for tropical aquatic macrophyte germplasm. Organised extensive aqua farming of macrophytes of aquarium relevance with the participation of local stakeholders is also suggested as a means for sustainable utilisation of the wetland for future generations, and in developing opportunities for rural employment. The above inferences can well be utilised for the development of strategy and policy for the exploration and utilisation of aquatic resources concerning various disturbance scenarios. Conservation and management plans for this wetland system for the sustainable ecosystem services such as biodiversity, food security, water resources, and trade-offs based on the macrophyte community structure can be a model for the global wetland ecosystems.Considering the location-based significance of the site, variability in occurrence within a range, and distributionof aquatic macrophytes of the area which is least affected by the mild environmental disturbances, we are suggesting this as an ideal site for the establishment of a macrophyte dominated ecological regime which can be further improved as a conservation and educational site for tropical aquatic macrophytes.

Chapter-5

DYNAMICS OF WATER QUALITY AND SEDIMENT PARAMETERS IN PONNANI *KOLE* WETLAND AND ITS IMPACT ON MACROPHYTES

ABSTRACT

Wetlands are sole ecosystems with wealthy nutrient status and high carrying capacity. Hydrology is pivotal in determning species composition and richness, primary productivity, organic accumulation and nutrient cycling of the wetland ecosystem. The current study indented to develop an understanding of seasonal variation in hydrology and sediment structure of different areas, with disturbances and without disturbance, in Ponnani *Kole* wetland ecosystem. A significant variation ($p<0.05$) could be observed spatially and seasonally for water parameters like pH, electric conductivity, hardness, temperature, acidity, alkalinity, total dissolved solids, calcium, magnesium, chloride, fluoride, iron, dissolved oxygen, sulphate, phosphate, depth of water column and rate of water flow; whereas turbidity, BOD and nitrate showed no significant variation during different seasons from different stations. Among the sediment variables recorded from four different zones, significant variation ($p<0.05$) could be observed spatially and seasonally for parameters like pH, electrical conductivity, phosphorus, potassium, calcium, sulphur, copper, iron, manganese and boron. However, organic carbon, magnesium and zinc showed no significant variation between seasons or zones. The total variation in physiognomic forms data with sediment variables explained by the first three axes in CCA was 85.12%. The functioning of ecosystems depends on the functional characteristics of local communities, the link between environmental variables and the biomass of macrophyte growth forms, such as those investigated in this study, can be a helpful tool for predicting the effects of environmental changes on ecosystem processes against possible future scenarios.

5.1 INTRODUCTION

Wetlands are a sole ecosystem with wealthy nutrient status and high carrying capacity. Such an area with enormous production potential hence demarcated as zones of source for food and fodder for human and its related allies. Wetlands also afford hydrological functions, including flood abatement, water purification, erosion control, recharge of groundwater aquifers and carbon sequestration (Zedler and Kercher, 2005; Mitsch and Gosselink, 2007). The healthy aquatic ecosystem is being determined by well-adjusted biodiversity and stable physio-chemical characteristics (Venkatesharaju *et al*., 2010). Hydrologic environment affects many abiotic factors like soil anaerobiosis and nutrient availability which in turn is accountable for the development of the biota within the wetland ecosystem. This interconnectedness consequently alters the wetland hydrology and physiochemical features (Mitsch and Gosselink, 2007). The worth of wetlands is receiving due attention as they add to a healthy environment for the biotic system. They retain water in dry periods, keeping water table high and stable. Wetlands alleviate flood and trap suspended solids and nutrients during flooding. The spatial and temporal variation in water depth, flow patterns, water quality, frequency and duration of inundation are the most important factors shaping the ecological condition of wetlands. Hence, these factors also resolve the functions of wetlands (Ramsar Convention Secretariat, 2006). Hydrographical parameters fix the subsistence of communities in an aquatic ecosystem and information about these parameters is essential to recognise the dynamics of the ecosystem. The rich diversity of an organism reflects good water quality, whereas contamination affects diversity and abundance of organisms (Kamble and Sakhare, 2012). Sedimentation may result in high turbidity, leading to adverse conditions for aquatic macrophytes and algae to undergo photosynthesis for survival (Albert and Minc, 2004). Wetland function could be understood by the study of hydroperiod, water budget, water turnover time, and sediment structure. Hydrology can shape species composition and richness, primary productivity, organic accumulation and nutrient cycling (Mitsch and Gosselink, 2007). Hydrographical parameters show significant variation due to the seasonal changes, which in turn influence the spatial and temporal distribution of planktonic communities (Naidu *et al*., 1976; Krishnamurthy and Santhanam, 1975). Despite these benefits, wetlands have been viewed as nasty waste areas and were drained and filled with lodging agriculture (Grand River Conservation Authority, 2003).

Sediment texture has an important role in physicochemical processes and species diversity of depositional environment (Babu *et al*., 2000). The response of macrophyte species fluctuate to sediment conditions and influence the species composition of aquatic macrophyte communities (Barko and Smart, 1981, 1983). Macan (1977) explained the correlation between sediment organic matter, macrophyte community composition and the spatial distribution of individual species. Joseph and Ousep (2009) studied the nutrient status of Cochin estuarine ecosystem and found that nitrate, nitrite, phosphate and inorganic phosphate coming from drainages and area of industrial pollution in the urban sector were playing a significant role. Peters *et al.* (2008) conducted a modelling of wetland vegetation distribution for identification of constraining environmental variables in a lowland wetland ecosystem. Vogiatzakis *et al*. (2009) examined the ephemeral aquatic habitat of Gavdos islands in Greece and explored the environmental factors shaping the distribution of plant communities in five study sites. Spatial and ecological effects on aquatic vegetation in Yellow River delta in China were studied by Song *et al*. (2009) and revealed that vegetation pattern was mostly allied to elevation, water depth, soil salinity and soluble potassium. Physico-chemical parameters in the water of Rupsha river and relation with edaphic factors in Khulna in Western Bangladesh was studied by Al-Noor and Kamruzzaman (2013).

The physicochemical analysis is of key importance to assess the water quality and sediment structure for its best usage and also to know the pollution load on receiving water bodies. Even if wetlands were the area of curiosity for researchers, only a little information about water and sediment structure from *Kole* wetlands was available. No detailed studies exist on the physicochemical aspects of water and sediment in agriculture fields, abandoned fields, sewage area and area of saline intrusion and it makes the comparison a more difficult task. The current study indented to develop an understanding of seasonal variation in hydrology and sediment structure of different areas, with disturbances and without disturbance, in Ponnani *Kole* wetland ecosystem.

5.2 MATERIALS AND METHODS

5.2.1 Study Area and Field Observations

During the present study, nine representative study sites were assessed for the water and sediment variables with different disturbances regimes. Two saline intrusion sites (**Porangue and Cheerppu**), three stations in the areas of agricultural activity (**Kalachal, Uppungalkadav, Muchikadavu)** and two stations (**Kummipalam, Thuyyam)** in sewage disposal regions representing anthropogenic disturbance and two undisturbed sites (**Naranipuzha, Mukolamtazhath)** selected as control stations (Figure

4.1 & Table 4.1). The surface water samples and soil samples were collected for two years (2014-2016) including post-monsoon, pre-monsoon and monsoon seasons. Sample collection was done during morning hours between 7.00 am to 10.00 am and brought to the laboratory for further analysis as described in chapter 1.5.4.3 and 1.5.4.4. Detailed result of water analysis and sediment analysis was shown in the Table S7 and Table S9.

5.2.2 Data analysis

Statistical analysis for Two way ANOVA (Analysis of Variance) was done using SPSS 17.0 for testing the significant differences, if any, among the parameters between stations and seasons. The range and the mean along with standard deviation of various physicochemical characteristics of different stations studied were analysed for three seasons namely pre-monsoon, monsoon and post-monsoon. Similarly to test the effect of the environmental parameters, analysis of variance (Two Way ANOVA) between stations and between seasons was done, and the F value was taken at 5% level.

To study the association of macrophyte species with environmental parameters Canonical correspondence analysis (CCA) with a forward selection procedure was carried out as described in chapter 1.5.5.9.

5.3 RESULTS

Twenty (20) hydrological parameters and 13 sediment parameters were recorded from four different zones of disturbances like the area of saline intrusion, the area of sewage disposal, the area of agricultural activities and undisturbed region for three different seasons like post-monsoon, pre-monsoon and monsoon for two years.

5.3.1 Water

A total of 216 water samples were analysed during the study period. A significant variation ($p<0.05$) could be observed spatially and seasonally for parameters like pH, electric conductivity, hardness, temperature, acidity, alkalinity, total dissolved solids, calcium, magnesium, chloride, fluoride, iron, dissolved oxygen, sulphate, phosphate, depth of water column and rate of water flow (Table 5.1). Whereas, turbidity, BOD and nitrate showed no significant variation in samples collected during different seasons from different stations. Detailed result of two-way ANOVA is given in Table S8.

The results of two way ANOVA (Table S8) showed season wise (F=10.288; p=.000) as well as zone wise (F=22.388; p=.000) significant variation ($p<0.05$) for mean turbidity; whereas no significant variation observed while analysing the combination of these two variables together (F=.792; p=.577). Similarly spatial (F=8.15; p=.000) and temporal (F= 26.34; p=.000) variability of BOD showed significant variation when factors considered independently, but the combination of two brought out insignificant variation (F=2.097; p=0.055) when considered together. Results of ANOVA pointed out a significant variation in the concentration of phosphate across different zones (F= 2.94; p=.03) and no significant variation was found with respect to seasons (F=2.31; p=.102). However, the combination of the two factors brings out significant variations (F=3.02; p=.008). Significant fluctuations were observed (F=35.80; p=.000) in the concentration of nitrate with respect to season, but no significant variation (F=2.14; p=.097) was noticed across different zones. On the other hand, the grouping of the two factors brought out insignificant variations (F= 1.57; p=.158) when considered together. Rate of water flow also showed significant variation across different zones (F=19.38; p= .000), but insignificant variation was observed between seasons (F=2.45; p=.089). The combination of two brings significant variation (F=12.97; p=.000) when considered together.

5.3.1.1 Macrophyte composition-water variable relationships

Canonical correspondence analysis operates on data on the abundance of physiognomic forms and environmental variables (Figure 5.1) and extracts synthetic gradients (ordination axes), from the measured water variables, that maximise niche severance among seven types of growth forms. The physiognomic forms points designate the relative locations of the two- dimensional niches of the groups in the ordination diagram. The total variation in physiognomic forms, with respect to water quality parameters, explained by first three axes in CCA was 84.87% with the first axis explaining 39.15% and the second axis explaining 24.59% (Table 5.2). It can be observed from the right top of the ordination diagram (Figure 5.1) that the water quality parameters like turbidity, depth and rate of flow are strongly correlated. Similarly, BOD and phosphate are correlated; fluoride, sulphate and alkalinity also showed a strong positive correlation.

Table 5.1. Test of between-subject effects----Water collected from Ponnani *Kole* wetlands during study period

Source	Zone				Season			Type III Sum of Squares Between samples			Type III Sum of Squares within samples			F	Significance
	Saline	Agriculture	Sewage	Control	PtM	PrM	Mn	Type III Sum of Squares	df	Mean Square	Type III Sum of Squares	df	Mean Square		
TURBIDITY	2.38	2.91	9.22	2.63	3.70	2.44	6.24	113.54	6	18.92	4876.32	204	23.91	.79	.580
pH	7.51	6.91	6.18	6.81	7.102	6.581	6.89	27.06	6	4.51	74.03	204	.36	12.43	.000
ELECTRICAL CONDUCTIVITY	24857.42	2848.06	1465.42	5264.33	9665.83	1361.72	588.61	9.61	6	1603.E9	1480.E1	204	7.25	22.10	.000
HARDNESS (as Ca CO_3)	4176.83	135.56	346.33	451.17	1382.78	1746.11	322.89	1.37	6	2.29	1.83	204	897562.31	25.52	.000
TEMPERATURE	29.05	28.17	28.42	28.15	27.22	31.01	27.01	63.09	6	10.52	684.02	204	3.35	3.14	.006
ACIDITY	5.17	6.111	20.00	8.17	6.11	16.00	6.22	5754.67	6	959.11	43692.20	204	214.77	4.48	.000
ALKALINITY	72.33	22.11	25.33	26.00	41.44	32.78	30.33	13172.74	6	2195.45	49572.43	204	243.00	9.04	.000
TOTAL DISSOLVED SOLIDS	17400.08	1983.00	1013.92	3679.83	6766.06	9556.06	390.11	4.70	6	7.84	7.25	204	3.55	22.06	.000
CALCIUM	663.93	24.38	41.47	61.07	276.80	178.98	79.58	5388685.45	6	898114.24	4096592.53	204	20081.34	44.72	.000
MAGNESIUM	614.10	18.61	58.92	72.53	167.84	315.50	32.29	4020862.46	6	670143.74	9843651.85	204	48253.19	13.89	.000
CHLORIDE	9466.17	165.00	931.67	828.17	3584.00	3834.44	230.56	1.33	6	2.22	1.62	204	7922681.76	28.02	.000
FLUORIDE	1.05	.42	.41	.43	.73	.55	.41	8.70	6	1.450	15.70	204	.08	18.85	.000
IRON (as Fe)	.88	1.17	1.38	.79	1.23	.78	1.20	12.87	6	2.145	90.41	204	.44	4.84	.000
DISSOLVED OXYGEN (DO)	6.37	5.81	5.60	6.07	6.52	5.45	5.87	30.43	6	5.071	127.98	204	.63	8.08	.000
BIOCHEMICAL OXYGEN DEMAND (BOD)	0.85	.91	1.69	1.205	1.739	.588	1.083	11.63	6	1.94	188.66	204	.93	2.10	.055
SULPHATE (as SO_4)	249.76	24.82	61.84	56.80	159.03	82.62	28.77	2072070.34	6	345345.06	3246294.84	204	15913.21	21.70	.000
PHOSPHATE (as PO_4)	0.03	.82	.03	.06	.05	.04	.82	60.45	6	10.07	680.46	204	3.34	3.02	.008
NITRATE	2. 95	3.05	4.21	3.33	5.55	2.11	2.39	73.39	6	12.23	1592.43	204	7.81	1.57	.158
DEPTH OF WATER COLUMN (in cm)	30.35	54.18	49.21	72.10	45.29	29.49	80.51	20577.71	6	3429.618	271824.21	204	1332.47	2.57	.020
RATE OF WATER FLOW	59.83	60.00	32.67	85.83	63.44	49.89	65.56	90825.63	6	15137.61	238160.67	204	1167.45	12.97	.000

Table 5.2. Eigen value for canonical correspondence analysis for water variables and physiognomic forms

Axis	Eigenvalue	% of Variability	Cumulative percentage
1	0.48406	39.15	39.15
2	0.30407	24.59	63.74
3	0.26129	21.13	84.87
4	0.077659	6.28	91.15
5	0.072536	5.87	97.02
6	0.036827	2.98	100

Biochemical Oxygen Demand (BOD) and phosphate content showed a positive influence on the abundance of free-floating macrophytes. At the right bottom quarter of the plot (Figure 5.1), the concentration of chloride, nitrate, and hardness are clustered and showed a strong correlation. Total dissolved solids and electrical conductivity are also showing a strong correlation. Presence of chloride, nitrate, calcium and hardness of water were positively correlated to the abundance of emergent hydrophytes. Moreover, wetland plants showed a positive correlation with electrical conductivity and TDS, whereas, mangrove and its associates were negatively related to TDS and conductivity. Temperature is an important factor influencing the abundance of suspended and submerged hydrophytes, whereas iron is negatively related to the occurrence of suspended and submerged macrophytes. Anchored floating macrophytes were showing a negative correlation with dissolved oxygen and pH in this ecosystem.

CCA supported results (Figure 5.2) of the indicator species analysis by signifying that certain species were associated with specific water variables. The most frequent macrophytes in our study like *Nymphaea pubescence*, *Ludwigia adscendens*, *Ipomoea aquatica*, *Ipomoea carnea*, *Ipomoea pes-caprae*, *Bacopa monnieri*, *Acanthus ilicifolius*, *Clerodendrum inerme*, *Avicennia officinalis*, *Alternanthera philoxeroides*, *Alternanthera tenella*, *Persicaria pulchra*, *Vallisneria natans*, *Eichhornia crassipes*, *Monochoria hastata*, *Cyperus javanicus*, *Schoenoplectiella supina*, *Salvinia adnata* and

Azolla pinnata were plotted in the graph (Figure 5.2). The total variation in species assemblage was explained by first four axes in CCA was only 59.61% with the first axis explaining 19.81%, the second 16.39%, third 12.69% and fourth by 10.72% (Table 5.3). Left bottom of ordination diagram depicted the water variables like acidity, the rate of water flow and temperature, and it is apparent that these parameters were closely related with the frequency of occurrence of *Vallisneria natans* and acidity is positively related to the occurrence of *Cyperus javanicus*. The values of nitrate, sulphate, calcium, magnesium, chloride, fluoride and hardness of water were positively correlated with the distribution of *Monochoria hastata*. pH is closely related to the distribution of *Ipomoea pes-caprae, Acanthus ilicifolius,* and *Alternanthera tenella*, whereas, pH and acidity are important variables for the occurrence of *Azolla pinnata*. *Ipomoea carnea* is strongly related to dissolved oxygen in the water body and showing a negative relationship with acidity and temperature. Left upper side of ordination diagram holds the water variables like BOD and phosphate which were closely related with the occurrence of *Persicaria pulchra* and the frequency of distribution of *Nymphaea pubescence* and *Salvinia adnata* was strongly related to the BOD of water. Similarly, the depth of the water body was directly related, but total dissolved solids and electric conductivity were negatively related to the occurrence of *Eichhornia crassipes.*

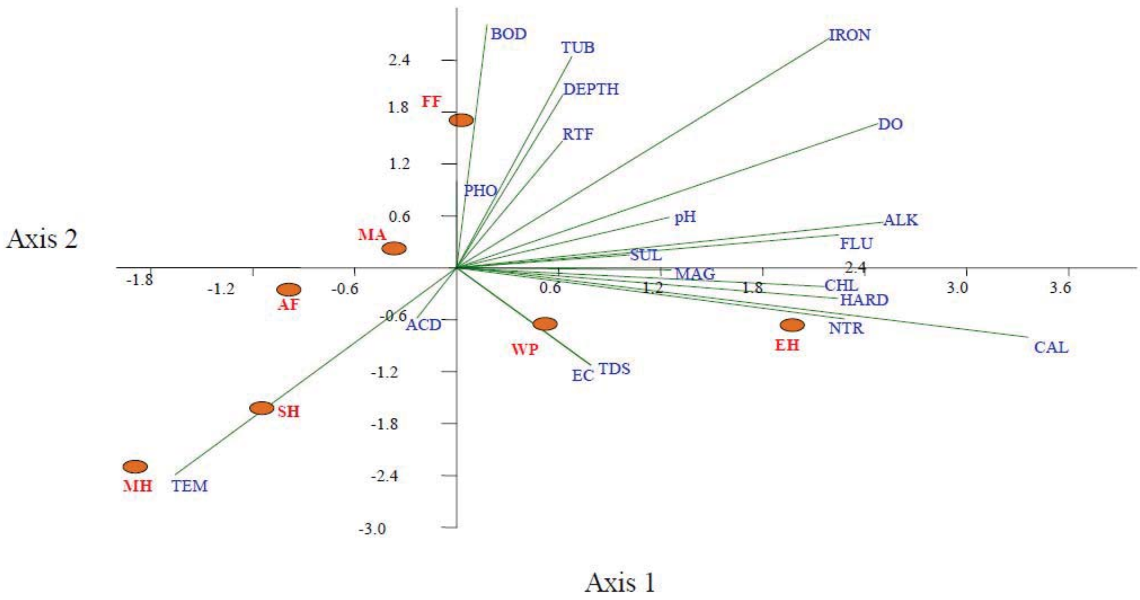

Figure 5.1. CCA ordination diagram showing the relationship between the physiognomic forms of aquatic macrophytes collected from Ponnani *Kole* and water parameters. Turbidity (TUB), pH (pH), Electric conductivity (EC), Total dissolved solids (TDS), Temperature (TEM), Acidity (ACD), Alkalinity (ALK), Hardness (HARD), Calcium (CAL), Magnesium (MAG), Chloride (CHL), Fluoride (FLU), Iron (IRON), Dissolved oxygen (DO), Biochemical oxygen demand (BOD), Sulphate (SUL), Phosphate (PHO), Nitrate (NTR), Rate of flow (RTF), Depth (DEPTH); **HABIT**: FF-Free floating; SH-Suspended hydrophytes; MH-Submerged hydrophytes; AF-Anchored floating; EH-Emergent hydrophytes; WP-Wetland plants; MA-Mangrove and associates.

Table 5.3 Eigenvalue for canonical correspondence analysis for water variables and macrophyte species

Axis	Eigenvalue	% of Variability	Cumulative percentage
1	0.6990	19.81	19.81
2	0.5710	16.39	36.2
3	0.4420	12.69	48.89
4	0.3735	10.72	59.61
5	0.2651	7.61	67.22
6	0.2203	6.33	73.55
7	0.2131	6.12	79.67
8	0.1800	5.17	84.84
9	0.1655	4.75	89.59
10	0.1166	3.35	92.94
11	0.1058	3.04	95.98
12	0.0542	1.56	97.54
13	0.0382	1.10	98.64
14	0.0248	0.71	99.35
15	0.0119	0.34	99.69
16	0.0091	0.26	99.95
17	0.0017	0.05	100
18	0.0005	0.01	100.01

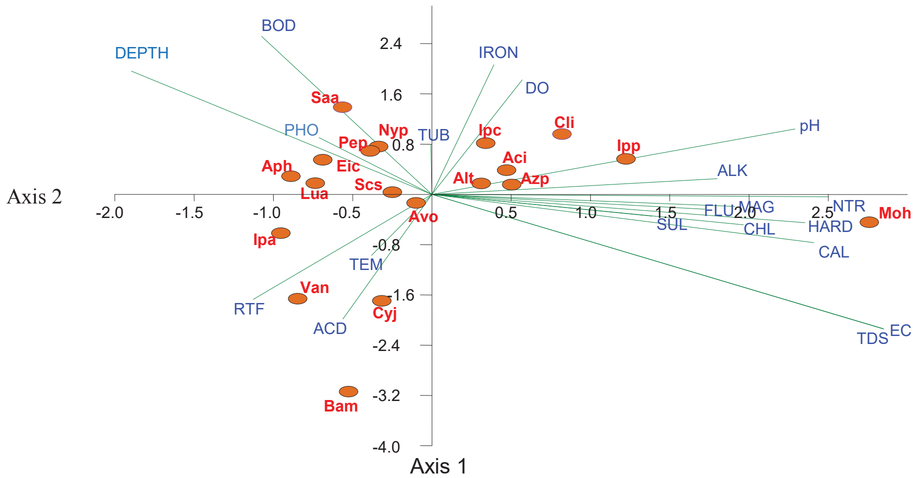

Figure 5.2. CCA ordination diagram showing the relationship between the abundant macrophyte species of Ponnani *Kole* wetlands and water quality parameters. Turbidity (TUB), pH (pH), Electric conductivity (EC), Total dissolved solids (TDS), Temperature (TEM), Acidity (ACD), Alkalinity (ALK), Hardness (HARD), Calcium (CAL), Magnesium (MAG), Chloride (CHL), Fluoride (FLU), Iron (IRON), Dissolved oxygen (DO), Biochemical oxygen demand (BOD), Sulphate (SUL), Phosphate (PHO), Nitrate (NTR), Rate of flow (RTF), Depth (DEPTH); *Nymphaea pubescence* (Nyp), *Ludwigia adscendens* (Lua), *Ipomoea aquatica* (Ipa), *Ipomoea carnea* (Ipc), *Ipomoea pes-caprae* (Ipp), *Bacopa monnieri* (Bam), *Acanthus ilicifolius* (Aci), *Clerodendrum inerme* (Cli), *Avicennia officinalis* (Avo), *Alternanthera philoxeroides* (Aph), *Alternanthera tenella* (Alt), *Persicaria pulchra* (Pep), *Vallisneria natans* (Van), *Eichhornia crassipes* (Eic), *Monochoria hastata* (Moh), *Cyperus javanicus* (Cyj), *Schoenoplectiella supina* (Scs), *Salvinia adnata* (Saa), *Azolla pinnata* (Azp).

5.3.2. Sediment

Thirteen sediment parameters were recorded from four different zones like the area of saline intrusion, area of sewage disposal, area of agricultural activities and undisturbed region for three different seasons like post-monsoon, pre-monsoon and monsoon. A significant variation ($p<0.05$) could be observed spatially and seasonally for parameters like pH, electrical conductivity, phosphorus, potassium, calcium, sulphur, copper, iron, manganese and boron. However, organic carbon, magnesium and zinc showed no significant variation between seasons or zones (Table 5.4). Detailed result of two-way ANOVA was given in Table S10.

The results of two way ANOVA (Table S10) exposed season wise ($F=3.19$; $p=.043$) as well as zone wise ($F=51.70$; $p=.000$) significant variation ($p<0.05$) for organic carbon; whereas, no significant difference was observed while analysing the combination of these two factors ($F=1.60$; $p=.149$). Considerable variation was observed ($F=19.21$; $p=.000$) in the concentration of magnesium with respect to season, but no significant variation ($F=.23$; $p=.873$) was noticed across different zones. However, the combination of the two factors points out not significant variations ($F= 1.41$; $p=.211$) when considered together. Similarly, spatial ($F=11.84$; $p=.000$) and temporal ($F= 21.07$; $p=.000$) variability of zinc showed significant variation when factors considered independently, but the combination of two bring out insignificant variation ($F=1.600$; $p=.149$) when considered together. Results of ANOVA also pointed out a significant variation of manganese across different zones ($F= 15.93$; $p=.000$) and insignificant variation was found with respect to seasons ($F=1.31$; $p=.273$). However, the combination of the two brings significant variations ($F=2.60$; $p=.019$) when considered together.

Table 5.4 TEST OF BETWEEN-SUBJECT EFFECTS-------SEDIMENT Collected from Ponnani *Kole* wetlands during study period

Source	Zone				Season			Type III Sum of Squares Between samples			Type III Sum of Squares within samples			F	Significance
	Saline	Agriculture	Sewage	Control	PtM	PrM	Mn	Type III Sum of Squares	df	Mean Square	Type III Sum of Squares	df	Mean Square		
pH	4.80	4.92	5.23	5.49	5.60	5.52	4.14	19.87	6	3.31	88.50	204	0.43	7.63	.000
ELECTRC CONDUCTIVITY	2.92	0.16	0.17	0.30	.914	1.47	0.03	130.99	6	21.83	18.33	204	0.09	242.97	.000
ORGANIC CARBON	0.19	1.32	0.49	0.82	0.70	0.89	0.74	2.59	6	4.31	54.98	204	0.27	1.60	.149
PHOSPHORUS	23.10	30.04	21.56	22.05	28.59	19.45	26.47	12889.53	6	2148.26	43295.73	204	212.23	10.12	.000
POTASSIUM	139.61	68.68	108.38	75.25	84.27	157.40	42.50	147451.56	6	24575.26	939832.43	204	4607.02	5.33	.000
CALCIUM	44.10	102.82	125.02	214.76	97.33	122.82	138.57	836434.68	6	139405.78	1269068.52	204	6220.92	22.41	.000
MAGNESIUM	24.37	23.19	22.89	21.87	19.20	31.92	18.15	1843.49	6	307.25	44391.66	204	217.61	1.41	.211
SULPHUR	211.83	45.91	44.40	74.02	96.62	141.61	27.85	401946.74	6	66991.12	1915537.81	204	9389.89	7.13	.000
COPPER	0.88	2.61	1.58	1.75	1.10	0.961	3.35	152.35	6	25.39	94.05	204	0.46	55.10	.000
IRON	255.75	442.78	375.00	440.71	456.75	254.78	445.56	1792979.24	6	298829.87	9660130.27	204	47353.58	6.31	.000
ZINC	1.60	4.50	5.01	3.91	5.77	2.47	3.28	91.18	6	15.20	1938.07	204	9.50	1.60	.149
MANGANESE	2.55	12.81	14.04	12.08	9.51	12.08	10.32	1346.95	6	224.49	17650.40	204	86.52	2.60	.019
BORON	1.39	1.21	0.75	0.88	1.11	1.23	0.88	11.15	6	1.86	80.03	204	0.39	4.74	.000

5.3.2.1. Macrophyte composition-Sediment variable relationships

CCA ordination diagram (Figure 5.3) explains the relation between sediment variables and seven physiognomic forms of macrophytes in Ponnani *Kole* lands. The total variation in physiognomic forms data with sediment variables explained by (Table 5.5) first three axes in CCA was 85. 12% with the first axis explaining 46.18%, the second axis 23.27% and 15.67% by the third axis.

Table 5.5. Eigenvalue for canonical correspondence analysis for sediment variables and physiognomic forms

Axis	Eigenvalue	% of Variability	Cumulative percentage
1	0.3818	46.18	46.18
2	0.1924	23.27	69.45
3	0.1296	15.67	85.12
4	0.0784	9.48	94.6
5	0.0353	4.27	98.87
6	0.0093	1.13	100

On the left top of the ordination diagram, the sediment variables like zinc and iron are strongly correlated and showing a negative correlation with potassium. Similarly, copper and calcium are also correlated. Copper, calcium, iron and zinc in the soil showed a positive influence on the abundance of wetland plants. Calcium, zinc and iron are closely related to the frequency of occurrence of free-floating plants. Left bottom of ordination diagram shows a negative correlation of organic carbon with sulphur and boron. Similarly, organic carbon is positively related to the abundance of anchored floating plants, whereas, sulphur and boron are negatively related to their abundance. pH is an important factor influencing the abundance of submerged plants.

CCA was also used to appraise the influence of sediment variables (limnological variables) on the composition of macrophyte species (Figure 5.4). The most common macrophytes plotted in figure 5.2 were also plotted here. The majority of the variance (65.4%) in species abundance was explained by the first four axes of CCA (Table 5.6). The first axis contributed 23.22% of the variance, second axis by 18.11%, third axis by 13.59% and fourth by 10.48% separately.

Table 5.6. Eigen value for canonical correspondence analysis for sediment variables and macrophyte species

Axis	Eigenvalue	% of Variability	Cumilative percentage
1	0.6431	23.22	23.22
2	0.5016	18.11	41.33
3	0.3764	13.59	54.92
4	0.2902	10.48	65.4
5	0.2632	9.50	74.9
6	0.2128	7.68	82.58
7	0.1621	5.85	88.43
8	0.1438	5.19	93.62
9	0.0874	3.16	96.78
10	0.0434	1.57	98.35
11	0.0314	1.13	99.48
12	0.0142	0.51	99.99
13	0.0005	0.01	100

The right upper part of CCA highlights a positive association of iron and manganese with *Ludwigia adscendens* and *Ipomoea aquatica,* but they are negatively correlated with boron. Right bottom of ordination diagram explains the positive association of *Avicennia officinalis* with copper and negative correlation with potassium. Similarly, *Alternanthera tenella* positively associated with potassium and negatively with copper. *Acanthus ilicifolius* is strongly related to calcium and phosphorus. Left bottom of CCA explains the negative correlation between electric conductivity and zinc. Frequency of occurrence of *Eichhornia crassipes* is positively related to electric conductivity, and that of *Ipomoea carnea* is with zinc. Magnesium and sulphur are positively correlated. Distribution of the submerged macrophyte *Vallisneria natans* is closely associated with magnesium in the sediment. The left upper part of CCA explains the correlation between pH and organic carbon whereas the distribution of *Monochoria hastata* is closely related to sediment pH.

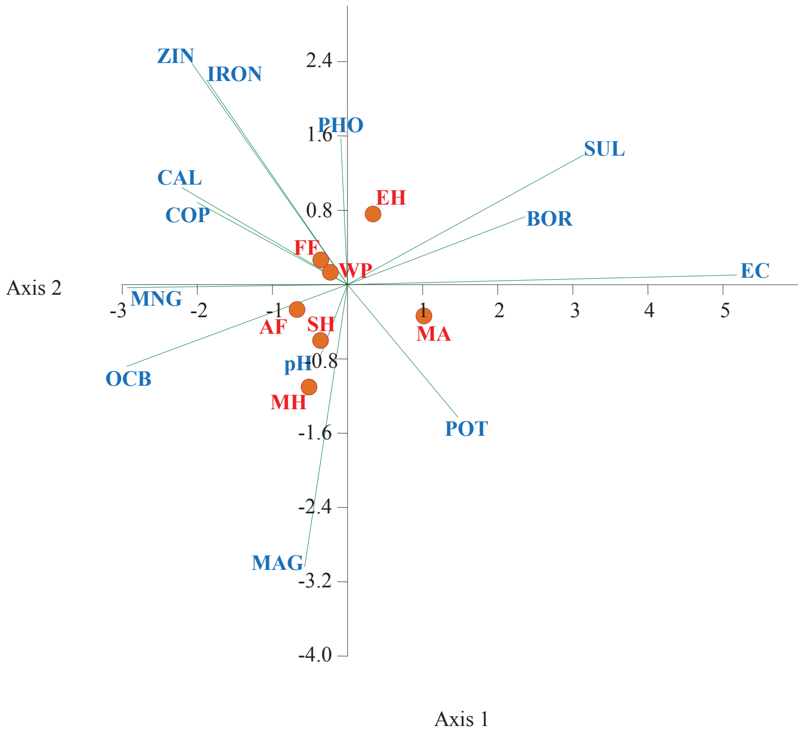

Figure 5.3. CCA ordination diagram showing the relationship between the physiognomic forms of aquatic macrophytes and sediment parameters collected from Ponnani *Kole* wetlands. pH (pH), Electric conductivity (EC), Organic carbon (OCB), Phosphorus (PHO), Potassium (POT), Calcium (CAL), Magnesium (MAG), Sulphur (SUL), Copper (COP), Iron (IRON), Zinc (ZIN), Manganese (MNG), Boron (BOR); **HABIT**: FF-Free floating; SH-Suspended hydrophytes; MH-Submerged hydrophytes; AF-Anchored floating; EH-Emergent hydrophytes; WP-Wetland plants; MA-Mangrove and associates.

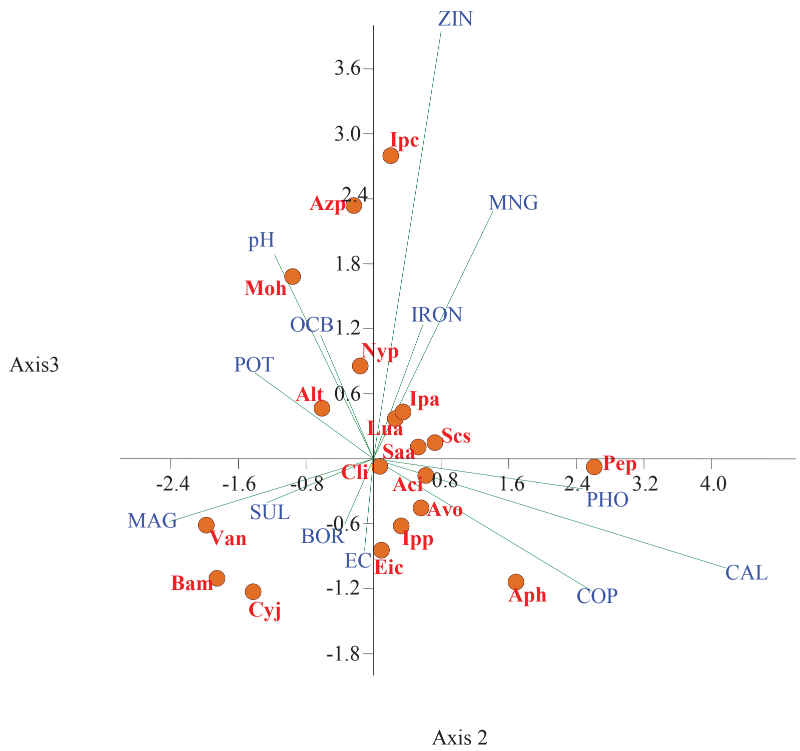

Figure 5.4. CCA ordination diagram showing the relationship between most abundant macrophyte species of Ponnani *Kole* and sediment parameters. pH (pH), Electric conductivity (EC), Organic carbon (OCB), Phosphorus (PHO), Potassium (POT), Calcium (CAL), Magnesium (MAG), Sulphur (SUL), Copper (COP), Iron (IRON), Zinc (ZIN), Manganese (MNG), Boron (BOR); *Nymphaea pubescence* (Nyp), *Ludwigia adscendens* (Lua), *Ipomoea aquatica* (Ipa), *Ipomoea carnea* (Ipc), *Ipomoea pes-caprae* (Ipp), *Bacopa monnieri* (Bam), *Acanthus ilicifolius* (Aci), *Clerodendrum inerme* (Cli), *Avicennia officinalis* (Avo), *Alternanthera philoxeroides* (Aph), *Alternanthera tenella* (Alt), *Persicaria pulchra* (Pep), *Vallisneria natans* (Van), *Eichhornia crassipes* (Eic), *Monochoria hastata* (Moh), *Cyperus javanicus* (Cyj), *Schoenoplectiella supina* (Scs), *Salvinia adnata* (Saa), *Azolla pinnata* (Azp).

5.4 DISCUSSION

Our study builds on earlier works assessing relationships between aquatic macrophytes and environmental variables (Heegaard *et al.,* 2001; Meerhoff *et al*., 2003; Akasaka and Takamura, 2010) and indicates the extent to which macrophyte biomass and community composition in *Kole* lands are related to a unique combination of study area, water and sediment characteristics.

As per the CCA developed, major water variables influencing the growth of macrophytes are temperature, BOD, electric conductivity, total dissolved solids, phosphate, nitrate and calcium. Free-floating macrophytes have the affinity for preferring water with high BOD. This may be due to the reduction in the availability of sunlight for submerged plants by the shade cast by free-floating macrophytes, leading to the fall in the rate of photosynthesis, reduction of dissolved oxygen and organic load in water causing the high BOD level. This is true with Kuttanad wetland ecosystem where free-floating macrophytes like *Salvinia molesta, Eichhornia crassipes* and *Pistia stratiotes* were preferred to grow in water with low dissolved oxygen and high BOD (Sylas, 2010). Tripathi *et al.* (2010) found that *Pistia stratiotes*, the free-floating macrophyte remove 83.1% BOD, 93.3% ammonia nitrogen, and 75.0% phosphorus when it spreads on the water surface. This also shows that the growth of free-floating forms is related to BOD, ammonia nitrogen and phosphorus in the water body. This study also shows the relation between free-floating forms with BOD and phosphate in *Kole* lands (Figure 5.1). Negative relationships between macrophyte abundance and lake turbidity have been reported in many studies (Lougheed *et al*., 2001; Hansel-Welch *et al*., 2001; Zimmer *et al*., 2009) and we also found negative correlations between turbidity and the distribution of submerged, suspended and emergent macrophytes in our study. According to Madsen *et al*. (2001) and Zhang *et al*. (2014a) rate of water flow directly reduces the growth of submerged macrophyte because of the strong mechanical strain and damage caused on plant tissues. This is true with submerged macrophytes of Ponnani *Kole* lands, showing a negative correlation with water flow (Figure 5.1). Behera *et al*. (2014) explained the relation between the mangrove ecosystem and water variables like nitrate, calcium, magnesium and hardness. Our study shows a negative correlation of mangroves with nitrate, chloride, calcium, magnesium and hardness of the water. Heegaard *et al.* (2001) also reported that alkalinity, Ca and Mg concentrations in water influenced macrophyte distribution in lakes in Ireland. According to Schneider *et al.* (2018) rooted floating plants were negatively related to the nitrate level. This is due to the uptake of inorganic nutrients like nitrogen by macrophytes for accumulating in their biomass (Nogueira and Esteves, 1993; James *et al*., 2004; Weisner and Thiere, 2010) which in turn reduces the availability of nitrate in the water body. This is true with the studies in Ponnani *Kole* where occurrence many macrophyte species like *Schoenoplectiella supina, Ludwigia adscendens* and *Alternanthera philoxeroides* were negatively related to nitrate in the water body, whereas the distribution of *Monochoria hastata* is positively correlated with nitrate. Depth of water depth is an essential factor influencing other environmental factors like light intensity, temperature and nutrient content which in turn can affect the growth and distribution of submerged macrophytes (Strand and Weisner 2001) and the structure of communities (Wantzen *et al.* 2008). According to Nahlik and Mitch (2006), free-floating plants offer both positive and negative ecosystem habitat and water quality patterns. On the negative side, they prohibited submersed photosynthesis, resulting in low dissolved oxygen in the water and hence less than optimum retention of oxygen-demanding substances. On the positive side, free-floating macrophytes provide shading for water column, thereby decreasing water temperature.

Light is the most critical variables for photosynthesis during the growth of submerged plants is exponentially attenuated with depth (Pedersen *et al.* 2013) in an aquatic ecosystem. This is agreed with the observations in Ponnani *Kole* where suspended, and submerged plants are negatively related to water depth and positively with temperature (Figure 5.1). Similarly *Vallisneria natans,* the submerged plant also shows a positive correlation with temperature (Figure 5.2). According to Kumar and Pandit (2008) depth of the water, body is an important factor for the presence, distribution and diversity of the emergent species. This observation is true with the study where emergent species like *Ludwigia adscendens, Alternanthera philoxeroides* and *Schoenoplectiella supina* are closely related to the depth of water column.

Similarly, *Eichhornia crassipes* the free-floating plant is also closely related to depth. This may be in line with Koch (2001) and, Combroux and Bornette (2004) who opined that macrophytes are inclined by water movements indirectly through the washout or deposition of fine sediment. According to Rameshkumar *et al*. (2019) EC, TDS and turbidity negatively influenced the aquatic macrophytes. In Ponnani Kole lands also many macrophytes show a negative correlation with EC and TDS such *Eichhornia crassipes, Schoenoplectiella supina, Ludwigia adscendens* and *Alternanthera philoxeroides* (Figure 5.2). pH, DO, and alkalinity has shown moderate importance as predictors for the richness of *Ipomoea carnea, Acanthus ilicifolius, Alternanthera tenella, Azolla pinnata* and *Ipomoea pes-caprae*.

Similarly, Vestergaard and Sand-Jensen (2000a) and Lauridsen *et al.* (2015) reported that pH and alkalinity are the important factors determining the distribution and richness of macrophytes in shallow lakes in northern and southern Europe. Siben *et al.* (2016) also reported the ability of salt-tolerant plants for surviving the atmosphere with high pH, alkalinity and electric conductivity. The same condition observed in the study area where salt-tolerant plants like *Ipomoea pes-caprae* and *Acanthus ilicifolius* are showing a positive correlation with high pH and alkalinity. Narayanaa *et al.* (2018) observed the need of high amount of nitrate, phosphate and sulphate for the growth of *Nelumbo nucifera*, *Salvinia adnata* and *Nymphoides indica* in the wetlands of Chikmagalur. In *Kole* wetlands of Ponnani, free-floating plants show a strong correlation with phosphate.

In this study sediment variables like pH, organic carbon, zinc, iron, calcium, copper and phosphorus were the main predictors of variation in the abundance of different growth forms of macrophytes (Figure 5.3). Saluja and Garg (2017) reported that emergent macrophyte species were mostly affected by soil carbon and phosphorus concentration along the littoral zone. This report is agreed with the study area where the distribution of emergent macrophytes shows a positive correlation with phosphorus in the sediment. Hajek *et al.* (2013) pointed out the importance of soil pH for governing the distribution of biotic community and also a balancing agent between ion exchange capacity and nutrient availability. *Alternanthera sessilis* was associated with higher oxygen level and pH indicating high photosynthetic activity (Saluja and Garg, 2017). Our study also reported the strong correlation between *Alternanthera tenella* and sediment variables like potassium, organic carbon and pH (Figure 5.4). Aquatic plant growth occurred in nutrient-rich water and sediments. Dstribution of emergent and floating species was correlated with electrical conductivity of water and total phosphorus (Khedr and El-demerdash, 1997). Ali *et al*. (1995) found evidence that several rooted submerged species occurred at sites with high concentrations of sediment phosphorus rather than water quality parameters. However contradictory to the findings of Ali *et al*. (1995) emergent plants are closely related to the sediment phosphorus in the study area. Roots of macrophytes can modify sediment oxidation –reduction potential by discharge and inclusion of oxygen, which further influences the nutrient content in the sediment-water interface (Zhang *et al*., 2004). Carbon is the major nutrient cycled in within wetlands. Anaerobic and aerobic respiration in the soil influences the nutrient cycling of carbon, hydrogen, oxygen and nitrogen (Ponnamperuma, 1972) and the solubility of phosphorus (Moore and Reddy, 1994) thus contributing to the chemical variations in its water. In the present study, organic carbon is a determining variable for the occurrence of anchored floating and submerged plants.

The interaction between hydrodynamics, sediment dynamics and macrophytes is complex. Despite this complexity, most of the fundamental interactions have been conceptualised at both individual plants and physiognomic forms. Among a set of abiotic factors, the degree of connectivity of the environments with the *Kole* wetland along with other morphometric variables, such as depth, the rate of water flow are the main determinants of macrophyte distribution. Thus, not only species but also groups of species with similar physiognomic forms respond to environmental factors in predicted ways. Therefore results suggest that in *Kole* land ecosystems, the morphometric, hydrological and sediment variables are the primary determinants of the ecological processes. The functioning of ecosystems depends on the functional characteristics of local communities, the link between environmental variables and the biomass of macrophyte life forms, such as those investigated in this study, can be a helpful tool for predicting the effects of environmental changes on ecosystem processes against possible future scenarios.

5.5 CONCLUSION

As it is understood that among the above-mentioned water variables except for BOD, turbidity and nitrate all others are showing significant variation when stations and seasons considered together. The total variation in physiognomic forms explained by the first three axes in CCA was 84.87% with the first axis explaining 39.15% and the second axis explaining 24.59%. Similarly, among the listed sediment variables except for organic carbon, magnesium and zinc all others are showing significant variation when season and stations considered together. When relating sediment variables and most common macrophytes, the majority of the variance (65.4%) in species abundance was explained by the first four axes of CCA. The first axis contributed 23.22% of the variance, second axis by 18.11%, third axis by 13.59% and fourth by 10.48% separately**.** Different physiognomic forms of macrophytes respond differently to environmental changes, which might alter the biomass composition in terms of physiognomic forms with environemtnal parameters. Among a set of abiotic factors, the degree of connectivity of the environment with the *Kole* wetland ecosystem, along with other variables like depth of water column and rate of flow, are the main determinants for the occurrence of different physiognomic forms of macrophyte. Thus, not only species but also groups of species with similar growth forms (functional approach, used in our work) respond to environmental factors in predicted ways. Thus, our results suggest that in *Kole* wetland ecosystem, the hydrological and sediment variables are the primary determinants of the ecological processes, that shaped macrophyte communities in the study area. The operation of ecosystems depends on the functional characteristics of local communities, the link between environmental variables and the biomass of macrophyte species, such as those investigated in this study, can be a helpful tool for predicting the effects of environmental changes on ecosystem processes against possible future scenarios.

Chapter - 6

SUSTAINABLE UTILISATION OF THE AQUATIC MACROPHYTES FROM PONNANI *KOLE* WETLANDS

ABSTRACT

The study aimed at exploring the untapped endemic aquatic plant resources which have high potential on medicinal plants in health care and ornamental plants for the aquarium industry which remains unknown. This investigation revealed the presence of 26 species of medicinal herbs under 23 genera and 18 families and 26 species of ornamental plants under 19 genera and 15 families. The data on the medicinally significant plants indicate that the observed species were used to treat gastrointestinal disorders, respiratory illnesses, dermatological glitches, urinogenital complaints, cardiovascular hitches and neuro disorders in several systems of medicine. Among the listed plant species *Bacopa monnieri*, *Centella asiatica, Evolvulus alsinoides, Cynodon dactylon* and *Hygrophila auriculata* are having greater importance in the therapeutic field and used for different ailments and as diet supplement. Similarly *Nymphaea nouchali*, *Nymphaea pubescence*, *Myriophyllum oliganthum, Nymphoides indica*, *Nymphoides crystatum*, *Bacopa monnieri, Limnophila heterophylla*, *Limnophila repens*, *Utricularia aurea*, *Utricularia gibba, Alternanthera philoxeroides*, *Hydrilla verticillata*, *Vallisneria natans*, *Eichhornia crassipes*, *Hygroryza aristata*, *Najas graminea*, *Marsilea quadrifolia* and *Ceratopteris thalictroides* are the ornamental water plants frequent in all seasons in the study area. Even though all growth forms can be observed in water gardens, anchored floating such as *Nymphaea, Nymphoides, Nelumbo*; and free-floating like *Eichhornia, Pistia* and *Salvinia* are widely used. The most favoured wetland medicinal plants can be domesticated in farmers arena after evolving proper agro-techniques, which will positively help to weaken the pressure on these plants in *Kole* land and other related delicate ecosystems. Many ornamentally important aquatic plants are present in commercially harvestable quantity in the natural environment. The sustainable utilisation of ornamental plants can control the overpopulation of other invasive aquatic macrophytes. The demand of *Nelumbo* and

Nymphaea increases in religious and wedding seasons because of the augmented need for flower offerings and flower arrangements.

The quantitative and qualitative floristic survey, constant monitoring and protection of aquatic and semi-aquatic bodies are needed to save the aquatic flora and to sustain the wild progenitors of medicinal and ornamental plants. Protection of natural populations of these freshwater plants can ensure their continued ecosystem functions and services and sustain natural ecosystem benefits. The data collected in this study highlights the diversity of plants with ornamental and medicinal values. This generates a better understanding of ornamental and medicinal plants of commercial use in *Kole* lands to humanity.

6.1 INTRODUCTION

The *Kole* wetland is a dazzling habitat for several species of aquatic and semi-aquatic flora. Majority of aquatic macrophytes are very delicate to fluctuations in the normal physiochemical parameters of the wetland. Hence any attempt for the modification of this wetland ecosystem may result in their extirpation. This will ultimately end in large scale economic loss in terms of the medicinal products and ornamental trade. Cook (1996) provided short records on the utility of aquatic and wetland plants of India. *Kole* wetland ecosystems designated as wastelands are being reclaimed for various developmental requirements bringing several taxa of immense potential in medicine and aesthetic use on the verge of extirpation. Potential of water plants is only marginally utilised, and no scientific approach has been developed for deriving greater economic and ecological benefits (Mohan Ram, 1991). Multifarious traditional use of macrophytes as bio-resource has been identified in the Cachar district of Assam (Meena and Rout, 2016). Aquatic macrophytes having medicinal and ornamental potentials in wetland area can be utilised for providing employment and income generating to local communities. To achieve the said goal, recurrent collection, often resulted in overexploitation, may be meticulous or supported by current approaches for the propagation of these plants. Macrophytes of *Kole* wetland ecosystem played a fascinating role in the life of humankind in earlier days as food, fodder and medicine. However worth of these wetland plants are overlooked and treated like weeds by changing the lifestyle of humankind.

Due to the rapid pace of urbanisation and industrialisation, wetland habitats are in severe threat of extinction. The increased popularity of water gardening and aquarium planting, in turn, augmented the harvest of the freshwater plants which may result in depletion of these resources. Therefore there is an urgent and utmost need to record and assess the diversity and potentiality of these aquatic medicinal and ornamental plants to formulate management and conservation measures. Most of the aquatic plants in *Kole* lands are grown in the wild, and people have open access to collect and utilise them. The abundance of these plants in the *Kole* lands is worked out to develop harvest strategies and suggest management measures. Community-oriented tactics need to be organized for propagation and sustainable harvest procedures for conservation and better exploitation. Conservation plan should be developed guaranteeing the full participation of the native stakeholders for the effective implementation. Population of these plant species require to be preserved *in situ* by adopting structured cultivation techniques and suitable conservation methods.

6. 1.1 Aquatic herbs of medicinal use

Scientific attempts have neither been made to record the accessibility to medicinal plants nor to highlight the known therapeutic properties of the wetland vegetation of this important zone used by different systems of medicine like Ayurveda, Siddha, folk, Homoeopathy and Unani. The knowledge on the medicinal property of plants has been accrued in many centuries (Kirtikar and Babu, 1980). The local populations have inherited rich traditional information on the usage of these plants against recurring diseases (Vedavathy, 2003). The importance of traditional medicine that provides health service to about 80% of the world population has not been realized to the magnitude that deserves (Bettolo, 1980). India with its excellent traditional knowledge in herbal medicine has higher potentials to increase its share in the world market. Maya and Nair (2003) analysed the economic importance of river vegetation of Kerala including both wetland and bank species. Swapna *et al.* (2011) made a review on the usefulness of Indian wetland plant species as food and medicine by incorporating the traditional understanding of local communities. The interest of the public in plant-based medicine together with the rapid expansion of pharmaceutical industries have necessitated an increased demand for medicinal herbs leading to the over exploitation of many species (Pushpangathan and Nair, 1997). Over utilization of indigenous medicinal plants should be reduced partly through the use of local indigenous knowledge and health care systems (Amusan, 2006).

6.1.2 Aquatic Ornamental Macrophytes

There are many ornamental aquatic plants in wetlands, and the market for them is growing progressively. The use of aquatic plants in the ornamental trade is anticipated to increase as the level of economic growth in the world increases. Aquatic plant cultivation can be a very pleasing and rewarding occupation.

Nature has given a wealth of ornamental plants, unfortunately, many of them have been destroyed, and several have become endangered through overexploitation by human beings (Arora, 1993). Ornamental plants provide aesthetic pleasure and improve the quality of our lives (Save, 2009). Plants exercise a strong positive effect on human behaviour (Lohr and Relf, 1993). It is estimated that 400 species of aquatic plants have been traded in Australia over the past 30 years (Petroeschevsky and Champion, 2008; Champion *et al*., 2010). Around 16 million American households have a water garden (Crosson, 2010); which requires importation and purchase of billions of aquatic plants. Water gardening and aquarium keeping have been well accepted in several countries over the past decade and is one of the best mounting segments of garden hobbyists (Maki and Galatowitsch, 2004). While aquarium release is one of the five top possibilities for the introduction of non-native invasive species (Ruiz *et al*.1997), has received relatively little attention from both scientists and policymakers. Wild ornamental species are also the sources for the medicinal significance (Aasati and Yadav, 2010). While the economic and environmental benefits of water gardens and aquaria are well known and appreciated, some phytosanitary actions should be implemented by National plant protection organisations to control the spread of some known synchronised pests in the ornamental trade (Lindgren and Darbyshire, 2010). Many aquatic plants utilised for ornamental purposes are not native to the country where it is planted (Brunel, 2009). With the augmented interest of homeowners in incorporating ornamental aquatic plants in their landscape, now is the time to establish an ethnic facility to meet the demand.

6.2 MATERIALS AND METHODS

Aquatic macrophytes were collected and identified from various stations of the study area as described in Chapter 1,General Introduction; section 1.5.4.1 and 1.5.4.2. The collected and identified macrophytes were classified as medicinal and ornamental plants based on their use in medicinal and aesthetic purpose (Table 6.1 and Table 6. 2). Usage of medicinal plants in diverse systems of medicine and the pharmacological terms were taken from pharmacological resources as used in the field of pharmacognosy (Udayan and Balachandran, 2009). Ornamental plants were categorised based on the aesthetics of its foliage and adaptability to the confined environment (Cook, 1996).

6.3 RESULTS

Kole lands in Ponnani serve as excellent habitat for numerous aquatic medicinal herbs and ornamental plants which can be harvested for economic benefits. This investigation revealed the presence of 26 species of medicinal herbs under 23 genera and 18 families (Table 6.1) and 26species of ornamental plants under 19 genera and 15 families (Table 6.2) in the Ponnani *Kole* lands.

Currently, macrophytes in this ecosystem are considered as weeds as the paddy cultivation, and open fishing are more economical. Providing basic information on the medicinal attributes and ornamental use of these plants can change the status of them from worst weed to plants of economic importance which are useful for humanity. The medicinal plants recorded from Ponnani *Kole* lands are commonly seen in rivers, ponds and paddy fields all over Kerala; however, *Kole* lands offer plenty of space for practicable agriculture and sustainable exploitation. Some of the therapeutic practices of such species are unique to the traditional medicinal understanding of the locality. Among the listed plant species (Table 6.1), *Evolvulus alsinoides, Centella asiatica, Hygrophila auriculata, Bacopa monnieri* and *Cynodon dactylon* are having greater importance in the therapeutic field and used for different ailments and as a diet supplement.

Similarly *Nymphaea nouchali*, *Nymphaea pubescence*, *Myriophyllum oliganthum, Nymphoides indica*, *Nymphoides crystatum*, *Bacopa monnieri*, *Limnophila heterophylla*, *Limnophila repens*, *Utricularia aurea*, *Utricularia gibba, Alternanthera* *philoxeroides*, *Hydrilla verticillata*, *Vallisneria natans*, *Eichhornia crassipes*, *Hygroryza aristata*, *Najas graminea*, *Marsilea quadrifolia* and *Ceratopteris thalictroides* are the ornamental water plants frequent in all seasons in the study area. Among the listed plants (Table 6.2) *Nymphaea nouchali*, *Nymphaea pubescence* and *Nelumbo nucifera* with showy flowers are mainly used in garden pools as ornamental and all others as aquarium plants. Even though all growth forms can be observed in water gardens, more decorative types received greater emphasis. Mainly anchored floating such as *Nymphaea, Nymphoides, Nelumbo*; and free-floating like *Eichhornia, Pistia* and *Salvinia* are extensively used. Flowers of *Nelumbo nucifera* and *Nymphaea pubescence* are mostly used for offerings in temples and decorations. The demand of these flowers increases in religious and wedding seasons because of the augmented need for flower offerings and flower arrangements. The price of a single lotus flower ranges from Rs. 2.00 to Rs. 5.00 at the place of harvest and Rs. 5.00 to Rs. 10.00 at flower stalls.

Table 6.1. Common names, vernacular names and the practices in different systems of medicine of aquatic medicinal florae from Ponnani *Kole* wetlands collected during the current study.

Sl. No	Name	Common Name	Vernacular	Systems of medicine	Usage (Table 6.3)	Occurrence
1	*Nymphaea nouchali*	Indian water lily	Neerambel, Vellambel, Poothali (M) Kanaval, Kokka (H)	Ayurveda Folk	Diarrhoea, Dysentery, Dyspepsia Cardio tonic, Cutaneous disease The disease of urinary tract, Dermatopathy, Menorrhagia, Erysipelas	Moderate
2	*Nelumbo nucifera*	Sacred lotus, Indian lotus	Thamara, Chenthamara (M) Kamal, Kanval (H)	Ayurveda Siddha Unani, Folk	Hyperdipsia, Cholera, Diarrhoea, Helminthiasis, Haemorrhage, Menorrhagia, Bronchitis	Rare
3	*Ludwigia perennis*		Neerkarayambu (M)	Folk	Dysentery, Headache, Gastric problems, Curing lumbago	Moderate
4	*Ludwigia adscendens*			Folk	Ulcers, Burns, Skin disease	Very High
5	*Centella asiatica*	Indian penny wort	Kudangal,Muthil (M) Brahmamanduki (H)	Ayurveda Folk, Siddha, Unani	Epilepsy, Leprosy, Polyuria, Distaste, Psychosis, Fever, Bronchial asthma, Stammer, Rejuvenator, Brain tonic, Nervine and cardiac tonic.	Low
6	*Mollugo pentaphylla*		Parpadakam (M)	Folk, Siddha	Aperient, Antiseptic, Poultices for Sore leg, Ear ache	Low
7	*Sphaeranthus africanus*		Veluthaadakkamanian (M)	Ayurveda	Abdominal tumour, Colic, Indigestion, Piles, Hydrocele, Diarrhoea, Leucorrhoea, Blood purifier	Low
8	*Oldenlandia corymbosa*		Parpadakam (M)	Ayurveda Folk	Blood purifier, Stimulate action of liver, Improve digestion, Diarrhoea, Menorrhagia, Distatse Giddiness, Intoxication, Skin disease	Moderate

Sl. No	Name	Common Name	Vernacular	Systems of medicine	Usage	
9	*Aniseia martinicensis*		Venthiruthali, Kulayadambu (M)	Folk	Bilious dyspepsia, Purgative	Moderate
10	*Evolvulus alsinoides*		Vishnukranti, Krishnakranthi (M) Syamakrantha (H)	Folk, Siddha, Unani, Ayurveda	Carminative, Rejuvenator,Used in Bronchitis, Asthma, Epilepsy, Anorexia, Piles, Abdominal disorder, Haematemesis, Insomnia, Psychosis, Amentia, Internal haemorrhage, Dysentery, Diarrhoea, Helminthiasis, All kinds of fever, As brain stimulant	Rare
11	*Ipomoea carnea*			Folk	Purgative	Moderate
12	*Ipomoea pes-caprae*	God's foot creeper	Kuthirakulamban(M) Dopatilata (H)	Folk, Siddha	Skin diseases, Swellings, Wounds, Ulcers, Dropsy, Menorrhagia, Haemorrhoids, Dyspepsia, Vomiting, Burning sensation	
13	*Bacopa monnieri*	Bacopa	Neerbrami (M) Jalnim, Barami (H)	Ayurveda Folk, Homeopathy Siddha	Brain tonic, Improve memory power, Intelligence and Mental health, Cure indigestion, Constipation, Insanity, Anaemia, Leprosy, Polyuria, Psychosis, Emaciation, Epilepsy	High
14	*Acanthus ilicifolius*		Chakaramulli, Chulli (M)	Folk, Siddha	Asthma, Paralysis, Leucorrhoea, Debility, Neuralgia, Rheumatism, Expectorant	Moderate
15	*Hygrophila auriculata*	Long-leaved barleria	Vayalchuli (M) Kamtakaliya, Talmakhana (H)	Ayurveda, Folk	Appetite, Aphrodisiac, Rejuvenator, Eye disease, Urinary calculi, Dysuria, Gout, Arthritis, Amavatha, Bladder stone, Arrest of abortion.	Moderate
16	*Hygrophila ringens*			Folk	Appetite, Arthritis, Amavatha, Eye disease, Bladder stone, Arrest abortion, Toothache	Moderate

Sl. No	Name	CommonName	Vernacular	Systems of medicine	Usage	
17	*Clerodendrum inerme*	Wild jasmine Gardenquine	Puzhamulla Chinnayila (M)	Folk, Siddha	Fever, To resolve Buboos, Rheumatism	Moderate
18	*Alternanthera tenella*	Sessile joy weed	Ponnamkannikkeera(M) Gudrisag (H)	Folk, Ayurveda Siddha, Unani	Rejuvenator, Night blindness, Diarrhoea, Leprosy, Dyspepsia, Splenomegaly, Snakebite, Fever, Skin disease	High
19	*Persicaria pulchra*		Veluthamuthalamooku (M)	Folk, Siddha, Unani	Ulcers, Stomach ache, Diarrhoea, Carminative, Purgative, Emetic	Moderate
20	*Hydrilla verticillata*	Hydrilla		Folk, Siddha	Abscess to maturity	High
21	*Monochoria vaginalis*		Karimkoovalam, Kolachembu	Ayurveda, Folk, Siddha, Unani	Strangury, Gastropathy, Hepatopathy, Asthma, Scurvy, Haemorrhage	Moderate
22	*Pistia stratiotes*	Nile cabbage, Water bonnet, Water lettuce	Akasathamara, Kudappayal, Muttappayal (M)	Folk, Siddha, Unani	Goitre, a Blood disorder, Emaciation, Skin diseases	Low
23	*Schoenoplectiella articulata*		Chelli (M)	Folk	Purgative	Moderate
24	*Hygroryza aristata*	Bengal wild rice	Neervallipullu,Varinellu (M) Jungali-dal (H)	Ayurveda Folk	Diuretic, Emollient, Galactagogue, Strangury, Diarrhoea, Otopathy, Fatigue, General debility	Moderate
25	*Cynodon dactylon*	Bermuda grass, Hariali grass, Dogs tooth grass	Karuka, Balikaruka (M)	Ayurveda, Folk, Homeopathy, Unani	Fever, Chronic diarrhoea Dysentery, Dropsy, Wounds, Catarrhal ophthalmia, Haemorrhage, Erysipelas, Scabies, Menorrhagia, Piles, Epilepsy, Insanity	Moderate
26	*Oryza sativa*	Paddy	Nellu (M)	Ayurveda Folk, Siddha, Unani	The disease of pitta, Aphrodisiac, Diuretic, Galactagogue, Vomiting, Debility, Piles	Low

Vernacular:Malayalam(M);Hindi(H)

Table 6.2.Occurrence of ornamental aquatic macrophytes in Ponnani *Kole* wetlands

Sl. No	Species	Common name	Occurrence
1	*Nymphaea nouchali*	Indian water lily	Moderate
2	*Nymphaea pubescence*	Hairy Water Lily	Moderate
3	*Nelumbo nucifera*	Indian lotus	Rare
4	*Aeschynomene indica*	Sola pith plant	Moderate
5	*Myriophyllum oliganthum*.	Water milfoil	Moderate
6	*Rotala indica*	Indian tooth cup	Low
7	*Rotala macrandra*	Giant red rotala	Moderate
8	*Nymphoides indica*	Water-snowflake, Banana-plant	High
9	*Nymphoides crystata*	Crested Floating heart	Moderate
10	*Bacopa monnieri*	Water Hyssop	High
11	*Limnophila heterophylla*	Manganari	Low
12	*Limnophila repens*	Manganari	Moderate
13	*Lindernia antipoda*	Sparrow false pimpernel	Low
14	*Lindernia rotundifolia*	Lindernia variegated	Moderate
15	*Utricularia reticulata*	Krishnapoovu, Net veined bladder	High
16	*Utricularia* gibba subsp. *Exoleta*	Huped bladderwort	Moderate
17	*Utricularia aurea*	Golden bladderwort	High
18	*Alternanthera philoxeroides*	Alligator weed	High
19	*Ceratophyllum demersum*	Coontail	Moderate
20	*Hydrilla verticillata*	Hydrilla	High
21	*Vallisneria natans*	Eel grass	High
22	*Eichhornia crassipes*	Water hyacinth	Very High
23	*Monochoria vaginalis*	Pickerel Weed	Moderate
24	*Pistia stratiotes*	Water lettuce	Low
25	*Aponogeton natans*	Floating lace Plant, Drifting Sword Plant	Moderate
26	*Najas indica*	Najas grass, Guppy grass	Moderate

6.4 DISCUSSION

As we know that, worldwide, wetlands are dwindling rapidly hence their resources, both plants and animals are also reducing at the same pace. The agricultural interests of *Kole* lands are facing severe difficulties due to the falling price of rice, growing spending for farming and unavailability of the agricultural work hands. This leads small scale farmers to leave their agricultural fields without farming or change the land use pattern which ultimately alters the vital function of the ecosystem. In the context of unexplored potential and shrinking resources, *Kole* lands should be properly managed giving high priority for the conservation and propagation of medicinally important herbal resources and ornamental plants of aesthetic use. Medicinal plants offer easily accessible and relevant resources for primary wellbeing with minimum side effects (Shahzadi and Bhat, 2012). This is true with medicinal plants of Ponnani *Kole* lands using as ingredients of many Ayurvedic preparations for different ailments. Chai *et al.* (2014) reported that anticancer and anti oxidative products are derived from *Centella asiatica, Nelumbo nucifera, Ipomoea aquatica* and *Ludwigia adscendens* which are frequently observed in the study area. The nutritive values of some macrophytes have been deliberated by various authors (Shaltout *et al.,* 2009; Nafea, 2017) and the present enumeration emphasizes the usefulness of the *Kole* land plant wealth which in turn may form another criterion to conserve the delicate ecosystem. Harvesting of the medicinally important aquatic macrophytes should be improved and managed for appropriate utilisation of these indigenous information and fitness care systems. Most of the wetland medicinal flora has a low shelf life; therefore creating quality by-products can enhance the revenue. Also the most preferred wetland therapeutic plants can be domesticated in farmers arena after evolving proper agro-techniques, which can positively help to weaken the pressure on these plants in *Kole* land and other related delicate ecosystems.

The ornamental aquatic plant industry is booming worldwide but neglected in Ponnani *Kole* lands. Utilisation of this untapped resource should be given more attention as a potential income source for the people residing around the area. Many ornamentally important aquatic plants are present in commercially harvestable quantity in the natural environment of this ecosystem. The sustainable utilisation of ornamental plants can control the overpopulation of other invasive aquatic macrophytes. Also, the culture of economically important plants can also provide an excellent employment opening for the villagers residing in the bordering and neighbouring areas of *Kole* wetlands. Lack of community involvements in management efforts, source of revenue, and shortage of awareness amongst decision makers on the exact values of wetland were major weaknesses in the protection of wetland resources (Kairo *et al*., 2000). The quantitative and qualitative floristic survey, regular monitoring and protection of aquatic and semi-aquatic bodies are needed to save the aquatic flora and to sustain the wild progenitors of medicinal and ornamental plants. Protection of natural populations of these freshwater plants can ensure their continued ecosystem functions and services and sustain natural ecosystem benefits. The data collected during the present study highlights the diversity of plants with ornamental and medicinal values. This generates a better understanding of ornamental and medicinal plants of commercial use in *Kole* lands to humanity.

6.5 CONCLUSION

The existence of aquatic species of *Kole* lands is vulnerable owing to the dwindling of the extent of wetland and alterations in land use pattern. Hence the aquatic resources, particularly those having economic worth and direct significance to the local public are required to be prioritised for protection. *Kole* lands provide not only useful resources but also significant in terms of ecology, renewal of ground water and maintaining the microclimate of the region. Eco-restoration of marshland zones, conservation instruction to communities and income generating avenues along with additional promotional activities like ecotourism would support the conservation of these valuable resources in long-run. A strong participatory approach linking local people and other stakeholders is mandatory for sustainable management of this wetland expanse. To achieve the said goal, the community needs to be organised for adopting sustainable harvest protocols for all these wetland species and required training should be given to them. Therefore a broad and comprehensive management strategy, based on ethnic, ecological and financial principles, need to be planned for this *Kole* wetland area for sustainable management by the full participation of local stakeholders.

Table 6.3: Glossary of medical terms

1	Anorexia	No appetite
2	Aphrodisiac	A drug that arouses sexual desire
3	Arthritis	Inflammation for joints
4	Aperient	Mild purgative
5	Bubo	Abscess of lymph gland
6	Carminative	Relieving flatulence
7	Catarrhal	Inflammation of the mucous membrane
8	Dermatopathy	Skin disease
9	Dropsy	Accumulation of serous fluid in cellular tissues or serous cavities
10	Dyspepsia	Reduced water intake
11	Dysuria	Painful urination or absence of urine
12	Emaciation	A state of extreme leanness
13	Emetic	Drug inducing vomiting
14	Emollient	A substance that softens the skin
15	Epilepsy	An affection of the nervous system resulting from an excessive or disordered discharge of cerebral neurons.
16	Erysipelas	An inflammatory disease affecting the face marked by redness of the skin
17	Expectorant	Aiding the secretion of the mucous membrane
18	Galactagogue	Producing milk
19	Gastropathy	Stomach disease
20	Goitre	Enlargement of the thyroid gland
21	Haemorrhage	Bleeding
22	Haemorrhoid	Piles
23	Helminthiasis	Presence of parasite worms in the body
24	Hepatopathy	Liver disease
25	Hydrocele	Circumscribed gathering of fluid in the tunica vaginalis testis
26	Hyperdipsia	Intense thirst
27	Insanity	Mental disease
28	Leucorrhoea	White discharge from the vagina and uterine cavity
29	Lumbago	Pain in the lower back
30	Menorrhagia	Profuse discharge of menses
31	Neuralgia	A painful regard of nerves due to functional disturbances
32	Octopathy	A morbid condition of the ear
33	Ophthalmia	Inflammation of the whole eye
34	Polyuria	Upsurge in the amount of urine due to diabetes
35	Poultice	Thick pasty preparation intended for local application
36	Psychosis	Mental disorder
37	Purgative	Promoting evacuation from bowel
38	Scurvy	Disease due to deficiency of vitamin C
39	Splenomegaly	Spleen enlargement
40	Stammer	Speech disorder
41	Strangury	Slow and painful discharge of urine

SUMMARY AND CONCLUSION

The present investigation brought out a comprehensive and systematic report of the diversity and ecology of freshwater macrophytes in Ponnani *Kole* wetland ecosystem. The Ponnani *Kole* land is spread in Chavakkad and Choondal to Thavannur, covering Chavakkad and Thalapally taluks of Thrissur district and Ponnani Taluk of Malappuram district; the northern-most extension of Vembanad *Kole* –the Ramsar site. This wetland comes under the 'Central Asian-Indian Flyway' and serves as 'stepping stone' for the trans-continental migrant birds. The study area is extending from the southern bank of Bharathapuzha in the north to Naranipuzha in the south in a stretch of twenty kilometres. Macrophytes being the primary producers of this ecosystem, the studies on its diversity and ecology are very significant.

Twelve stations were fixed based on the prevailing environmental disturbances and ecological peculiarities. Since the seasonal variables of a year showed fluctuations, two-year samplings were carried out for estimating macrophyte diversity and abundance, water and sediment parameters from these twelve stations viz. Porangue, Cheerppu, Mukolamthazhath, Aynichira, Kottamukku, Kalachal, Naranipuzha, Uppungalkadavu, Vadakkekkottol, Muchikadavu, Kummipalam and Thuyyam spread across Ponnani *Kole* lands. These stations were pooled, as disturbed and undisturbed areas and also based on the type of disturbances developed, such as the area of saline intrusion, area of agricultural activities and area of sewage disposal. The seasonal trends from the regular two-year observations were found to be useful for elucidating the ecological status of the study area. The seasons selected were the post-monsoon, pre-monsoon and monsoon periods of 2014-2016. The study was carried out with a hypothesis that the community structure of the macrophytes in the *Kole* wetland varies with the region, time, water and sediment quality parameters. The results emerging from the study on composition and distribution of macrophytes of *Kole* lands can provide actual information on species richness. Results also point out the importance of macrophytes not only in the ecosystem level but also their relevance in the medicinal and ornamental fields.

From each station, 100m transect was laid parallel to the bank and observed for the macrophyte diversity and plants were collected for identification. Along the transect, one spot was selected randomly by lot for sampling and then three more samples were collected with uniform distance to achieve systematic random sampling. Thus quadruplicate of samples was collected for the estimation of macrophyte abundance, hydrographic parameters and sediment parameters. Taxonomic identification of the collected plants was carried out using standard Floras and Monographs. The taxonomic characteristics of the aquatic macrophytes were recorded along with their local names, abundance, spread/distribution, physiognomic form and use in medicinal and ornamental levels. The collected plants were categorised into seven major physiognomic forms such as Free-floating, Suspended hydrophytes, Submerged hydrophytes, Anchored floating, Emergent hydrophytes, Wetland plants and Mangrove and associates.

Hydrological parameters such as turbidity, pH, EC, hardness, temperature, acidity, alkalinity, TDS, calcium, magnesium, chloride, fluoride, iron, DO, BOD, sulphate, phosphate, nitrate, depth of water column and rate of flow were estimated using standard methods. Sediment parameters like pH, EC, organic carbon, phosphorus, potassium, calcium, magnesium, sulphur, copper, iron, zinc, manganese and boron were also estimated. Data so collected were analysed statistically adopting appropriate techniques and interpreted to arrive at specific conclusions. The following are important findings of the investigation.

- The study recorded 87 species of true aquatic macrophytes in which 82 were angiosperms spread over 53 genera of 28 families, 4 were pteridophytes spread over four genera of 3 families, and one was a macroscopic alga. Cyperaceae and Poaceae were the most abundant families with 11 species, each belonging to six and nine genera respectively. The next richest family was Convolvulaceae with six species belonging to 4 genera. Plantaginaceae and Hydrocharitaceae were represented by five species each. The genus *Cyperus* was the richest with five species followed by *Limnophila* with four species whereas *Rotala, Ludwigia, Oldenlandia*, *Ipomoea, Lindernia* and *Utricularia* were represented by three species each. Out of 82 angiosperms recorded, 34 were monocots, and 48 were dicots. Among seven physiognomic forms, Wetland plants were dominated and represented by 37 species followed by Emergent Hydrophytes (13), Anchored Floating (10), Mangrove and associates (9), Suspended Hydrophytes (8), free-floating (6) and Submerged Hydrophytes (4).

- The distribution, abundance and community structure of macrophytes in aquatic systems are highly seasonal. Seasonal variation in the community assemblage of macrophytes showed that variation in the mean biomass, evenness (1-ƛ) and average taxonomic distinctness (AvTD; Δ+) of aquatic macrophytes were not significant ($p>0.05$) during monsoon, post-monsoon and pre-monsoon seasons. However, the number of species in the macrophyte assemblage in post-monsoon and monsoon showed significant variation from that of pre-monsoon. Diversity was found to be higher in post-monsoon, whereas a decrease in diversity was observed in pre-monsoon. Significant variation in taxonomic distinctness (VarTD, **Λ+)** was observed between three different seasons. Lower VarTD was observed in pre-monsoon and higher in post-monsoon. Even though the bio-climatic condition of the region was found to be fluctuating with seasons, the range of variability seemed to be within the tolerable limit of macrophytes; the fluctuations play a significant role in the determination of community structure of macrophytes.

- The K-dominance plot indicates higher species diversity in most of the sampling stations during post-monsoon than monsoon and pre-monsoon. The curve also explains 90% of the stations have less than 20 species during pre-monsoon whereas 80% of the stations have less than ten species during monsoon.

- The funnel plot showed that the AvTD in pre-monsoon is above 95% confidence level of the global mean. Mean AvTD of macrophytes in post-monsoon and monsoon are very close to the expected value simulated from the whole assemblage. Funnel plot developed to configure the ordination of VarTD of macrophyte assemblages in three different seasons showed that VarTD in post-monsoon, pre-monsoon and monsoon falls within a 95% confidence limit of the global mean.

- The results of ANOVA and post hoc analysis showed significant ($p<0.05$) variation in the free-floating and submerged macrophyte community assemblage during different seasons. All other physiognomic forms like suspended, anchored, emergent, wetland and mangrove were not showing significant variation seasonally.

- Community structure of aquatic macrophytes in different regions of mild disturbances (area of saline intrusion, area of agricultural activities, area of sewage disposal) in Ponnani *Kole* wetlands showed significant variation. Mean diversity did not differ significantly among various zones of disturbance except saline intruded zones. Taxonomically, similar species grew well in all regions of the study excluding in the saline intrusion area. In the undisturbed region, considered as control, the presence of all macrophytes was recorded in equal proportions except for mangroves and suspended hydrophytes.

- The K-dominance plot clearly shows that the curve representing macrophytes of saline zone rises rapidly and lies above the curves of sewage, control and agriculture zones because only a few species were recorded from this zone. However, the curves representing agriculture fields, sewage and control zones lie on the lower side and rising slowly because of the occurrence of a large number of species with the dominance of many species.

- Diversity indices viz. Species Richness, Biomass, Shannon Diversity Index, Simpsons Evenness Index, Average Taxonomic Distinctiveness and Variation in Taxonomic Distinctiveness of aquatic macrophytes and results of ANOVA and post-hoc analysis for different disturbances (saline area, agricultural area, sewage disposal area and undisturbed zone) showed significant variation.

- Simulation tests to check the deviation of AvTD recorded from the global mean (funnel plot) showed that the AvTD in saline intrusion areas was well below the 95% confidence level of the global mean. Mean AvTD values in the area of intensive agricultural activities and the control area was very close to the expected range simulated from the global assemblage, while AvTD in sewage disposal area fell below the 95% confidence level.

- VarTD values for intensive agriculture, sewage disposal and control were observed within the 95% confidence limit of the global mean for all the sites with values for saline intrusion shown (funnel plot) above the global mean limits. The result shows an equal dominance of all macrophyte species belonging to various higher taxa in all zones of study except that of the saline intrusion areas.

- NMDS plot showed 60% similarity for Macrophytes assemblages within the four different zones. However, between the sewage, agriculture and control zones, macrophyte assemblages showed 40% similarity. Only 20% similarity was observed between the macrophyte assemblages of saline zones with all other studied areas.

- Macrophytes recorded from the different zones of disturbance in wetland were categorised based on their habits, and the results showed that in the area of saline intrusion, the dominant macrophytes include mangroves and its associates, like *Ipomoea pes-caprae, Acanthus ilicifolius, Clerodendrum inerme, Avicennia officinalis* and *Cyperus javanicus*, which constituted about 58% of the total biomass. In the areas of intense agricultural activity, anchored floating macrophytes like *Nymphaea nouchali, N. pubescence, Nymphoides crystata, Marsilea quadrifolia,* (30.37%) and wetland plants like *Aeschynomene indica, Hygrophila auriculata, Alternanthera tenella* and *Eragrostis gangetica* (23.54%) were dominated. In the sewage disposal area, anchored floating (30.83%) and free-floating plants (30.36%) were the dominant groups with free-floating plants like *Eichhornia crassipes, Pistia stratiotes, Lemna perpusilla* and *Salvinia adnata* were very recurrent. In the control area, wetland plants (28.06%) and anchored floating (28.61%) were the dominant groups.

- Among the hydrological parameters studied, a significant variation ($p<0.05$) could be observed spatially and seasonally for pH, electric conductivity, hardness, temperature, acidity, alkalinity, total dissolved solids, calcium, magnesium, chloride, fluoride, iron, dissolved oxygen, sulphate, phosphate, depth of water column and rate of water flow; whereas turbidity, BOD and nitrate showed no significant variation during different seasons from different stations. Among the sediment variables recorded from four different zones, significant variation ($p<0.05$) could be observed spatially and seasonally for parameters like pH, electrical conductivity, phosphorus, potassium, calcium, sulphur, copper, iron, manganese and boron. However, organic carbon, magnesium and zinc showed no significant variation between seasons or zones.

- Canonical correspondence analysis (CCA) was adopted to analyse the relationship between the abundance of physiognomic forms and environmental variables. The total variation in physiognomic forms, concerning water quality parameters, explained by the first three axes in CCA was 84.87%. The ordination diagram explains that water quality parameters like turbidity, depth and rate of flow are strongly correlated. Similarly, BOD and phosphate are correlated; fluoride, sulphate and alkalinity also showed a strong positive correlation. BOD and phosphate content showed a positive influence on the abundance of free-floating macrophytes. Presence of chloride, nitrate, calcium and hardness of water were positively correlated to the abundance of emergent hydrophytes. Wetland plants showed a positive correlation with electrical conductivity and TDS, whereas, mangrove and its associates were negatively related to TDS and conductivity. Temperature is an important factor influencing the abundance of suspended and submerged hydrophytes, whereas iron is negatively related to the occurrence of suspended and submerged macrophytes. Anchored floating macrophytes were showing a negative correlation with dissolved oxygen and pH in this ecosystem.

- CCA supported results of the indicator species analysis by signifying that certain species were associated with specific water variables. Acidity, rate of water flow and temperature were closely related to the frequency of occurrence of *Vallisneria natans* and acidity is positively related to the occurrence of *Cyperus javanicus*. Nitrate, sulphate, calcium, magnesium, chloride, fluoride and hardness of water were positively correlated with the distribution of *Monochoria hastata*. pH is closely related to the distribution of *Ipomoea pes-caprae, Acanthus ilicifolius,* and *Alternanthera tenella*, whereas, pH and acidity are essential variables for the occurrence of *Azolla pinnata*. *Ipomoea carnea* is strongly related to dissolved oxygen in the water body and showing a negative relationship with acidity and temperature. BOD and phosphate which were closely related with the occurrence of *Persicaria pulchra* and the frequency of distribution of *Nymphaea pubescence* and *Salvinia adnata* were strongly related to the BOD of water. Similarly, the depth of the water body was directly related, but total dissolved solids and electric conductivity were negatively related to the occurrence of *Eichhornia crassipes.*

- CCA used to appraise the influence of sediment variables on physiognomic forms showed that copper, calcium, iron and zinc in the soil have a positive influence on the abundance of wetland plants. Calcium, zinc and iron are closely related to the frequency of occurrence of free-floating plants. Organic carbon is positively related to the abundance of anchored floating plants, whereas, sulphur and boron are negatively related to their abundance. pH is an important factor influencing the abundance of submerged plants.

- Similarly, a positive association of iron and manganese with *Ludwigia adscendens* and *Ipomoea aquatic* and negative correlation with boron was observed. *Avicennia officinalis* was positively associated with copper and negatively correlated with potassium; *Alternanthera tenella* positively associated with potassium and negatively with copper. *Acanthus ilicifolius* is strongly related to calcium and phosphorus. Frequency of occurrence of *Eichhornia crassipes* is positively related to electric conductivity, and that of *Ipomoea carnea* is with zinc. Distribution of the submerged macrophyte *Vallisneria natans* is closely associated with magnesium and *Monochoria hastata* is closely related to sediment pH.

- Investigation revealed the presence of 26 species of medicinal herbs and 26 species of ornamental plants in the study area. The observed species of macrophytes were used to treat gastrointestinal disorders, respiratory illnesses, dermatological glitches, urinogenital complaints, cardiovascular hitches and neuro disorders in several systems of medicine. *Bacopa monnieri*, *Centella asiatica, Evolvulus alsinoides, Cynodon dactylon* and *Hygrophila auriculata* are having greater importance in the therapeutic field and used for different ailments and as a diet supplement. Similarly *Nymphaea nouchali*, *Nymphaea pubescence*, *Myriophyllum oliganthum, Nymphoides indica*, *Nymphoides crystatum*, *Bacopa monnieri, Limnophila heterophylla*, *Limnophila repens*, *Utricularia aurea*, *Utricularia gibba, Alternanthera philoxeroides*, *Hydrilla verticillata*, *Vallisneria natans*, *Eichhornia crassipes*, *Hygroryza aristata*, *Najas graminea*, *Marsilea quadrifolia* and *Ceratopteris thalictroides* are the ornamental water plants frequent in all seasons in the study area.

Detailed knowledge concerning the floristic composition, ecology and environmental factors that influence vegetation types, provide a strong basis to research and helps in the improvement of conservation and management practices in relation to the vegetation and biodiversity of *Kole* wetland ecosystems. The data collected in this study highlights the diversity of plants with ornamental and medicinal values for understanding their commercial use to humanity. Not only species but also groups of species with similar growth forms (functional approach, used in our work) respond to environmental factors in predicted ways.

Thus, our results suggest that in *Kole* wetland ecosystem, the hydrological and sediment variables are the primary determinants of the ecological processes that shaped macrophyte communities in the study area. The operation of ecosystems depends on the functional characteristics of macrophyte communities, the link between environmental variables and the biomass of macrophyte species, such as those investigated in this study, can be a helpful tool for predicting the effects of environmental changes on ecosystem processes against possible future scenarios. By this study, we can also underscore the detail changes of macrophytes composition in a seasonal frame and also we can correlate these studies in depicting the pollution status of a water body. The observed disturbances indicated that the future growth of agriculture and other human led activities would augment the rate of species loss by typical aquatic plants susceptible to slight disorders in this wetland system. This phenomenon could accordingly alter the functional status and community structure. Sustainable wetland utilisation, fit for purpose, can be achieved through empowering local communities as primary users and preservers, while technical support should come from government and educational agencies. It involves various operational methods including the upkeep of the wetland as an aqua-park, fish reserve, centre for culture augmentation and repository for tropical aquatic macrophyte germplasm.

Conservation and management plans for this wetland system for the sustainable ecosystem services such as biodiversity, food security, water resources, and trade-offs based on the macrophyte community structure can be a model for the global wetland ecosystems. Considering the location-based significance of the site, variability in the occurrence of aquatic macrophytes within a range, and distribution of the area which is least affected by the mild environmental disturbances, we are suggesting this as an ideal site for the establishment of a macrophyte dominated ecological regime. The area thus demarcated can be further developed to a conservation and educational site for tropical aquatic macrophytes. To achieve the said goal, the community needs to be organised for adopting sustainable harvest protocols for all these wetland species and required training should be given to them. Therefore a broad and comprehensive management strategy, based on ethnic, ecological and financial principles, need to be planned for this *Kole* wetland area for sustainable management by the full participation of local stakeholders. A strong participatory approach linking local people and other stakeholders is mandatory for sustainable management of this wetland expanse.

Recommendations

1. Location-specific conservation and management plan for the area has to be developed

The shrinkage of Ponnani *Kole* wetland, as a result of land reclamation, has been the most critical environmental consequence of various human interventions. This fragile ecosystem is influencing the life and health of people living around the region and is imperative for the conservation of biodiversity and for sustaining human life. Reclamation of this wetland ecosystem, including the encroachments for developmental activities, needs to be reassessed. The amendment to the Kerala Conservation of Paddy Land and Wetland Act 2008 is one of the crucial decisions that the Kerala government has undertaken. The state urgently wants to issue in ecological rationale in decision-making and conserve paddy fields and wetlands for the long term health of the state. It is indispensable that the authorities develop a sustainable action plan to restore and conserve the Ponnani *Kole* wetland system at the earliest. Since there are multiple agencies involved in wetland conservation, right from planning to implementation and monitoring, there is a need to consolidate all these functions under an umbrella agency for better synchronisation and responsibility. Developing an economic valuation for the ecosystem services (such as health, environmental, cultural and recreational benefits) offered by these wetlands to make the indirect and unappreciated benefits of these wetlands visible and comparable, enabling policymakers to see the actual economic value of the wetland and implant them into planning.

2. Formation of stakeholder groups for creating awareness and implementation of the participatory conservation plans

Being one among the most sensitive ecosystems, it needs a highly proactive and participatory conservation strategy customised to the local situation, with sufficient returns apparent to the locals. The government must be a facilitator, while stakeholder should become caretaker of wetlands. Significant decisions about the conservation and welfare of wetlands should be initiated by the end-users of water bodies. Their suggestions should provide guidelines for decision-makers in higher levels of government. The wetland rules do consider "overall well being of the people". However, we believe this should be rephrased to "overall development of ecosystem" to prevent encroachments and construction activities on wetlands. For the same reason, the section "expedient in the public interest" should be rephrased with "expedient in the environmental interest". Sustainable wetland utilisation, fit for purpose, can be achieved through empowering local communities as primary users and preservers, while technical support should come from government and educational agencies. Organised extensive aqua farming of macrophytes of aquarium relevance with the participation of local stakeholders is also suggested as a means for sustainable utilisation of the wetland for future generations, and in developing opportunities for rural employment.

3. Sustainable utilisation of resources of the *Kole* wetlands

The aquatic resources, particularly those having food, medicinal and ornamental values, are required to be prioritised for protection. Eco-restoration of these *Kole* lands, conservation instruction to communities and income generating avenues along with additional promotional activities like ecotourism would support the conservation of these valuable resources in long-run. Most of the wetland medicinal flora has a low shelf life; therefore, creating quality by-products can enhance the revenue. Also, the most preferred wetland therapeutic plants can be domesticated in farmer's arena after evolving proper agro-techniques, which can positively help to weaken the pressure on these plants in *Kole* land ecosystem. The ornamental aquatic plant industry is also booming worldwide but neglected in Ponnani *Kole* lands. The utilisation of this untapped resource should be given more attention as a potential income source for the people residing around the area. The culture of economically important plants can also provide an excellent employment opening for the villagers residing in the bordering and neighbouring areas of *Kole* wetlands. The community needs to be organised for adopting sustainable harvest protocols for all these wetland species and required training should be given to them. Therefore a broad and comprehensive management strategy, based on ethnic, ecological and financial principles, need to be planned for this

Kole wetland area for sustainable management of these useful resources by the full participation of local stakeholders.

4. Setting up of an institution/authority for coordinating conservation, education, and sustainable utilisation

A management authority for protection, development and spreading awareness by initiating educational programs about the significance of wetlands in schools, colleges and among the general public in the vicinity of the wetlands, besides regular monitoring of wetlands for their ecosystem characters, would offer vital inputs to uphold the wetlands from further weakening. Sufficient tie-ups of trained academicians and professionals; including ecologists, economists, watershed management specialists, planners and decision-makers must be associated with local expertise for the overall running of wetlands. Promoting long term multidisciplinary research, preparing an environmental status report and establishing education centre are the immediate needs for the conservation of all its genetic diversity. The management authority should do proper survey, plans and prepare project proposals for the integrated resource management for all-round development of the wetland system. There should be a collaboration between the department of agriculture, department of animal husbandry and department of fishery along with local administration in the state; and also with national and international institutions for up-keeping the international status of this ecosystem. It involves various operational methods including the upkeep of the wetland as an aqua-park, fish reserve, territory for migratory birds, centre for culture augmentation, centre for eco-tourism and repository for tropical aquatic macrophyte germplasm.

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Table S1. Rainfall data for the study area during 2014-2016

month	season	Total Rain Fall (mm)			
October-14	Post- Monsoon 2014	107.6			
November-14	Post- Monsoon 2014	40.4			
December-14	Post- Monsoon 2014	0.0			
January-15	Post- Monsoon 2014	0.0			
February-15	Premonsoon 2015	0.0			
March-15	Premonsoon 2015	21.0			
April-15	Premonsoon 2015	172.2			
May-15	Premonsoon 2015	108.4			
June-15	Monsoon 2015	759.0			
July-15	Monsoon 2015	456.9			
August-15	Monsoon 2015	452.1	2014-2015		
September-15	Monsoon 2015	388.6	Avg	**208.85**	mm
October-15	Post- Monsoon 2015	229.7	Max	**759.00**	mm
November-15	Post- Monsoon 2015	147.0	Total	**2506.20**	mm
December-15	Post- Monsoon 2015	0.0			
January-16	Post- Monsoon 2015	0.0			
February-16	Premonsoon 2016	0.0			
March-16	Premonsoon 2016	0.0			
April-16	Premonsoon 2016	115.2			
May-16	Premonsoon 2016	8.8			
June-16	Monsoon 2016	269.2			
July-16	Monsoon 2016	331.2			
August-16	Monsoon 2016	343.2	2015-2016		
September-16	Monsoon 2016	144.1	Avg	**132.37**	mm
			Max	**343.20**	mm
Total	Avg	**170.61**	Total	**1588.40**	mm
	Max	**759.00**			
	Total	**4094.60**			
			Avg	**170.61**	mm
			Avg Ann. Rain fall	**2047.3**	**mm**

Courtesy: Kerala Agriculture University, Kelappaji College of Engineering Tavanur, Malppuram

Table S 2 WATER DEPTH IN MM

POST-MONSOON	Muchikadav	Aynichira	Kottamukku	Naranipuzha	Vadakkekkottol
	300	250	500	550	520
	1000	600	400	200	740
	500	750	200	800	210
	1250	800	250	1350	860
	1400	750	350	400	600
	650	900	250	200	500
	450	750	250	250	100
	780	800	480	450	150
	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
	791.25	**700**	**335**	**525**	**460**
PRE-MONSOON	480	320	280	320	80
	120	120	480	270	150
	280	200	360	520	120
	670	120	540	1260	160
	200	100	150	120	10
	100	400	100	470	200
	100	250	800	620	300
	130	500	400	200	170
	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
	260	**251.25**	**388.75**	**472.5**	**148.5**
MONSOON	1200	600	400	200	300
	800	400	400	750	700
	2100	1500	300	1600	650
	1720	1000	250	400	500
	1250	650	500	250	320
	900	420	450	800	750
	2250	1450	350	1750	700
	1800	1100	300	450	550
	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
	1502.5	**890**	**368.75**	**775**	**558.75**

Table S3. Relative abundance (gm.M^{-2}) of aquatic macrophytes in three different seasons within Ponnani *Kole* wetlands.

	Species	Habit	Post-monsoon	Pre-monsoon	Monsoon
1	*Nymphaea nouchalli*	AF	715.68	1502.93	278.97
2	*Nymphaea pubescence*	AF	612.43	40.99	19.46
3	*Nelumbo nucifera*	AF	0	69.20	0
4	*Melochia corchorifolia*	WP	0	0	19.948
5	*Aeschynomene indica*	WP	149.84	0	346.50
6	*Rotala indica*	WP	32.96	0	0
7	*Rotala macrandra*	WP	369.02	0	1.94
8	*Rotala malampuzhensis*	WP	0	0	10.192
9	*Ludwigia adscendens*	EH	408.57	972.74	816.86
10	*Ludwigia hyssopifolia*	WP	20.24	0	0
11	*Ludwigia perennis*	WP	44.27	41.58	95.57
12	*Mollugo pentaphylla*	WP	0	39.6	0
13	*Centella asiatica*	WP	11.52	0	4.01
14	*Oldenlandia brachypoda*	WP	0	0	395.60
15	*Oldenlandia corymbosa*	WP	35.70	9.57	79.14
16	*Oldenlandia herbacea*	WP	0	5.10	0
17	*Eclipta prostrate*	WP	0	0	3.40
18	*Sphaeranthus africanus*	WP	21.19	0	0
19	*Nymphoides crystata*	AF	0	0	99.35
20	*Nymphoides indica*	AF	168.53	386.84	124.4
21	*Aniseia martinicensis*	MA	257.28	0	37.68
22	*Evolvulus alsinoides*	WP	0	0	22.65
23	*Ipomoea aquatica*	AF	364.2	380.24	736.24
24	*Ipomoea carnea*	AF	148.53	0	0
25	*Merremia tridentata*	WP	0	0	211.66
26	*Bacopa monnieri*	AF	166.08	1175.22	138.88
27	*Limnophila aquatica*	EH	32.02	1.73	10.31
28	*Limnophila heterophylla*	EH	22.69	0	0
29	*Limnophila repens*	WP	37.74	0	105.71
30	*Lindernia antipoda*	WP	121.52	3.85	0
31	*Lindernia hyssopioides*	WP	0	0	1.99
32	*Lindernia rotundifolia*	WP	0	1.88	14.58
33	*Utricularia aurea*	SH	11.68	54.09	159.44
34	*Utricularia gibba* subsp. *exoleta*	SH	89.39	0	33.02
35	*Utricularia reticulata*	SH	290.58	0	60.20
36	*Hygrophila ringens*	WP	58.85	11.07	444.29
37	*Hygrophila auriculata*	WP	330.4	0	147.76
38	*Clerodendrum inerme*	MA	427.87	0	0
39	*Avicennia officinalis*	MA	0	942.25	0
40	*Alternanthera philoxeroides*	EH	0	0	2878.76
41	*Alternanthera tenella*	WP	1638.88	181.27	360.98
42	*Persicaria pulchra*	WP	27.50	0	671.11
43	*Persicaria glabra*	WP	428.19	0	125.67
44	*Ceratophyllum demersum*	SH	0	90.98	5.92
45	*Elodea canadensis*	SH	0	54.45	0
46	*Hydrilla verticillata*	SH	123.81	65.44	473.06

47	*Vallisneria natans*	MH	264.82	1933.79	5.47
48	*Najas graminea*	MH	38.96	234.64	0
49	*Najas indica*	MH	18.64	1.28	0.26
50	*Eichhornia crassipes*	FF	1829.47	339.64	4068.28
51	*Monochoria hastata*	EH	1254.41	12.08	0
52	*Monochoria vaginalis*	EH	0	976.45	202.
53	*Lemna perpusilla*	FF	19.25	54.06	0
54	*Aponogeton natans*	AF	0	1.48	0
55	*Eriocaulon setaceum*	MH	30.06	0	0
56	*Cyperus cephalotes*	EH	0	277	0
57	*Cyperus difformis*	WP	35.16	509.30	0
58	*Cyperus haspan*	WP	89.72	0	7.02
59	*Cyperus dubius*	WP	210.04	0	0
60	*Cyperus javanicus*	MA	0	854.97	0
61	*Eleocharis dulcis*	EH	129.49	329.69	0
62	*Fimbristylis miliacea*	MA	172.16	0	0
63	*Fuirena ciliaris*	WP	63.70	10.87	0
64	*Schoenoplectiella articulata*	EH	276.07	0	1062.60
65	*Schoenoplectiella supina*	EH	1543.05	0	0
66	*Cynodon dactylon*	WP	0	57.53	117.43
67	*Eragrostis atrovirens*	WP	0	47.96	0
68	*Eragrostis gangetica*	WP	0	517.28	74.43
69	*Hygroryza aristata*	FF	543.48	0	349.84
70	*Hymenachne amplexicaulis*	WP	207.24	0	0
71	*Leersia hexandra*	WP	0	752.16	110.25
72	*Paspalum distichum*	MA	72.92	0	0
73	*Sacciolepis interupta*	EH	5.49	0	128.44
74	*Sporobolus virginicus*	MA	97.86	11.51	0
75	*Oryza rufipogon*	WP	22.08	0	34.99
76	*Oryza sativa*	WP	135.91	0	0
77	*Nitella mucronata*	SH	170.12	0	0
78	*Ceratopteris thalictroides*	SH	0	15.58	0
79	*Marsilea quadrifolia*	AF	67.24	140.46	194.31
80	*Salvinia adnata*	FF	579.66	368.79	1002.76
81	*Azolla pinnata*	FF	805.7	7.68	1.12

*Mean values of dry weight for 40 observation in each season. **Habit**: FF-Free floating; SH-Suspended hydrophytes; MH-Submerged hydrophytes; AF-Anchored floating; EH-Emergent hydrophytes; WP-Wetland plants; MA-Mangrove and associates.

Table S4: SPSS output for the comparison of mean diversity from three different seasons of Ponnnai *Kole* wetlands

GET FILE='C:\Users\User\Downloads\spss.sav'. ONEWAY d Hlog2 @1Lambda Delta Lambda BY category /POSTHOC=DUNCAN ALPHA(0.05).

ONEWAY d Hlog2 @1Lambda Delta Lambda S N BY category /POSTHOC=DUNCAN ALPHA(0.05).

ONEWAY S Biomass Hlog2 @1Lambda Delta Lambda BY category /POSTHOC=DUNCAN ALPHA(0.05).

Oneway

[DataSet1] C:\Users\User\Downloads\spss.sav

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
S	Between Groups	70.817	2	35.408	9.185	.000
	Within Groups	451.050	117	3.855		
	Total	521.867	119			
N	Between Groups	117585.817	2	58792.908	.864	.424
	Within Groups	7964401.350	117	68071.806		
	Total	8081987.167	119			
H'(log2)	Between Groups	4.674	2	2.337	4.144	.018
	Within Groups	65.983	117	.564		
	Total	70.657	119			
1-Lambda	Between Groups	.294	2	.147	2.164	.119
	Within Groups	7.945	117	.068		
	Total	8.239	119			
Delta+	Between Groups	365.341	2	182.671	.451	.638
	Within Groups	47400.233	117	405.130		
	Total	47765.574	119			
Lambda+	Between Groups	472259.920	2	236129.960	4.635	.012
	Within Groups	5961154.504	117	50950.038		
	Total	6433414.424	119			

Species richness

Duncan[a]

season	N	Subset for alpha = 0.05	
		1	2
pre-monsoon	40	3.55	
monsoon	40		4.63
post-monsoon	40		5.43
Sig.		1.000	.071

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 40.000.

Biomass

Duncan

season	N	Subset for alpha = 0.05
		1
pre-mon	40	337.10
post-mon	40	398.73
monsoon	40	407.43
Sig.		.260

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 40.000.

Shannon Diversity

Duncan

season	N	Subset for alpha = 0.05	
		1	2
pre-mon	40	1.06787	
monsoon	40	1.22608	1.22608
post-mon	40		1.54257
Sig.		.348	.062

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 40.000.

Simpson Evenness

Duncan

season	N	Subset for alpha = 0.05
		1
pre-mon	40	.405589
monsoon	40	.447180
post-monsoon	40	.524991
Sig.		.054

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 40.000.

Average taxonomic distinctness (AvTD)

Duncan[a]

season	N	Subset for alpha = 0.05
		1
pre-mon	40	75.7400
monsoon	40	78.9868
post-mon	40	79.7705
Sig.		.404

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 40.000.

Variation in taxonomic distinctness (VarTD)

Duncan[a]

season	N	Subset for alpha = 0.05	
		1	2
pre-mon	40	177.429	
monsoon	40	267.591	267.591
post-mon	40		330.273
Sig.		.077	.217

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 40.000.

Oneway

[DataSet1] C:\Users\User\Downloads\spss.sav

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
FREEFLOATING HYDROPHYTES	Between Groups	278233.819	2	139116.910	3.690	.028
	Within Groups	4410725.660	117	37698.510		
	Total	4688959.479	119			
SUSPENDED HYDROPHYTES	Between Groups	3070.651	2	1535.325	.741	.479
	Within Groups	242336.218	117	2071.250		
	Total	245406.869	119			
SUBMERGED HYDROPHYTES	Between Groups	67276.615	2	33638.308	6.177	.003
	Within Groups	637199.496	117	5446.150		
	Total	704476.111	119			
ANCHORED FLOATING HYDROPHYTES	Between Groups	87575.211	2	43787.605	1.104	.335
	Within Groups	4639119.886	117	39650.597		
	Total	4726695.097	119			
EMERGENT HYDROPHYTES	Between Groups	52275.364	2	26137.682	1.305	.275
	Within Groups	2342504.967	117	20021.410		
	Total	2394780.331	119			
WETLAND PLANTS	Between Groups	46433.204	2	23216.602	1.670	.193
	Within Groups	1626869.028	117	13904.863		
	Total	1673302.232	119			
MANGROVE AND ASSOCIATES	Between Groups	39391.166	2	19695.583	2.335	.101
	Within Groups	987010.268	117	8435.985		
	Total	1026401.434	119			

FREEFLOATING HYDROPHYTES

Duncan[a]

season	N	Subset for alpha = 0.05	
		1	2
PRE-MONSOON	40	19.25430	
POST- MON	40	94.43890	94.43890
MONSOON	40		135.55000
Sig.		.086	.346

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 40.000.

SUBMERGED HYDROPHYTES

Duncan[a]

season	N	Subset for alpha = 0.05	
		1	2
MONSOON	40	.21	
POST- MON	40	8.81	
PRE-MONSOON	40		54.18
Sig.		.603	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 40.000.

MANGROVE AND ASSOCIATES

Duncan[a]

season	N	Subset for alpha = 0.05	
		1	2
MONSOON	40	.94	
POST- MON	40	25.70	25.70
PRE-MONSOON	40		45.22
Sig.		.230	.344

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 40.000.

SUSPENDED HYDROPHYTES

Duncan[a]

season	N	Subset for alpha = 0.05
		1
Pre-monsoon	40	7.01
Post -monsoon	40	17.10
Monsoon	40	18.29
Sig.		.301

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 40.000.

ANCHORED FLOATING HYDROPHYTES

Duncan[a]

season	N	Subset for alpha = 0.05
		1
Post-monsoon	40	68.76260
Pre-monsoon	40	116.75280
Monsoon	40	132.21370
Sig.		.182

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 40.000.

EMERGENT HYDROPHYTES

Duncan[a]

season	N	Subset for alpha = 0.05
		1
Monsoon	40	35.08
Pre-monsoon	40	39.92
Post -monsoon	40	81.58
Sig.		.169

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 40.000.

WETLANDPLANTS

Duncan[a]

season	N	Subset for alpha = 0.05
		1
Pre -monsoon	40	54.72550
Monsoon	40	85.17060
Post -monsoon	40	102.29101
Sig.		.090

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 40.000.

Table S5. Relative abundance (gm.M^{-2}) of aquatic macrophytes from the three disturbances and control study zones within Ponnani *Kole* wetands

			Disturbance Zones			
	Species	**Habit**	**Saline***	**Agriculture***	**Sewage***	**Control***
1	*Nymphaea nouchali*	AF	0	862.07	0	170.38
2	*Nymphaea pubescens*	AF	0	1025.56	956.38	147.63
3	*Aeschynomene indica*	WP	0	522.69	0	0
4	*Myriophyllum oliganthum*	EH	0	93.012	0	0
5	*Rotala indica*	WP	0	22.58	0	0
6	*Rotala macrandra*	WP	0	91.368	0	4.76
7	*Rotala malampuzhensis*	WP	0	55.348	0	0
8	*Ludwigia adscendens*	EH	0	1536.86	875.34	897.25
9	*Ludwigia hyssopifolia*	WP	0	4.99	37.07	0
10	*Ludwigia perennis*	WP	0	228.57	193.92	29.22
11	*Centella asiatica*	WP	0	6.5	0	0
12	*Oldenlandia brachypoda*	WP	0	11.70	0	172.58
13	*Oldenlandia corymbosa*	WP	0	0.52	0	0
14	*Sphaeranthus africanus*	WP	0	0	22.572	0
15	*Nymphoides crystata*	AF	0	704.60	52.57	0
16	*Nymphoides indica*	AF	1.17	264.76	38.50	84.01
17	*Aniseia martinicensis*	MA	0	69.26	0	35.756
18	*Ipomoea aquatica*	AF	0	267.94	2002.44	333.72
19	*Ipomoea carnea*	AF	0	68.57	1564.99	0
20	*Ipomoea pes-caprae*	MA	1879.29	0	0	0
21	*Merremia tridentata*	WP	544.03	8.30	37.74	69.65
22	*Bacopa monnieri*	AF	0	10.05	358.87	20.79
23	*Limnophila aquatica*	EH	0	714.40	9.48	0.58
24	*Limnophila heterophylla*	EH	0	52.48	0	0
25	*Limnophila indica*	EH	0	5.78	0	0
26	*Limnophila repens*	WP	0	155.17	0	0
27	*Lindernia rotundifolia*	WP	0	135.82	4.28	0
28	*Utricularia aurea*	SH	0	124.49	95.80	0.18
29	*Utricularia gibba* subsp. *exoleta*	SH	0	1.711	64.56	0.04
30	*Utricularia reticulata*	SH	422.56	71.68	65.09	198.51
31	*Acanthus ilicifolius*	MA	5520.52	0	0	0
32	*Hygrophila ringens*	WP	254.53	40.97	0	0
33	*Hygrophila auriculata*	WP	298.18	534.43	0	0
34	*Clerodendrum inerme*	MA	1922.50	0	0	0
35	*Avicennia officinalis*	MA	3386.28	0	54.69	633.27
36	*Alternanthera philoxeroides*	EH	5.46	423.36	425.46	667.76
37	*Alternanthera tenella*	WP	0	446.42	302.12	96.52
38	*Persicaria pulchra*	WP	0	248.01	1320.59	590.28
39	*Persicaria glabra*	WP	0	242.20	264.96	386.76
40	*Ceratophyllum demersum*	SH	0	0.3	0	16.61
41	*Elodea canadensis*	SH	0	944.19	0	0
42	*Hydrilla verticillata*	SH	0	545.59	1.14	7.58
43	*Vallisneria natans*	MH	0	601.89	1458.21	474.38
44	*Eichhornia crassipes*	FF	2700.71	677.59	2063.18	0

45	*Monochoria hastata*	EH	1795.64	429.85	2571.82	47.16
46	*Monochoria vaginalis*	EH	0	427.4	331.54	110.20
47	*Pistia stratiotes*	FF	0	0	1396.78	0
48	*Colocasia esculenta*	WP	0	0	643.40	0
49	*Lemna perpusilla*	FF	0	7.62	0.66	0
50	*Aponogeton natans*	AF	0	28.99	0	0
51	*Najas graminea*	MH	0	320.76	0	0
52	*Najas indica*	MH	0	8.01	0	0
53	*Eriocaulon setaceum*	MH	0	53.90	0	0
54	*Cyperus difformis*	WP	0	0	28.64	35.16
55	*Cyperus haspan*	WP	807.58	30.9	0	5.21
56	*Eleocharis dulcis*	EH	0	35.64	85.25	0
57	*Cyperus dubius*	WP	201.78	0	0	0
58	*Cyperus javanicus*	MA	4080.01	574.72	0	64.12
59	*Schoenoplectiella articulata*	EH	974.51	40.32	84.92	50.21
60	*Schoenoplectiella supine*	EH	2297.10	23.95	98.64	757.99
61	*Cynodon dactylon*	WP	239.90	73.65	90.97	117.43
62	*Eragrostis atrovirens*	WP	610.60	0	53.22	0
63	*Eragrostis gangetica*	WP	148.17	520.93	0	556.44
64	*Hygroryza aristata*	FF	148.16	226.18	0	180.04
65	*Hymenachne amplexicaulis*	WP	0	11.00	0	49.44
66	*Leersia hexandra*	WP	71.77	42.57	100.81	282.30
67	*Paspalum distichum*	MA	104.05	0	19.44	0
68	*Sacciolepis interupta*	EH	1177.06	0	0	83.36
69	*Sporobolus virginicus*	MA	549.40	83.82	135.09	0
70	*Oryza rufipogon*	WP	0	17.74	0	0
71	*Oryza sativa*	WP	0	28.80	360.04	0
72	*Nitella mucronata*	SH	0	26.59	245.92	0
73	*Ceratopteris thalictroides*	SH	0	71.60	15.56	0
74	*Marsilea quadrifolia*	AF	0	669.51	483.25	121.04
75	*Salvinia adnata*	FF	0	1923.66	2855.41	690.87
76	*Azolla pinnata*	FF	0	789.27	564.2	347.56

*Mean values of dry weight for 48 observation except agriculture, and agriculture 72 sample. **HABIT**: FF-Free floating; SH-Suspended hydrophytes; MH-Submerged hydrophytes; AF-Anchored floating; EH-Emergent hydrophytes; WP-Wetland plants; MA-Mangrove and associates

Table S6: SPSS out put for the comparison of mean diversity indices from different zones of disturbance from the Ponnnai Kole wetlands

GET FILE='C:\Users\User\Downloads\spss.sav'. ONEWAY d Hlog2 @1Lambda Delta Lambda BY category /POSTHOC=DUNCAN ALPHA(0.05).

ONEWAY d Hlog2 @1Lambda Delta Lambda S N BY category /POSTHOC=DUNCAN ALPHA(0.05).

ONEWAY S Biomass Hlog2 @1Lambda Delta Lambda BY category /POSTHOC=DUNCAN ALPHA(0.05).

Oneway

[DataSet1] C:\Users\User\Downloads\spss.sav

ANOVA

		Sum of Squares	df	F	Sig.
Species Richness	Between Groups	320.655	3	25.354	4.666E-14
	Within Groups	893.715	212		
	Total	1214.370	215		
Biomass	Between Groups	3.841E+06	3	11.114	8.340E-07
	Within Groups	2.442E+07	212		
	Total	2.827E+07	215		
Shannon Diversity	Between Groups	27.447	3	17.607	3.040E-10
	Within Groups	110.158	212		
	Total	137.605	215		
Simpson Evenness	Between Groups	2.993	3	15.362	4.427E-09
	Within Groups	13.768	212		
	Total	16.761	215		
AvTD	Between Groups	73762.459	3	33.357	1.059E-17
	Within Groups	156266.086	212		
	Total	230028.546	215		
VarTD	Between Groups	2.853E+06	3	19.833	2.271E-11
	Within Groups	1.016E+07	212		
	Total	1.302E+07	215		

Species richness

Duncan[a,b]

category	N	Subset for alpha = 0.05	
		1	2
SALINE	48	1.67	
SEWAGE	48		4.13
CONTROL	48		4.27
AGRICULTURE	72		4.90
Sig.		1.000	.068

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 41.143.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Biomass

Duncan[a,b]

category	N	Subset for alpha = 0.05		
		1	2	3
AGRICULTURE	72	269.57		
CONTROL	48		405.96	
SEWAGE	48		472.21	
SALINE	48			627.98
Sig.		1.000	.319	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 41.143.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Shannon Diversity

Duncan[a,b]

category	N	Subset for alpha = 0.05	
		1	2
SALINE	48	.37832	
SEWAGE	48		1.11455
CONTROL	48		1.21442
AGRICULTURE	72		1.29587
Sig.		1.000	.228

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 41.143.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Simpson Evenness

Duncan[a,b]

category	N	Subset for alpha = 0.05	
		1	2
SALINE	48	.160775	
SEWAGE	48		.412654
CONTROL	48		.435814
AGRICULTURE	72		.462160
Sig.		1.000	.353

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 41.143.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Average taxonomic distinctness (AvTD)

Duncan[a,b]

category	N	Subset for alpha = 0.05	
		1	2
SALINE	48	30.77	
SEWAGE	48		73.74
CONTROL	48		74.51
AGRICULTURE	72		76.51
Sig.		1.000	.627

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 41.143.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Variation in taxonomic distinctness (VarTD)

Duncan[a,b]

category	N	Subset for alpha = 0.05		
		1	2	3
SALINE	48	40.238		
CONTROL	48		193.428	
AGRICULTURE	72		246.040	
SEWAGE	48			379.395
Sig.		1.000	.220	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 41.143.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table S7 The detailed result of different water parameters in different seasons and differents zones

Seasons	Zones	Turbidity	pH	EC	Temperature	Acidity	Alkalinity (Total)	TDS	Total hardness (as Ca CO3)	Calcium [as Ca]	Magnesium	Chloride (as cl)	Fluoride (as f)	Iron (as Fe)	DO	BOD	Sulphate [as SO4]	Phosphate [as PO4]	Nitrate [as NO3]	Depth (in cm)	Rate of water flow
Post-monsoon	Saline	3	7.6	45000	29	1.5	94	32250	5900	1000	826.5	16800	1.6	1.63	5.6	2.5	920	0.04	1.34	15	110
Post-monsoon	Saline	5	7.3	45500	27	1.5	97	32300	5950	1020	826.2	16850	1.7	1.64	5.8	2.6	922	0.039	1.35	40	100
Post-monsoon	Saline	4	7.5	47000	27	2.5	98	32100	5750	960	825.9	16760	1.9	1.6	7	2.9	916	0.042	1.34	25	130
Post-monsoon	Saline	4	7.4	46500	29	2.5	95	32150	5800	940	826.2	16710	2	1.61	7	2.8	914	0.043	1.36	28	140
Post-monsoon	Saline	1.5	7.7	48000	30	2	70	33500	7400	790	1320	13100	1.8	1.42	5.8	2.7	1000	0.037	1.68	20	95
Post-monsoon	Saline	1.6	7.71	47900	31	1.7	69	33520	7410	795	1321	13170	1.7	1.43	7	2.8	1002	0.038	1.69	40	97
Post-monsoon	Saline	1.7	7.79	47600	26	2.3	75	33400	7450	781	1329	12900	2	1.51	5.6	2.5	1004	0.034	1.67	72	85
Post-monsoon	Saline	1.6	7.76	47700	29	2	74	33420	7420	786	1326	12830	2.1	1.52	8	2.4	1002	0.035	1.66	18	83
Post-monsoon	Control	0.45	7.68	4730	27.5	3.8	35	3300	595	106	82	1300	0.5	0.85	6.3	2.4	110	0.03	0.84	30	74
Post-monsoon	Control	0.5	7.7	4750	28	3.9	36	3314	590	107	82.5	1330	0.52	0.87	6.1	2.45	111	0.031	0.86	100	76
Post-monsoon	Control	0.55	7.66	4710	26.5	4.1	33	3308	605	102	82.74	1400	0.48	0.81	6.7	2.2	117	0.033	0.83	50	64
Post-monsoon	Control	0.5	7.64	4690	26	4.2	32	3294	610	101	83.24	1370	0.46	0.79	6.9	2.15	118	0.034	0.82	125	66
Post-monsoon	Agriculture	0.52	6.79	600	27.5	11	24.5	425	87	14.2	12.1	160	0.4	1.42	8	3.5	5.4	0.032	2	28	0
Post-monsoon	Agriculture	0.54	6.8	602	27	11.5	24	420	89	14.1	12.12	161	0.41	1.4	8	3.4	5.5	0.031	2.1	40	0
Post-monsoon	Agriculture	0.48	6.77	616	28.5	9	23.5	427	85	14.6	12.2	164	0.44	1.44	8.2	3.7	5.2	0.034	2.2	16	0
Post-monsoon	Agriculture	0.46	6.76	614	29	8.5	24	432	83	14.7	12.18	163	0.43	1.42	7.5	3.8	5.1	0.035	2.3	32	0
Post-monsoon	Control	3	6.8	200	28	3.7	29.5	140	39	7.1	5.35	63	0.37	2.15	5.8	3.7	20.5	0.315	2.5	55	98
Post-monsoon	Control	3.1	6.81	201	27	3.8	29	141	38	7	5.37	61	0.36	2.14	7.5	3.6	20.7	0.316	2.54	20	95
Post-monsoon	Control	3.2	6.85	209	29	4.2	30.5	148	41	7.3	5.33	65	0.39	2.19	7	3.9	20.3	0.313	2.59	80	102
Post-monsoon	Control	3.1	6.86	210	28	4.3	31	147	42	7.4	5.31	67	0.4	2.2	6.3	4	20.1	0.312	2.6	135	105
Post-monsoon	Agriculture	0.9	6.5	239	27.5	7.5	15	163	40	6.5	6.3	68	0.48	1.95	5.7	2.8	32.5	0.025	1.54	10	78
Post-monsoon	Agriculture	0.8	6.48	240	27	7.7	14	161	41	6.6	6.28	67	0.49	1.97	5.6	2.7	32.6	0.024	1.55	24	80
Post-monsoon	Agriculture	1.1	6.54	235	26.5	8.5	17	169	43	6.3	6.34	72	0.46	1.91	5.9	3	32.3	0.027	1.56	17	72
Post-monsoon	Agriculture	1.2	6.56	234	27	8.3	18	171	44	6.2	6.36	73	0.45	1.89	6	3.1	32.2	0.028	1.53	36	70
Post-monsoon	Agriculture	2.3	6.95	246	27	5.8	21	170	35	7.1	4.36	71	0.4	0.96	6.5	2.5	22.9	0.038	2.08	24	68
Post-monsoon	Agriculture	2.2	6.96	247	28	5.7	21.5	172	35.5	7	4.35	70	0.39	0.97	6.7	2.6	23	0.037	2.06	35	67
Post-monsoon	Agriculture	2.5	6.93	243	29	6.2	23	169	36.5	7.3	4.38	73	0.42	0.94	6.4	2.3	22.7	0.04	2.05	55	72
Post-monsoon	Agriculture	2.6	6.92	244	28	6.3	22.5	173	37	7.4	4.39	74	0.43	0.93	6.8	2.2	22.6	0.041	2.2	13	73
Post-monsoon	Sewage	1.3	6.24	48	27	17	13	34	18.5	3.8	1.95	37	0.26	0.99	4.1	3.8	7.8	0.045	2.3	15	28
Post-monsoon	Sewage	1.2	6.21	45	27.5	16	12.5	33	19	3.7	1.97	38	0.27	1	5.5	3.9	7.7	0.046	2.4	10	30
Post-monsoon	Sewage	1.5	6.25	55	29	19	15	36	17	4.2	1.93	35	0.24	0.97	6	3.6	8.2	0.043	2.36	23	32
Post-monsoon	Sewage	1.6	6.22	52	28.5	20	15.5	37	17.5	4.3	1.91	34	0.23	0.96	6	3.5	8.3	0.042	2.35	20	30
Post-monsoon	Sewage	0.4	7.2	2550	28	1.8	48	1810	312	67.3	34	920	0.53	0.39	6.3	2.6	70	0.035	1.98	25	28
Post-monsoon	Sewage	0.3	7.21	2560	28.5	1.9	47	1808	315	67.5	35	910	0.51	0.4	6.1	2.5	69	0.037	1.96	42	30
Post-monsoon	Sewage	0.6	7.18	2620	30	2.1	53	1816	308	67.1	35.5	940	0.59	0.35	6.9	3	74	0.029	1.99	76	26
Post-monsoon	Sewage	0.7	7.17	2630	29.5	2.2	52	1818	305	66.9	33.5	950	0.61	0.34	7.1	3.1	75	0.027	2.01	132	24
Pre-monsoon	Saline	0.1	7.45	37500	33	10	90	25950	5900	365	1190.8	17800	0.99	1.33	6.3	0.3	165	0.034	1.36	30	30
Pre-monsoon	Saline	0.2	7.44	37200	32.9	11	92	26000	5850	370	1190.9	17750	1	1.34	6.4	0.2	170	0.035	1.35	70	28
Pre-monsoon	Saline	0.3	7.42	36500	32.6	13	93	25850	5700	355	1190.6	17600	0.97	1.3	6	0.2	155	0.032	1.38	12	34
Pre-monsoon	Saline	0.2	7.41	36800	32.7	14	93	25800	5750	350	1190.5	17650	0.96	1.31	6.1	0.1	150	0.031	1.39	62	36
Pre-monsoon	Saline	5.6	7.95	38200	32.9	9	99	26400	7000	530	1350	23850	2.05	1.21	7.2	0	140	0.04	1.69	40	14

Pre-monsoon	Saline	5.7	7.93	38400	33	8.5	102	26700	7050	540	1351	23900	2.06	1.2	7.3	0	141	0.038	1.7	58	16
Pre-monsoon	Saline	5.4	7.99	37800	32.7	7	95	26900	6800	505	1372	23700	2.01	1.28	6.8	0	146	0.042	1.67	73	10
Pre-monsoon	Saline	5.3	8.01	37600	32.6	7.5	96	26400	6750	505	1371	23750	2	1.27	6.7	0	145	0.044	1.66	12	8
Pre-monsoon	Control	1.35	6	11910	32.9	28.5	19	8350	3520	324	652	7350	0.87	0.98	6.5	0.95	306	0.05	0.85	48	65
Pre-monsoon	Control	1.4	6.01	11900	33	29	19.5	8345	3540	322	650	7250	0.88	0.99	6.4	0.9	302	0.051	0.86	12	63
Pre-monsoon	Control	1.2	5.96	11950	32.6	27.5	21	8355	3480	316	660	7500	0.83	1	5.8	0.85	305	0.053	0.83	28	69
Pre-monsoon	Control	1.25	5.95	11960	32.7	27	20.5	8354	3460	318	662	7500	0.82	0.99	5.6	0.9	303	0.054	0.82	67	71
Pre-monsoon	Agriculture	1.9	7.2	940	32.5	3.7	24.5	660	138	19.5	21.8	198	0.34	0.9	3.2	0.6	65	0.049	2.1	15	0
Pre-monsoon	Agriculture	2	7.21	942	32	3.8	25	661	137	19	21.85	197	0.33	0.89	3.3	0.5	64	0.05	2	12	0
Pre-monsoon	Agriculture	1.6	7.18	950	32	4.3	23.5	663	142	20.5	21.94	202	0.36	0.92	3	0.8	67	0.047	2.3	17	0
Pre-monsoon	Agriculture	1.7	7.17	952	31.5	4.2	23	664	143	21	21.89	203	0.37	0.93	4	0.9	68	0.046	2.4	30	0
Pre-monsoon	Control	1.7	5.3	1370	31.5	27	13.5	950	175	31.5	24.1	188	0.47	0.89	5.8	1.3	99.33	0.06	2.6	32	70
Pre-monsoon	Control	1.8	5.31	1371	31	29	13	940	173	31	24	186	0.45	0.9	6.7	1.2	99.22	0.07	2.59	27	73
Pre-monsoon	Control	1.5	5.28	1380	33	26	14.5	970	185	32.5	24.6	192	0.51	0.87	6.2	1.5	99.55	0.04	2.64	52	68
Pre-monsoon	Control	1.4	5.27	1379	32.5	30	15	980	187	33	24.5	194	0.53	0.86	6.3	1.6	99.66	0.03	2.65	126	65
Pre-monsoon	Agriculture	2.8	6.13	910	31	23.5	13	640	148	19	24	122	0.65	0.99	5.8	0.9	110	0.039	1.56	27	34
Pre-monsoon	Agriculture	2.9	6.12	915	30	23	13.5	641	147	20	24.1	124	0.63	0.95	7	0.7	112	0.038	1.57	12	33
Pre-monsoon	Agriculture	2.5	6.17	923	33	24.5	15	646	153	21	24.5	118	0.67	1	6	0.8	116	0.037	1.54	32	38
Pre-monsoon	Agriculture	2.6	6.18	928	34	25	14.5	645	152	20	24.6	116	0.69	0.94	6.1	0.8	118	0.038	1.53	24	39
Pre-monsoon	Agriculture	1.2	6.5	1195	31	3.9	18.5	830	123	15	21.9	188	0.48	0.66	5.1	1.8	53.6	0.049	2.09	80	34
Pre-monsoon	Agriculture	1.1	6.49	1196	30.5	3.8	19	842	125	14.5	21.91	185	0.47	0.65	5	1.7	53.61	0.05	2.07	52	35
Pre-monsoon	Agriculture	1.4	6.52	1193	33	4.1	17.5	833	135	17	21.84	192	0.5	0.68	5.3	2	53.66	0.047	2.06	122	30
Pre-monsoon	Agriculture	1.5	6.53	1192	33.5	4.2	17	839	137	17.5	21.83	195	0.51	0.69	5.4	2.1	53.65	0.046	2.1	64	29
Pre-monsoon	Sewage	2.1	6.19	1245	31	7.8	19	870	255	37	41.3	119	0.68	2.55	5.1	1.8	173	0.012	2.4	8	0
Pre-monsoon	Sewage	2.3	6.2	1240	30	7.7	20	869	254	38	41.29	118	0.69	2.56	5	1.7	175	0.014	2.42	12	0
Pre-monsoon	Sewage	2.4	6.17	1249	33	8.2	17	874	265	35	41.32	121	0.66	2.53	5.3	2	167	0.011	2.38	5	0
Pre-monsoon	Sewage	2	6.16	1250	34	8.3	16	875	266	34	41.33	122	0.65	2.52	5.4	2.1	165	0.015	2.36	6	0
Pre-monsoon	Sewage	23	3.66	9800	33	130	0	7100	3000	230	530	7000	0.88	3.2	5.8	0	320	0.018	1.95	15	145
Pre-monsoon	Sewage	25	3.67	9700	33.1	135	0	7200	3100	220	525	7100	0.9	3.22	4	0	317	0.02	1.93	10	148
Pre-monsoon	Sewage	19	3.62	10200	32.6	110	0	6900	2600	250	538	6800	0.84	3.16	6.2	0	324	0.014	2.03	80	139
Pre-monsoon	Sewage	17	3.61	10300	32.5	105	0	6800	2500	260	543	6700	0.82	3.14	6.4	0	327	0.012	2.05	45	136
Monsoon	Saline	3.9	6.53	190	30	9	27	135	37	5.8	5.35	19	0.89	1.24	5.7	0.9	5.9	0.014	1.02	25	94
Monsoon	Saline	4	6.54	191	32	8	26	136	38	5.7	5.36	20	0.9	1.23	5.8	0.8	6	0.015	1.03	15	96
Monsoon	Saline	3.7	6.51	194	26	7	29	133	35	5.5	5.33	17	0.87	1.2	5.5	1.2	5.7	0.012	1	42	90
Monsoon	Saline	3.6	6.5	193	24	8	30	132	34	5.4	5.32	16	0.86	1.21	5.4	1.1	5.6	0.011	0.99	36	88
Monsoon	Saline	6.7	7	387	29	4.5	27	270	55	8.5	8.27	114	0.9	1.49	5.7	1.4	14	0.015	1.49	42	56
Monsoon	Saline	6.65	7.06	380	27	4	29	272	53	8	8.29	113	0.89	1.5	5.8	1.45	14.1	0.014	1.47	20	58
Monsoon	Saline	6.5	7.02	390	30	3.5	25	267	56	7.5	8.25	110	0.92	1.45	5.5	1.6	13.6	0.017	1.45	56	52
Monsoon	Saline	6.55	7.04	383	26	4	23	267	52	8	8.23	111	0.93	1.44	5.4	1.55	13.5	0.018	1.43	63	50
Monsoon	Control	16.2	6.76	129	25.5	4.3	19.5	88	28.5	8.2	1.96	36.5	0.25	1.82	5.3	0.42	2.8	0.013	1.65	120	65
Monsoon	Control	16	6.78	131	25	4.5	19	87	28	8.5	1.95	36	0.24	1.81	5.4	0.43	2.9	0.014	1.67	80	67
Monsoon	Control	16.7	6.74	125	26.5	3.7	21	90	27.5	7.8	1.93	35.5	0.27	1.84	5.1	0.38	2.6	0.011	1.63	210	61
Monsoon	Control	16.7	6.72	123	27	3.5	20.5	91	28	7.5	1.92	36	0.28	1.85	5	0.37	2.5	0.01	1.61	172	59

Monsoon	Agriculture	14.1	6.61	69	24	3.8	13.5	49	25.5	3.1	4.38	24	0.19	1.19	5.5	0.1	2.2	0.019	3.02	180	118
Monsoon	Agriculture	14	6.6	70	24.5	3.6	13	50	25	3	4.39	23	0.2	1.2	6	0.2	2.3	0.02	3.04	40	116
Monsoon	Agriculture	14.3	6.63	67	26	4.2	14.5	46	27	3.3	4.35	21	0.17	1.17	6.5	0.1	2	0.017	3	35	122
Monsoon	Agriculture	14.4	6.64	66	25.5	4.4	15	47	26.5	3.4	4.36	20	0.16	1.16	6	0	1.9	0.016	2.98	28	124
Monsoon	Control	1.8	6.6	73	27	3.8	17.5	51	25.5	4.7	3.3	23.5	0.49	0.6	6	1.2	4.2	0.03	4.6	20	67
Monsoon	Control	1.9	6.61	72	27.5	3.7	17	50.5	25	4.6	3.4	23	0.5	0.62	6.2	1.4	4.3	0.031	4.52	75	69
Monsoon	Control	2.1	6.65	75	28.5	4.2	18.5	53	26.5	4.9	3.5	24.5	0.47	0.66	5.9	0.6	4	0.032	4.56	160	63
Monsoon	Control	2.2	6.66	76	29	4.3	19	53.5	27	5	3.4	25	0.46	0.64	5	0.8	3.9	0.031	4.62	40	61
Monsoon	Agriculture	7.8	6.79	81	27.5	3.8	27	57	35	6.5	4.88	21	0.53	2.75	5.8	1.8	8.9	0.012	0.18	57	62
Monsoon	Agriculture	7.9	6.8	80	28	3.6	26.5	56.5	35.5	66	4.9	21.5	0.54	2.76	5.9	1.9	9	0.011	0.19	110	60
Monsoon	Agriculture	7.4	6.75	85	26.5	4.2	29	59	37	6.3	4.84	23	0.51	2.73	6.1	2.1	8.7	0.01	0.16	90	68
Monsoon	Agriculture	7.3	6.74	86	26	4.4	29.5	59.5	36.5	6.2	4.82	22.5	0.5	2.72	5	2.2	8.6	0.011	0.15	28	70
Monsoon	Agriculture	3.8	6.74	87	26	1.9	15.5	61	23	4.9	2.9	31	0.55	1.39	6.5	0	10.8	0.01	0.54	94	72
Monsoon	Agriculture	3.7	6.75	85	26.5	1.8	15	61.5	22	5	2.91	30.5	0.54	1.4	6.6	0	10.7	0.02	0.55	150	74
Monsoon	Agriculture	4	6.72	91	28	2.1	16.5	65	25	4.7	2.93	33	0.57	1.37	6.3	0	11	0	0.52	130	76
Monsoon	Agriculture	4.1	6.71	93	27.5	2.2	17	64.5	26	4.6	2.94	33.5	0.58	1.36	6.2	0	11.1	0.01	0.51	75	78
Monsoon	Sewage	22.5	6.4	120	28	7.8	33	87	45	12.9	3.5	28	0.23	1.66	5.8	3.1	3.2	0.019	7.8	42	35
Monsoon	Sewage	22.7	6.39	118	29	7.6	32	88	43	13	3.6	27	0.25	1.67	5.7	3	3	0.02	7.81	25	30
Monsoon	Sewage	23.3	6.44	124	26	8.2	35	85	47	12.7	3.3	32	0.21	1.64	6.2	3.3	3.3	0.017	7.78	65	25
Monsoon	Sewage	23.1	6.45	126	25	8.4	36	84	49	12.6	3.2	33	0.19	1.63	5	3.4	2.9	0.016	7.77	130	30
Monsoon	Sewage	7.7	6.8	120	27	1.8	32	82	40	7	5.85	28	0.2	0.9	5	2	3	0.05	1.5	80	17
Monsoon	Sewage	7.6	6.85	115	25	1.9	34	81	39	6.8	5.9	28.5	0.19	0.89	4.8	1.9	2.8	0.06	1.48	130	18
Monsoon	Sewage	8.1	6.78	122	29	2.1	28	88	44	7.4	5.81	32	0.26	0.96	5.4	2.2	3.4	0.01	1.52	45	13
Monsoon	Sewage	8.2	6.73	127	31	2.2	26	89	45	7.6	5.76	31.5	0.27	0.97	5.6	2.3	3.6	0	1.54	95	12
Post-monsoon	Saline	3.2	7.85	33629	30	1	91	23540	4842	1482	277.04	15200	1.5	0.6	6.9	0.9	193	0.041	9.89	20	55
Post-monsoon	Saline	3.3	7.86	33630	31	3	92	23542	4844	1484	277.06	15400	1.49	0.59	6.9	0.7	194	0.037	9.91	10	53
Post-monsoon	Saline	3	7.83	33627	28	2	89	23538	4838	1478	277	14800	1.52	0.62	6.7	0.8	190	0.038	9.85	15	57
Post-monsoon	Saline	2.9	7.82	33626	27	2	88	23536	4836	1476	276.98	14600	1.53	0.63	7.2	0.8	191	0.04	9.83	25	59
Post-monsoon	Saline	1.7	7.83	35300	28	1.5	106	24700	5240	1470	381	15900	1.75	0.73	7.2	0.6	170	0.04	8.97	20	64
Post-monsoon	Saline	1.6	7.82	35310	27	2	108	24710	5230	1475	381.81	15950	1.73	0.75	7.3	0.55	172	0.042	8.99	30	66
Post-monsoon	Saline	1.9	7.85	35318	30	2	100	24740	5200	1450	381.21	15750	1.71	0.71	8	0.45	179	0.041	8.89	12	60
Post-monsoon	Saline	2	7.86	35328	31	2.5	102	24730	5210	1445	382.02	15800	1.69	0.69	6.7	0.4	179	0.041	8.91	18	58
Post-monsoon	Control	1.2	7.8	850	27.5	1.8	41	585	115	10.6	21.4	432	0.46	0.65	6.2	0.45	60	0.034	13.36	140	54
Post-monsoon	Control	1.1	7.82	820	28	1.9	43	590	117	10.7	21.42	434	0.47	0.67	6.4	0.4	61	0.035	13.35	65	56
Post-monsoon	Control	0.9	7.76	810	26.5	2.2	39	575	113	10.2	21.36	438	0.44	0.61	5.8	0.35	63	0.032	13.38	45	50
Post-monsoon	Control	0.8	7.74	840	26	2.1	37	570	111	10.1	21.34	440	0.43	0.59	7	0.4	64	0.031	13.39	78	48
Post-monsoon	Agriculture	3.5	7.1	412	25.5	3.7	34.5	285	79	13.4	11.2	165	0.34	1.5	7.9	0	36.5	0.025	9.5	55	0
Post-monsoon	Agriculture	3.4	7.09	414	26	3.5	35	283	78	13.5	11.22	163	0.35	1.6	7.8	0	36.7	0.026	9.45	50	0
Post-monsoon	Agriculture	3.7	7.12	408	26.5	4.5	33.5	289	81	13.7	11.16	171	0.32	1.3	8.1	0	36.3	0.023	9.54	70	0
Post-monsoon	Agriculture	3.8	7.13	406	26	4.3	33	291	82	13.8	11.14	173	0.31	1.2	8.2	0	36.1	0.022	9.59	48	0
Post-monsoon	Control	1.4	6.78	145	24	3.8	19	102	29	6.5	3.2	57	0.3	0.39	5.8	0.7	27	0.043	4.55	40	165
Post-monsoon	Control	1.5	6.77	147	23.5	3.7	18.5	100	28	6.6	3.1	55	0.31	0.4	7.5	0.6	28	0.044	4.54	20	167
Post-monsoon	Control	1.2	6.8	149	26	4.2	21	106	31	6.3	3.6	59	0.28	0.37	6.2	0.9	25	0.041	4.57	25	155
Post-monsoon	Control	1.1	6.81	151	26.5	4.3	21.5	108	32	6.2	3.7	61	0.27	0.36	6.3	1	24	0.04	4.58	45	153

Post-monsoon	Agriculture	3.7	6.4	175	26	7.5	19.5	120	33	7.1	3.89	71	0.72	1.15	5.3	0	39.6	0.021	5.9	35	115
Post-monsoon	Agriculture	3.6	6.3	176	26.5	7	19	121	33.5	7	3.9	72	0.73	1.16	6	0	39.4	0.02	6	80	112
Post-monsoon	Agriculture	4	6.6	173	28	8.5	20.5	123	35	7.3	3.87	69	0.7	1.13	5.5	0	40	0.023	5.7	20	105
Post-monsoon	Agriculture	3.9	6.7	172	27.5	9	21	124	34.5	7.4	3.86	68	0.69	1.12	7	0	40.2	0.024	5.6	125	108
Post-monsoon	Agriculture	0.7	7.25	160	23.5	1.9	21	115	35	7.1	4.38	59	0.6	1.08	5.6	0	11	0.034	5.3	20	125
Post-monsoon	Agriculture	0.6	7.24	161	24	1.8	21.5	116	35.5	7	4.39	58	0.62	1.07	5.7	0	11.5	0.035	5.2	60	128
Post-monsoon	Agriculture	0.9	7.27	166	22	2.1	23	113	37	7.3	4.35	61	0.59	1.1	8	0	12.5	0.032	5.5	40	115
Post-monsoon	Agriculture	1	7.28	165	22.5	2.2	22.5	112	36.5	7.4	4.36	62	0.63	1.11	5.3	0	13	0.031	5.6	55	112
Post-monsoon	Sewage	16.5	5.8	61	23	27	21	42	15	3.8	0.98	19	0.4	2.96	4.1	0.9	12.3	0.019	9.78	25	0
Post-monsoon	Sewage	16.7	5.82	60	22	26	22	41	16	3.7	0.99	18.5	0.5	2.98	4.2	0.8	12.1	0.02	9.77	20	0
Post-monsoon	Sewage	16.1	5.76	65	25	29	19	46	13	4.2	0.96	21	0.2	2.92	6	1.1	12.7	0.017	9.8	32	0
Post-monsoon	Sewage	15.9	5.74	66	26	30	18	47	12	4.3	0.95	21.5	0.1	2.9	6	1.2	12.9	0.016	9.81	15	0
Post-monsoon	Sewage	19.7	7.6	780	27	1.8	36	565	125	15	19.9	390	0.5	1.46	7	0.8	110	0.04	16	60	0
Post-monsoon	Sewage	19.5	7.62	760	26.5	1.7	35	563	127	14.9	19.88	393	0.52	1.47	7	0.7	108	0.042	16.01	125	0
Post-monsoon	Sewage	20.1	7.56	820	29	2.2	40	557	115	15.4	19.94	382	0.46	1.42	6.2	1.2	114	0.036	16.06	150	0
Post-monsoon	Sewage	20.3	7.54	840	29.5	2.3	41	555	113	15.5	19.96	379	0.44	1.41	6.4	1.3	116	0.034	16.05	42	0
Pre-monsoon	Saline	0	7.6	9970	28	6.5	116	6974	7300	580	1414	7050	0.23	0.16	6	0	6.6	0.06	1.87	5	12
Pre-monsoon	Saline	0	7.5	9975	27	6	118	6976	7350	570	1419	7100	0.24	0.17	6	0	6.8	0.05	1.88	9	13
Pre-monsoon	Saline	0	7.4	9950	30	5.5	112	6970	7100	550	1404	6950	0.2	0.14	6.7	0	6.3	0.04	1.85	10	8
Pre-monsoon	Saline	0	7.5	9945	31	6	110	6968	7050	540	1399	6900	0.21	0.13	6.7	0	6.3	0.01	1.84	7	7
Pre-monsoon	Saline	0.75	7.6	42250	30	4.2	11	29600	1620	525	72.6	920	0.025	0.15	6	0	7.8	0.033	2.2	5	28
Pre-monsoon	Saline	0.7	7.8	42200	29.5	4.3	9	29580	1630	530	72.5	940	0.02	0.17	6	0	7.7	0.035	2.21	5	26
Pre-monsoon	Saline	0.85	7.4	42350	28	3.8	12	29640	1580	515	73.2	880	0.015	0.23	6.8	0	8.2	0.029	2.23	7	32
Pre-monsoon	Saline	0.9	7.2	42400	28.5	3.7	8	29620	1570	510	73.3	860	0.02	0.25	6.7	0	8.3	0.027	2.24	11	34
Pre-monsoon	Control	1.45	7.2	42700	27.2	1.9	41	29970	710	210	48.8	198	0.43	0.08	6	1.38	4.3	0.052	3.22	20	188
Pre-monsoon	Control	1.5	7.5	42600	28.8	1.8	40	29990	730	225	48.9	197	0.45	0.12	6	1.38	4.2	0.054	3.25	10	186
Pre-monsoon	Control	1.35	6.5	42900	28.5	2.1	43	29950	690	190	48.4	202	0.46	0.13	5.8	1.39	4.7	0.05	3.2	10	182
Pre-monsoon	Control	1.3	6.8	43000	27.5	2.2	44	29930	670	175	48.3	203	0.42	0.07	5.6	1.39	4.8	0.048	3.17	13	180
Pre-monsoon	Agriculture	0	7.9	44900	30.5	1.8	27.5	31400	1350	250	190	1600	0.37	0.16	3.2	0	4.5	0.06	2.13	20	63
Pre-monsoon	Agriculture	0	8	45000	30	1.9	27	31450	1300	260	191	1700	0.36	0.17	3	0	5	0.07	2.12	20	68
Pre-monsoon	Agriculture	0	7.7	44700	31.5	2.1	28.5	31320	1450	230	198	1400	0.39	0.14	3	0	5.5	0.04	2.15	10	65
Pre-monsoon	Agriculture	0	7.6	44600	32	2.2	29	31270	1500	220	197	1300	0.4	0.13	2.9	0	5	0.03	2.16	10	72
Pre-monsoon	Control	0.3	6.7	500	29.5	3.8	15.5	320	78	9.4	13.5	72	0.3	0.16	5.8	0	5.3	0.04	1.29	12	70
Pre-monsoon	Control	0.2	6.71	490	29	3.9	15	321	76	9.2	13.4	71	0.2	0.17	6	0	5.2	0.039	1.3	47	72
Pre-monsoon	Control	0.4	6.74	430	30.5	4.1	16.5	324	82	9.8	13.7	76	0.4	0.14	5.4	0	5.7	0.042	1.27	62	68
Pre-monsoon	Control	0.3	6.73	420	31	4.2	17	323	84	10	13.8	77	0.3	0.13	5.2	0	5.8	0.043	1.26	20	66
Pre-monsoon	Agriculture	0.19	7.38	290	33.5	3.8	13.5	220	59	12.6	6.9	57	0.21	0.16	4.265	0	5.6	0.042	2.83	42	54
Pre-monsoon	Agriculture	0.17	7.4	280	34	3.7	13.8	225	58	12.4	7	58	0.22	0.17	4.267	0	5.7	0.043	2.84	40	56
Pre-monsoon	Agriculture	0.21	7.34	310	32.5	4.2	14.2	200	61	13	6.7	55	0.19	0.13	4.261	0	5.4	0.04	2.81	40	52
Pre-monsoon	Agriculture	0.23	7.32	320	32	4.3	14.5	195	62	13.2	6.6	54	0.18	0.14	4.259	0	5.3	0.039	2.8	22	50
Pre-monsoon	Agriculture	0.2	7.45	387	29	1.9	19	272	49	19.1	0.48	45	0.24	0.1	5.8	0	3.7	0.04	4.42	25	0
Pre-monsoon	Agriculture	0.1	7.46	389	28	1.8	18.5	274	48	19	0.47	45.5	0.25	0.2	5	0	3.9	0.03	4.41	12	0
Pre-monsoon	Agriculture	0.4	7.43	383	31	2.1	21	268	51	19.3	0.5	47	0.22	0	6.2	0	4.1	0.06	4.44	35	0

Pre-monsoon	Agriculture	0.5	7.42	381	32	2.2	21.5	266	52	19.4	0.51	46.5	0.21	0.1	6.3	0	4.3	0.07	4.45	65	0
Pre-monsoon	Sewage	3	3.9	210	29	25	7.7	140	79	15	9.73	23	0.1	0.2	4	0	7.8	0.033	1.2	12	0
Pre-monsoon	Sewage	3.2	3.7	212	28	24.5	7.5	141	78	15.5	9.74	23.5	0	0.19	4	0	7.7	0.034	1.21	15	0
Pre-monsoon	Sewage	3.3	3.6	202	31	27	8.3	148	81	17	9.71	25	0.3	0.23	3.9	0	8.2	0.031	1.23	10	0
Pre-monsoon	Sewage	2.9	4	200	32	27.5	8.5	147	82	16.5	9.7	24.5	0.4	0.22	3.8	0	8.3	0.03	1.24	15	0
Pre-monsoon	Sewage	0.4	6.8	1900	26.5	1.9	38	1340	397	78	48.3	2500	0.47	0	5.8	1.3	7.9	0.055	2.16	15	105
Pre-monsoon	Sewage	0.5	6.7	1880	26	1.8	36	1343	395	76	48.1	2400	0.46	0.2	5	1.2	7.8	0.056	2.17	15	100
Pre-monsoon	Sewage	0.2	7.2	1920	28	2.1	42	1334	403	82	48.9	2700	0.49	0.1	6.2	1.5	8.2	0.049	2.12	10	90
Pre-monsoon	Sewage	0.1	7.3	1940	27.5	2.2	44	1331	405	84	49.1	2800	0.5	0.1	6	1.6	8.1	0.048	2.11	20	85
Monsoon	Saline	0.4	7.48	2970	26	5.5	68	2070	2000	439	293.08	1525	0.33	0.27	6.5	0.29	180	0.05	1.83	30	95
Monsoon	Saline	0.35	7.5	2990	27	6	69	2075	2004	438.8	293.04	1520	0.35	0.29	6.7	0.29	181	0.04	1.85	24	97
Monsoon	Saline	0.2	7.42	2940	28	6.2	63	2068	2012	437.9	293.1	1570	0.27	0.22	6	0.29	176	0.01	1.82	45	100
Monsoon	Saline	0.25	7.44	2940	27	6.3	64	2075	1992	437.9	293.02	1585	0.29	0.22	7.2	0.29	175	0.02	1.84	40	104
Monsoon	Saline	0.85	7.89	4710	27.3	6.2	73	3300	3230	847	220	1890	0.33	0.37	5.8	0.56	192	0.05	2.1	46	62
Monsoon	Saline	0.83	7.88	4730	27.5	6	74	3310	3220	845	218	1885	0.32	0.35	5	0.56	194	0.06	2.21	30	64
Monsoon	Saline	0.75	7.83	4780	26.7	5.8	71	3350	3180	847.4	222.32	1883	0.35	0.38	5.7	0.57	196	0.03	2.2	54	60
Monsoon	Saline	0.77	7.84	4780	26.5	6	70	3340	3170	849.4	220.32	1878	0.36	0.34	5.6	0.57	198	0.02	2	65	58
Monsoon	Control	0.48	7.59	305	26.5	5.8	30.5	210	86	23.5	5.81	57	0.32	0.31	6.3	0	24.8	0.05	3.21	125	63
Monsoon	Control	0.49	7.6	307	27	5.7	31	211	85	23.7	5.8	56	0.31	0.3	6.5	0	24.7	0.06	3.25	90	67
Monsoon	Control	0.51	7.55	301	25.5	6.2	29.5	213	83	24.5	5.85	59	0.34	0.33	6	0	25	0.03	3.22	225	60
Monsoon	Control	0.52	7.54	299	25	6.3	29	214	82	24.3	5.86	60	0.35	0.34	5.5	0	25.1	0.02	3.18	180	58
Monsoon	Agriculture	0.45	6.99	167	25.5	7.5	19.5	67	31.5	8.9	2.4	62	0.33	1.37	5.6	0.99	9.4	0.02	2.17	190	120
Monsoon	Agriculture	0.5	7	165	25	7.7	19	66	31	9	2.41	64	0.32	1.38	5.7	0.99	9.5	0.01	2.14	45	123
Monsoon	Agriculture	0.55	6.97	173	26.5	8.3	21	69	32.5	8.7	2.46	58	0.35	1.35	5.4	1	9.2	0.03	2.17	40	125
Monsoon	Agriculture	0.5	6.96	175	27	8.5	20.5	70	33	8.6	2.45	56	0.36	1.34	5	1	9.1	0.02	2.16	30	124
Monsoon	Control	2.1	6.7	198	29	7.8	27	78	30	6.5	3.9	47	0.39	0.6	6	2.08	13.5	0.03	1.27	25	64
Monsoon	Control	2.2	6.72	195	28.5	7.7	26	79	31	6.6	3.91	46	0.4	0.5	6.2	2.09	13	0.04	1.34	80	68
Monsoon	Control	2	6.8	202	27	8.2	29	81	33	6.3	3.88	49	0.37	0.7	6	2.06	14.5	0.05	1.26	175	73
Monsoon	Control	2.1	6.78	205	27.5	8.3	30	82	34	6.2	3.87	50	0.36	0.6	6.3	2.05	15	0.04	1.25	45	71
Monsoon	Agriculture	4.1	6.65	223	27.5	8.2	39	89	47	9.7	5.36	57	0.37	1.97	5.8	0	13	0.04	2.82	55	65
Monsoon	Agriculture	4.3	6.67	221	28	8.4	39.5	88	48	9.8	5.37	57.5	0.38	1.98	5.9	0	13.5	0.05	2.84	115	67
Monsoon	Agriculture	4.4	6.61	227	26.5	7.8	40.5	91	45	9.5	5.34	58.5	0.35	1.95	6	0	11	0.02	2.79	95	63
Monsoon	Agriculture	4	6.59	229	26	7.6	41	92	44	9.4	5.33	59	0.34	1.94	6.2	0	10.5	0.01	2.84	30	61
Monsoon	Agriculture	3.7	7.06	247	25	5.7	22	98	33	7.1	3.5	61	0.4	1.53	6.8	1.07	6.8	14	4.43	98	72
Monsoon	Agriculture	3.8	7.07	245	24	5.5	23	97	34	7	3.6	60	0.5	1.54	6.5	1.07	7	14.1	4.42	160	73
Monsoon	Agriculture	3.5	7.04	251	27	6.3	25	102	30	7.3	3.3	63	0.2	1.51	6.5	1.06	6.7	14.6	4.43	140	68
Monsoon	Agriculture	3.4	7.03	253	28	6.5	26	103	31	7.4	3.2	64	0.1	1.5	7.3	1.06	7.1	14.5	4.45	70	67
Monsoon	Sewage	14.8	6.4	88	26	11.5	21	34	23	4.7	2.9	23	0.34	1.78	5.8	1.07	5.8	0.03	1.2	40	34
Monsoon	Sewage	14.9	6.39	89	25.5	11	20	33.5	23.5	4.6	2.91	23.5	0.35	1.77	5.8	1.07	5.7	0.02	1.21	30	36
Monsoon	Sewage	14.5	6.44	86	28	13	23	36	25	4.9	2.93	25	0.32	1.8	6.2	1.07	6	0.05	1.23	70	38
Monsoon	Sewage	14.6	6.45	85	28.5	12.5	24	36.5	24.5	5	2.94	24.5	0.31	1.81	6.3	1.07	6.1	0.06	1.25	125	40
Monsoon	Sewage	0.3	7.3	380	28.5	12	29	155	40	10.5	3.9	78	0.37	0.4	6	2.14	17	0.05	2.16	85	15
Monsoon	Sewage	0.35	7.5	370	28	11.5	28.5	153	41	10.7	3.92	76	0.38	0.38	5.9	2.14	17.1	0.06	2.17	140	14
Monsoon	Sewage	0.5	6.9	410	28	12	31	157	44	10.3	3.88	82	0.34	0.44	6	2.13	17.8	0.03	2.12	50	17
Monsoon	Sewage	0.45	6.7	400	28.5	12.5	31.5	159	43	10.1	3.86	84	0.35	0.46	6.3	2.13	17.7	0.02	2.11	105	18

Table S8 Result of two- way ANOVA showing variation in the mean for water variables during different seasons in different zones

Tests of Between -Subjects Effects

Dependent Variable: TURBIDITY

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2258.804[a]	11	205.346	8.591	.000
Intercept	3840.359	1	3840.359	160.661	.000
SEASON2	491.823	2	245.912	10.288	.000
CATEGORY2	1605.493	3	535.164	22.388	.000
SEASON2 * CATEGORY2	113.536	6	18.923	.792	.577
Error	4876.320	204	23.904		
Total	10818.754	216			
Corrected Total	7135.124	215			

Dependent Variable: pH

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	79.957[a]	11	7.269	20.030	.000
Intercept	9835.505	1	9835.505	27103.120	.000
SEASON2	13.433	2	6.717	18.509	.000
CATEGORY2	43.011	3	14.337	39.508	.000
SEASON2 * CATEGORY2	27.061	6	4.510	12.429	.000
Error	74.030	204	.363		
Total	10315.020	216			
Corrected Total	153.987	215			

Dependent variable:

ELECTRICAL CONDUCTIVITY

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3.403E+10	11	3.094E+09	42.655	.000
Intercept	1.552E+10	1	1.552E+10	214.015	.000
SEASON2	7.074E+09	2	3.537E+09	48.768	.000
CATEGORY2	1.796E+10	3	5.987E+09	82.538	.000
SEASON2 * CATEGORY2	9.618E+09	6	1.603E+09	22.101	.000
Error	1.480E+10	204	7.253E+07		
Total	6.255E+10	216			
Corrected Total	4.883E+10	215			

Dependent Variable: TEMPERATURE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	819.302[a]	11	74.482	22.213	.000
Intercept	169495.791	1	169495.791	50549.590	.000
SEASON2	646.897	2	323.449	96.464	.000
CATEGORY2	27.167	3	9.056	2.701	.047
SEASON2 * CATEGORY2	63.090	6	10.515	3.136	.006
Error	684.024	204	3.353		
Total	175913.460	216			
Corrected Total	1503.326	215			

Dependent Variable: ACIDITY

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	17501.333[a]	11	1591.030	7.429	.000
Intercept	20367.677	1	20367.677	95.097	.000
SEASON2	5591.596	2	2795.798	13.054	.000
CATEGORY2	7104.889	3	2368.296	11.058	.000
SEASON2 * CATEGORY2	5754.667	6	959.111	4.478	.000
Error	43692.200	204	214.177		
Total	80460.200	216			
Corrected Total	61193.533	215			

Dependent Variable: ALKALINITY (TOTAL)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	105312.593[a]	11	9573.872	39.398	.000
Intercept	278197.010	1	278197.010	1144.834	.000
SEASON2	5958.141	2	2979.071	12.259	.000
CATEGORY2	87230.815	3	29076.938	119.657	.000
SEASON2 * CATEGORY2	13172.741	6	2195.457	9.035	.000
Error	49572.427	204	243.002		
Total	417249.760	216			
Corrected Total	154885.019	215			

Dependent Variable: TOTAL DISSOLVED SOLIDS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.669E+10	11	1.518E+09	42.708	.000
Intercept	7.589E+09	1	7.589E+09	213.568	.000
SEASON2	3.482E+09	2	1.741E+09	49.003	.000
CATEGORY2	8.812E+09	3	2.937E+09	82.664	.000
SEASON2 * CATEGORY2	4.702E+09	6	7.837E+08	22.056	.000
Error	7.249E+09	204	3.553E+07		
Total	3.065E+10	216			
Corrected Total	2.394E+10	215			

Dependent Variable: CALCIUM [as Ca]

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.137E+07	11	1.943E+06	96.758	.000
Intercept	8.188E+06	1	8.188E+06	407.720	.000
SEASON2	1.719E+06	2	859586.179	42.805	.000
CATEGORY2	1.458E+07	3	4.861E+06	242.090	.000
SEASON2 * CATEGORY2	5.389E+06	6	898114.241	44.724	.000
Error	4.097E+06	204	20081.336		
Total	3.235E+07	216			
Corrected Total	2.547E+07	215			

Dependent Variable: MAGNESIUM

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.907E+07	11	1.734E+06	35.937	.000
Intercept	7.644E+06	1	7.644E+06	158.415	.000
SEASON2	3.432E+06	2	1.716E+06	35.559	.000
CATEGORY2	1.216E+07	3	4.055E+06	84.032	.000
SEASON2 * CATEGORY2	4.021E+06	6	670143.744	13.888	.000
Error	9.844E+06	204	48253.195		
Total	3.530E+07	216			
Corrected Total	2.892E+07	215			

Dependent Variable: CHLORIDE (as Cl)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.889E+09	11	4.444E+08	56.094	.000
Intercept	1.699E+09	1	1.699E+09	214.398	.000
SEASON2	7.067E+08	2	3.534E+08	44.601	.000
CATEGORY2	2.974E+09	3	9.912E+08	125.108	.000
SEASON2 * CATEGORY2	1.332E+09	6	2.220E+08	28.018	.000
Error	1.616E+09	204	7.923E+06		
Total	7.909E+09	216			
Corrected Total	6.505E+09	215			

Dependent Variable: FLUORIDE (as F)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	27.390[a]	11	2.490	32.365	.000
Intercept	69.821	1	69.821	907.520	.000
SEASON2	4.226	2	2.113	27.462	.000
CATEGORY2	14.948	3	4.983	64.764	.000
SEASON2 * CATEGORY2	8.700	6	1.450	18.848	.000
Error	15.695	204	.077		
Total	110.733	216			
Corrected Total	43.085	215			

Dependent Variable: IRON (as Fe)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	32.603[a]	11	2.964	6.687	.000
Intercept	233.712	1	233.712	527.289	.000
SEASON2	6.343	2	3.171	7.155	.001
CATEGORY2	10.600	3	3.533	7.972	.000
SEASON2 * CATEGORY2	12.871	6	2.145	4.840	.000
Error	90.419	204	.443		
Total	369.722	216			
Corrected Total	123.022	215			

Dependent Variable: DISSOLVED OXYGEN

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	88.455[a]	11	8.041	12.818	.000
Intercept	7447.288	1	7447.288	11871.392	.000
SEASON2	32.034	2	16.017	25.532	.000
CATEGORY2	16.559	3	5.520	8.799	.000
SEASON2 * CATEGORY2	30.425	6	5.071	8.083	.000
Error	127.975	204	.627		
Total	7853.283	216			
Corrected Total	216.431	215			

Dependent Variable: BIOCHEMICAL OXYGEN DEMAND (BOD)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	82.239[a]	11	7.476	8.084	.000
Intercept	283.919	1	283.919	307.010	.000
SEASON2	48.726	2	24.363	26.344	.000
CATEGORY2	22.621	3	7.540	8.154	.000
SEASON2 * CATEGORY2	11.628	6	1.938	2.096	.055
Error	188.657	204	.925		
Total	549.889	216			
Corrected Total	270.895	215			

Dependent Variable: SULPHATE [as SO4]

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.311E+06	11	391904.738	24.628	.000
Intercept	2.024E+06	1	2.024E+06	127.198	.000
SEASON2	740401.598	2	370200.799	23.264	.000
CATEGORY2	1.622E+06	3	540639.817	33.974	.000
SEASON2 * CATEGORY2	2.072E+06	6	345345.057	21.702	.000
Error	3.246E+06	204	15913.210		
Total	9.312E+06	216			
Corrected Total	7.557E+06	215			

Dependent Variable: PHOSPHATE [as PO4]

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	118.623[a]	11	10.784	3.233	.000
Intercept	11.827	1	11.827	3.546	.061
SEASON2	15.431	2	7.715	2.313	.102
CATEGORY2	29.418	3	9.806	2.940	.034
SEASON2 * CATEGORY2	60.447	6	10.074	3.020	.008
Error	680.458	204	3.336		
Total	818.890	216			
Corrected Total	799.081	215			

Dependent Variable: NITRATE [as NO3]

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	647.826[a]	11	58.893	7.545	.000
Intercept	2400.913	1	2400.913	307.572	.000
SEASON2	558.851	2	279.426	35.796	.000
CATEGORY2	50.070	3	16.690	2.138	.097
SEASON2 * CATEGORY2	73.391	6	12.232	1.567	.158
Error	1592.428	204	7.806		
Total	4661.568	216			
Corrected Total	2240.254	215			

Dependent Variable: DEPTH OF WATER COLUMN in cm

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	161434.750[a]	11	14675.886	11.014	.000
Intercept	554702.124	1	554702.124	416.296	.000
SEASON2	93647.009	2	46823.504	35.140	.000
CATEGORY2	42594.931	3	14198.310	10.656	.000
SEASON2 * CATEGORY2	20577.708	6	3429.618	2.574	.020
Error	271824.208	204	1332.472		
Total	1012031.000	216			
Corrected Total	433258.958	215			

Dependent Variable : RATE OF WATER FLOW

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	169099.704[a]	11	15372.700	13.168	.000
Intercept	743600.000	1	743600.000	636.941	.000
SEASON2	5708.061	2	2854.030	2.445	.089
CATEGORY2	67866.370	3	22622.123	19.377	.000
SEASON2 * CATEGORY2	90825.630	6	15137.605	12.966	.000
Error	238160.667	204	1167.454		
Total	1175290.000	216			
Corrected Total	407260.370	215			

Table S9 The detailed result of different sediment variables in different seasons and different zones

Seasons	Zones	pH	EC	Organic carbon	Phosphorus	Potassium	Calcium	Magnesium	Sulphur	Copper [ppm]	Irom [ppm]	Zinc [ppm]	Manganese [ppm]	Boron (mg/kg)
Post-monsoon	Saline	6.8	3.09	0.04	80	98	101.4	30	79.7	2.7	153	0.92	2.2	1.14
Post-monsoon	Saline	6.9	3.11	0.05	82	99	101.6	30.1	79.9	2.72	155	0.93	2.3	1.15
Post-monsoon	Saline	6.6	3.05	0.02	76	96	101	29.8	79.3	2.66	149	0.9	2	1.12
Post-monsoon	Saline	6.5	3.03	0.01	74	95	100.8	29.7	79.1	2.64	147	0.89	1.9	1.11
Post-monsoon	Saline	6.2	4.39	0.1	28	128	91	30.9	67	1.19	281.8	0.57	2.4	2.08
Post-monsoon	Saline	6.3	4.41	0.2	27	126	90.5	30.7	66.5	1.21	281.4	0.55	2.5	2.07
Post-monsoon	Saline	5.9	4.35	0.3	30	132	92	30.6	68	1.15	281.2	0.61	2.2	2.1
Post-monsoon	Saline	6	4.33	0.2	31	134	92.5	31	68.5	1.13	282	0.63	2.1	2.11
Post-monsoon	Control	6.8	0.3	1.5	41	27	266	30.7	15.9	1.6	489	1.35	0.4	0.87
Post-monsoon	Control	6.7	0.32	1.7	40	28	267	30.9	16	1.62	488.5	1.37	0.5	0.85
Post-monsoon	Control	7	0.26	1.1	43	25	265.5	30.3	15.7	1.56	490	1.31	0.2	0.91
Post-monsoon	Control	7.1	0.24	0.9	44	24	267.5	30.1	15.6	1.54	490.5	1.29	0.1	0.93
Post-monsoon	Agriculture	4.6	0.14	0.9	26	18	95.5	25.5	24.6	0.63	266	0.58	2.8	0.76
Post-monsoon	Agriculture	4.4	0.16	1	28	19	95.7	25.7	24.8	0.65	268	0.59	2.4	0.78
Post-monsoon	Agriculture	5	0.1	0.8	22	16	95.1	25.1	24.2	0.59	262	0.56	2.2	0.72
Post-monsoon	Agriculture	5.2	0.08	0.9	20	15	94.9	24.9	24	0.57	260	0.55	3	0.7
Post-monsoon	Control	6	0.05	0.4	30	19	392.8	25.9	14.8	1.29	604.8	5.35	9.4	0.9
Post-monsoon	Control	6.1	0.06	0.3	31	20	392.7	25.7	15	1.31	605.2	5.37	9.6	0.85
Post-monsoon	Control	5.8	0.03	0.6	28	17	393	25.6	14.4	1.25	604	5.31	9	1
Post-monsoon	Control	5.7	0.02	0.7	27	16	393.1	26	14.2	1.23	603.6	5.29	8.8	1.05
Post-monsoon	Agriculture	6	0.06	2.2	41	31	116.8	23.5	16.7	1.45	669	1.57	2.7	1.59
Post-monsoon	Agriculture	6.1	0.07	2.3	42	31.5	116.4	23.7	16.9	1.47	669.3	1.58	2.9	1.61
Post-monsoon	Agriculture	5.8	0.04	2	39	33	116.2	23.1	16.3	1.41	668.4	1.55	2.3	1.55
Post-monsoon	Agriculture	5.7	0.03	1.9	38	32.5	117	22.9	16.1	1.39	668.1	1.54	2.1	1.53
Post-monsoon	Agriculture	6	0.14	1.9	24	38	157.8	28.8	16.8	2.52	624.3	3.65	10	1.77
Post-monsoon	Agriculture	6.2	0.16	1.8	23.5	37	157.4	28.4	17.2	2.53	624.5	3.67	11	1.78
Post-monsoon	Agriculture	5.6	0.1	2.1	22	40	157.2	28.2	15.6	2.5	623.9	3.61	11.5	1.75
Post-monsoon	Agriculture	5.4	0.08	2.2	22.5	41	158	29	16	2.49	623.7	3.59	9.5	1.74
Post-monsoon	Sewage	5.5	0.06	0.09	45	20	96.8	15.8	15.7	0.95	449.3	3.5	9.9	0.65
Post-monsoon	Sewage	5.7	0.07	0.08	46	20.5	96.4	15.7	15.9	0.97	449.4	3.55	10.1	0.66
Post-monsoon	Sewage	5.1	0.04	0.06	43	22	96.2	16	15.3	0.91	449	3.4	9.3	0.63
Post-monsoon	Sewage	4.9	0.03	0.05	42	21.5	97	16.1	15.1	0.89	449.1	3.35	9.5	0.62
Post-monsoon	Sewage	5.9	0.07	0.3	21	14	65	19	9.8	0.47	457	0.95	2.6	0.23

Post-monsoon	Sewage	6.1	0.08	0.2	20	14.5	65.1	18.8	9.6	0.49	457.6	0.96	2.7	0.21
Post-monsoon	Sewage	5.5	0.05	0.1	23	16	64.8	18.7	10.2	0.43	455.8	0.93	2.4	0.27
Post-monsoon	Sewage	5.3	0.04	0.2	24	15.5	64.7	19.1	10.4	0.41	455.2	0.92	2.3	0.29
Pre-monsoon	Saline	4.6	5.48	0.16	28	257.31	77.35	11.71	353.1	0.36	50	2.56	1.7	2.6
Pre-monsoon	Saline	4.7	5.49	0.17	27.5	257.33	77.37	11.73	354.1	0.39	50.5	2.58	1.9	2.7
Pre-monsoon	Saline	4.4	5.46	0.14	30	257.27	77.29	11.67	351.1	0.3	49	2.52	1.3	2.4
Pre-monsoon	Saline	4.3	5.45	0.13	30.5	257.25	77.27	11.65	350.1	0.27	48.5	2.5	1.1	2.3
Pre-monsoon	Saline	6.5	4.67	0.38	2.6	258.7	104.24	10.8	407	0.69	440.1	0.77	1.9	1.4
Pre-monsoon	Saline	6.6	4.69	0.4	2.5	258.72	104.36	10.82	407.5	0.72	441.1	0.79	1.8	1.5
Pre-monsoon	Saline	6.3	4.63	0.34	2.8	258.66	104	10.76	406	0.63	438.1	0.73	2.1	1.2
Pre-monsoon	Saline	6.2	4.61	0.32	2.9	258.64	103.88	10.74	405.5	0.6	437.1	0.71	2.2	1.1
Pre-monsoon	Control	5.8	1.69	1.09	18	181.9	148.37	13.86	550	0.68	1541	2.9	9.6	2.3
Pre-monsoon	Control	6	1.71	1.11	17.5	181.92	149.47	13.88	549.7	0.72	1541.2	2.85	9.8	2.4
Pre-monsoon	Control	5.4	1.65	1.05	20	181.86	146.17	13.82	550.6	0.6	1540.6	3	9.2	2.1
Pre-monsoon	Control	5.2	1.63	1.03	20.5	181.84	145.07	13.8	550.9	0.56	1540.4	3.05	9	2
Pre-monsoon	Agriculture	3.2	1.33	0.8	8.5	190.94	164.17	8.5	209.3	1.84	187.3	0.95	18.4	0.8
Pre-monsoon	Agriculture	3.5	1.35	0.9	8.7	192.94	166.17	8.53	210.3	1.86	188.3	0.97	18.6	0.7
Pre-monsoon	Agriculture	3.6	1.29	0.6	9.5	180.94	160.17	8.44	207.3	1.8	185.3	0.91	18	1
Pre-monsoon	Agriculture	3.3	1.27	0.5	9.3	178.94	158.17	8.41	206.3	1.78	184.3	0.89	17.8	1.1
Pre-monsoon	Control	6	0.23	0.15	10.7	37.84	154.38	9.56	20.8	1.7	132.7	1.8	20	0.1
Pre-monsoon	Control	6.1	0.25	0.14	10.3	37.86	156.38	9.58	21.2	1.9	133.7	1.84	20.2	0
Pre-monsoon	Control	5.8	0.19	0.17	11.7	37.8	150.38	9.52	20	1.3	130.7	1.72	19.6	0.2
Pre-monsoon	Control	5.7	0.17	0.18	11.3	37.78	148.38	9.5	19.6	1.1	129.7	1.68	19.4	0.1
Pre-monsoon	Agriculture	4.2	0.22	1.6	67	102.9	102.32	12.19	46	1.05	170.4	1.3	6.8	1.5
Pre-monsoon	Agriculture	4.3	0.23	1.65	66	102.93	102.48	12.21	47	1.06	171.4	1.31	6.6	1.6
Pre-monsoon	Agriculture	4	0.2	1.5	69	102.84	102	12.15	44	1.01	168.4	1.28	7.2	1.3
Pre-monsoon	Agriculture	3.9	0.19	1.45	70	102.81	101.84	12.13	43	1	167.4	1.27	7.4	1.2
Pre-monsoon	Agriculture	5.3	0.26	1.27	18	133.3	246.45	9.8	19	0.7	186.5	1.65	17.3	3.04
Pre-monsoon	Agriculture	5.4	0.28	1.29	19	133.33	248.45	9.6	18.7	0.8	187.5	1.67	17.5	3.05
Pre-monsoon	Agriculture	5.1	0.22	1.23	16	133.24	242.45	10.2	19.6	0.5	184.5	1.61	16.9	3.02
Pre-monsoon	Agriculture	5	0.2	1.21	15	133.21	240.45	10.4	19.9	0.4	183.5	1.59	16.7	3.01
Pre-monsoon	Sewage	6.5	0.16	0.1	29	54	510.07	9.6	25	1.44	41	3.25	14.8	0.6
Pre-monsoon	Sewage	6.7	0.18	0.08	28	54.02	512.07	9.65	24.4	1.46	40.5	3.27	15	0.7
Pre-monsoon	Sewage	6.1	0.12	0.07	31	53.96	506.07	9.5	26.2	1.4	43	3.21	14.4	0.4
Pre-monsoon	Sewage	5.9	0.1	0.11	32	53.94	504.07	9.45	26.8	1.38	43.5	3.19	14.2	0.3
Pre-monsoon	Sewage	5.9	0.8	0.93	23	266.21	166.92	12.83	114.6	0.61	187.1	8.3	27	3.4
Pre-monsoon	Sewage	6.1	0.78	0.95	22	266.31	167.92	12.85	115.6	0.63	189.1	8.32	28	3.3

Pre-monsoon	Sewage	5.5	0.84	0.89	25	266.01	164.92	12.79	112.6	0.57	183.1	8.26	25	3.6
Pre-monsoon	Sewage	5.3	0.86	0.87	26	265.91	163.92	12.77	111.6	0.55	181.1	8.24	24	3.7
Monsoon	Saline	2.6	0.008	0.12	9.56	19.08	10.98	15.96	133.06	0.78	212.86	0.35	2.96	0.9
Monsoon	Saline	2.62	0.009	0.13	9.58	19.1	10.97	15.98	133.08	0.77	212.88	0.37	2.98	0.7
Monsoon	Saline	2.56	0.006	0.1	9.52	19.04	11	15.92	133.02	0.8	212.82	0.31	2.92	0.89
Monsoon	Saline	2.54	0.005	0.09	9.5	19.02	11.01	15.9	133	0.81	212.8	0.29	2.9	0.82
Monsoon	Saline	4.05	0.24	0.16	15.88	23.9	17.25	17.45	30.35	1.03	286.2	0.53	1.46	1.8
Monsoon	Saline	4.03	0.25	0.18	15.9	23.92	17.28	17.47	30.37	1.04	286.21	0.55	1.48	1.7
Monsoon	Saline	4.09	0.2	0.12	15.84	23.93	17.19	17.41	30.29	1.01	286.18	0.49	1.42	1.1
Monsoon	Saline	4.11	0.19	0.1	15.82	23.89	17.16	17.39	30.31	1	286.17	0.47	1.4	1.8
Monsoon	Control	4.36	0.006	0.45	29.2	47.24	262.7	19.52	20.36	3.6	108.29	1.37	2.36	0.87
Monsoon	Control	4.38	0.008	0.47	29.21	47.22	262.68	19.5	20.39	3.61	108.31	1.4	2.34	0.85
Monsoon	Control	4.32	0.002	0.41	29.18	47.28	262.74	19.56	20.3	3.58	108.25	1.31	2.4	0.71
Monsoon	Control	4.3	0	0.39	29.17	47.3	262.76	19.58	20.27	3.57	108.23	1.28	2.42	0.69
Monsoon	Agriculture	4.29	0.003	1.19	18.14	2.8	122.64	19.38	11.33	5.2	405.65	2.19	3.14	0.6
Monsoon	Agriculture	4.27	0.001	1.21	18.16	3	120.64	19.4	11.35	5.21	404.65	2.2	3.16	0.68
Monsoon	Agriculture	4.33	0.007	1.15	18.1	2.6	118.64	19.34	11.29	5.18	403.65	2.17	3.1	0.62
Monsoon	Agriculture	4.35	0.009	1.13	18.08	2.8	120.64	19.32	11.27	5.17	404.65	2.16	3.08	0.6
Monsoon	Control	4.5	0.007	1.31	26.18	54.75	459.08	20.6	9.89	2.8	665.26	5.97	29.18	1
Monsoon	Control	4.51	0.008	1.33	26.2	54.77	459.1	20.61	9.9	2.7	665.28	5.98	29.2	0.8
Monsoon	Control	4.48	0.005	1.27	26.14	54.71	459.04	20.58	9.87	3	665.22	5.95	29.14	0.9
Monsoon	Control	4.47	0.004	1.25	26.12	54.69	459.02	20.57	9.86	3.1	665.2	5.94	29.12	0.95
Monsoon	Agriculture	4.21	0.005	2.35	71.15	40.2	93.47	20.45	18.39	4.6	715.57	8.12	9.68	1.2
Monsoon	Agriculture	4.23	0.004	2.37	71.17	40.28	93.49	20.43	18.41	4.61	715.59	8.1	9.7	1.3
Monsoon	Agriculture	4.17	0.007	2.31	71.11	40.32	93.43	20.49	18.35	4.58	715.53	8.16	9.64	1.24
Monsoon	Agriculture	4.15	0.008	2.29	71.09	40.16	93.41	20.51	18.33	4.57	715.51	8.18	9.62	1.1
Monsoon	Agriculture	4.4	0.008	0.66	33.04	37.04	79.13	18.6	33	6.95	562.68	3.36	13.3	1.3
Monsoon	Agriculture	4.44	0.009	0.68	33.06	37.06	79.11	18.58	33.04	6.97	562.7	3.38	13.5	1.25
Monsoon	Agriculture	4.32	0.006	0.62	33	37	79.17	18.64	33.06	6.89	562.64	3.32	12.9	1.4
Monsoon	Agriculture	4.28	0.005	0.6	32.98	36.98	79.19	18.66	32.98	6.91	562.62	3.3	12.7	1.4
Monsoon	Sewage	4.6	0.008	0.19	22	10.02	67.6	10.57	12.85	1.88	451.97	3.68	3.4	0.43
Monsoon	Sewage	4.8	0.01	0.21	22.04	10.03	67.61	10.59	12.87	1.9	451.99	3.69	3.5	0.45
Monsoon	Sewage	4.2	0.004	0.15	22.06	10	67.58	10.53	12.81	1.84	451.93	3.66	3.2	0.39
Monsoon	Sewage	4	0.002	0.13	21.98	9.99	67.57	10.51	12.79	1.82	451.91	3.65	3.1	0.41
Monsoon	Sewage	4	0.009	0.25	7.14	144.14	115.8	19.98	43.81	2.83	582.64	3.43	27	0.09
Monsoon	Sewage	3.9	0.01	0.27	7.16	144.16	115.82	19.97	43.83	2.85	582.66	3.44	28	0.1
Monsoon	Sewage	4.2	0.007	0.21	7.1	144.1	115.76	20	43.77	2.79	582.6	3.41	25	0.11

Monsoon	Sewage	4.3	0.006	0.19	7.08	144.08	115.74	20.01	43.75	2.77	582.58	3.4	24	0.08
Post-monsoon	Saline	2.8	3.76	0.29	42.56	64.29	24.1	14.46	575.6	0.87	604.6	10.9	7.38	1.1
Post-monsoon	Saline	2.7	3.78	0.3	42.58	64.31	24.08	14.48	575.4	0.89	604.4	11.1	7.4	1.08
Post-monsoon	Saline	3	3.72	0.27	42.52	64.25	24.14	14.42	576	0.83	605	10.5	7.34	1.12
Post-monsoon	Saline	3.1	3.7	0.26	42.5	64.23	24.16	14.4	576.2	0.81	605.2	10.3	7.32	1.14
Post-monsoon	Saline	5.76	3.68	0.15	15.1	337.9	29.6	14.45	370.4	0.35	300	0.7	3.59	2.04
Post-monsoon	Saline	5.77	3.7	0.14	15	337.93	29.8	14.46	370.6	0.37	303	0.72	3.61	2.02
Post-monsoon	Saline	5.74	3.64	0.17	15.3	337.84	29.2	14.43	370	0.31	294	0.66	3.55	2
Post-monsoon	Saline	5.73	3.62	0.18	15.4	337.81	29	14.42	369.8	0.29	291	0.64	3.53	2.02
Post-monsoon	Control	5.77	0.34	0.53	15.79	161.4	46.09	14.95	117.5	0.25	261.8	8.23	8	0.88
Post-monsoon	Control	5.79	0.36	0.55	15.8	161.42	46.11	14.97	117.7	0.27	262	8.25	8.01	0.9
Post-monsoon	Control	5.73	0.3	0.49	15.77	161.36	46.05	14.91	117.1	0.21	261.4	8.19	7.98	0.86
Post-monsoon	Control	5.71	0.28	0.47	15.76	161.34	46.03	14.89	116.9	0.19	261.2	8.17	7.97	0.92
Post-monsoon	Agriculture	5.29	0.15	1.08	18.19	109.7	33.23	7.5	101.6	0.37	739	7.7	7.35	0.74
Post-monsoon	Agriculture	5.31	0.17	1.1	18.21	109.9	33.25	7.52	101.8	0.36	735	7.72	7.37	0.72
Post-monsoon	Agriculture	5.25	0.11	1.04	18.15	109.3	33.19	7.46	101.2	0.39	733	7.66	7.31	0.7
Post-monsoon	Agriculture	5.23	0.09	1.02	18.13	109.1	33.17	7.44	101	0.4	741	7.64	7.29	0.68
Post-monsoon	Control	5.86	0.08	0.16	6.2	38.57	42.45	12.16	30.5	1.36	331.8	9.8	20.95	0.8
Post-monsoon	Control	5.88	0.07	0.18	6.1	38.58	42.47	12.18	30.7	1.37	332	9.6	20.97	0.9
Post-monsoon	Control	5.82	0.1	0.12	6.5	38.55	42.41	12.12	30.1	1.34	331.4	10.2	20.91	1
Post-monsoon	Control	5.8	0.11	0.1	6.4	38.54	42.39	12.1	29.9	1.33	331.2	10.4	20.89	1.1
Post-monsoon	Agriculture	5.47	0.15	0.83	11.18	44.24	37.36	12.35	51.7	0.87	771	11.4	10.29	1.6
Post-monsoon	Agriculture	5.49	0.16	0.85	11.19	44.26	37.38	12.37	51.8	0.88	770.6	11.6	10.31	1.62
Post-monsoon	Agriculture	5.43	0.13	0.79	11.16	44.2	37.32	12.31	51.5	0.85	770.4	11	10.25	1.58
Post-monsoon	Agriculture	5.41	0.12	0.77	11.15	44.18	37.3	12.29	51.4	0.84	771.2	10.8	10.23	1.56
Post-monsoon	Agriculture	6.19	0.09	0.4	24.48	100.75	59.6	13.9	115.9	0.15	297.6	14.45	46.66	1.8
Post-monsoon	Agriculture	6.21	0.1	0.3	24.5	100.77	59.8	13.92	116.1	0.17	297.8	14.47	46.68	1.82
Post-monsoon	Agriculture	6.15	0.07	0.6	24.44	100.69	59.2	13.86	115.5	0.11	297.2	14.41	46.62	1.78
Post-monsoon	Agriculture	6.13	0.06	0.7	24.42	100.71	59	13.84	115.3	0.09	297	14.39	46.6	1.76
Post-monsoon	Sewage	5.21	0.04	0.21	8.88	19.88	25.35	13.15	98	0.23	477	9.8	11.55	0.67
Post-monsoon	Sewage	5.19	0.03	0.22	8.89	19.89	25.37	13.17	100	0.24	477.1	9.9	11.57	0.69
Post-monsoon	Sewage	5.25	0.06	0.19	8.86	19.86	25.31	13.11	94	0.21	476.8	9.6	11.51	0.71
Post-monsoon	Sewage	5.27	0.07	0.18	8.85	19.85	25.29	13.09	92	0.2	476.7	9.5	11.49	0.73
Post-monsoon	Sewage	5.6	0.1	1.57	41.13	245.53	71.8	13.89	20.8	2.7	455.7	12.8	13.95	0.25
Post-monsoon	Sewage	5.8	0.11	1.59	41.14	245.54	72	13.91	21	2.6	455.9	12.6	13.98	0.27
Post-monsoon	Sewage	5.2	0.08	1.53	41.11	245.51	71.4	13.85	20.4	2.9	455.3	13.2	13.89	0.23
Post-monsoon	Sewage	5	0.07	1.51	41.1	245.5	71.2	13.83	20.2	3	455.1	13.4	13.86	0.21

Pre-monsoon	Saline	5.86	5.06	0.25	15.58	198	12.81	57	236	0.32	68.8	0.42	0.64	0.5
Pre-monsoon	Saline	5.84	5.04	0.27	15.62	198.9	12.83	58	234	0.3	69	0.43	0.66	0.51
Pre-monsoon	Saline	5.9	5.1	0.21	15.46	196.2	12.77	55	240	0.33	68.4	0.4	0.6	0.48
Pre-monsoon	Saline	5.92	5.12	0.19	15.5	195.3	12.75	54	242	0.29	68.2	0.39	0.58	0.47
Pre-monsoon	Saline	6.09	4.5	0.33	14.1	246.4	31.58	56.89	258	0.63	176.25	0.95	2.5	1.14
Pre-monsoon	Saline	6.11	4.48	0.31	14.08	246.35	31.6	56.91	262	0.64	176.27	0.97	2.3	1.15
Pre-monsoon	Saline	6.05	4.54	0.37	14.14	246.5	31.54	56.85	246	0.61	176.21	0.91	2.6	1.12
Pre-monsoon	Saline	6.03	4.56	0.39	14.16	246.55	31.52	56.83	250	0.6	176.19	0.89	2.2	1.11
Pre-monsoon	Control	6.36	0.84	0.42	13.9	72.35	26.44	53.61	76.68	0.5	178.7	1.06	3.3	0.88
Pre-monsoon	Control	6.38	0.86	0.43	14	72.37	26.42	53.63	76.7	0.48	178.9	1.08	3.4	0.89
Pre-monsoon	Control	6.32	0.8	0.4	13.7	72.31	26.48	53.57	76.64	0.54	178.3	1.02	3.1	0.86
Pre-monsoon	Control	6.3	0.78	0.39	13.6	72.29	26.5	53.55	76.62	0.56	178.1	1	3	0.85
Pre-monsoon	Agriculture	4.9	0.08	0.75	7.6	27.19	30.56	22	1.99	1.7	175.6	1.3	5.2	1.37
Pre-monsoon	Agriculture	4.85	0.07	0.77	7.4	27.21	30.58	21	2.01	1.9	175.4	1.5	5.3	1.39
Pre-monsoon	Agriculture	5	0.1	0.71	8	27.15	30.52	24	1.95	1.3	176	0.9	5	1.33
Pre-monsoon	Agriculture	5.05	0.11	0.69	8.2	27.13	30.5	25	1.93	1.1	176.2	0.7	4.9	1.31
Pre-monsoon	Control	5.64	0.2	2.23	13.5	161.85	30	23.31	0.66	0.55	193.59	1.8	10.75	0.3
Pre-monsoon	Control	5.66	0.19	2.25	13.7	161.87	29	23.33	0.67	0.57	193.55	1.81	10.77	0.32
Pre-monsoon	Control	5.62	0.22	2.19	13.1	161.81	32	23.27	0.64	0.51	193.53	1.78	10.71	0.26
Pre-monsoon	Control	5.6	0.23	2.17	12.9	161.79	33	23.25	0.63	0.49	193.61	1.77	10.69	0.24
Pre-monsoon	Agriculture	5.96	0.15	1.54	34.44	78	81.95	67.55	10.47	1.7	238.16	4.45	11.25	0.18
Pre-monsoon	Agriculture	5.94	0.16	1.56	34.46	76	81.97	67.57	10.49	1.9	238.18	4.47	11.27	0.19
Pre-monsoon	Agriculture	6	0.13	1.5	34.4	82	81.89	67.51	10.43	1.3	238.12	4.41	11.21	0.16
Pre-monsoon	Agriculture	6.02	0.12	1.48	34.38	84	81.91	67.49	10.41	1.1	238.1	4.39	11.19	0.15
Pre-monsoon	Agriculture	5.7	0.26	2.5	12.7	202.2	133.37	67.46	88.37	0.9	265.8	4.4	38.4	0.4
Pre-monsoon	Agriculture	5.72	0.28	2.7	12.68	202.18	133.41	67.48	88.39	0.7	265.4	4.5	38.6	0.41
Pre-monsoon	Agriculture	5.66	0.22	2.1	12.74	202.24	133.29	67.42	88.33	0.6	265.2	4.2	38	0.38
Pre-monsoon	Agriculture	5.64	0.2	1.9	12.76	202.26	133.25	67.4	88.31	1	266	4.1	37.8	0.37
Pre-monsoon	Sewage	6.1	0.04	0.66	18.7	29.74	39.4	57.6	10.96	0.66	106	0.55	1.5	0.65
Pre-monsoon	Sewage	6.15	0.05	0.68	18.9	29.76	39.2	57.4	10.98	0.69	108	0.57	1.7	0.66
Pre-monsoon	Sewage	6	0.02	0.62	18.3	29.7	39.8	58	10.92	0.6	102	0.51	1.1	0.63
Pre-monsoon	Sewage	5.95	0.01	0.6	18.1	29.68	40	58.2	10.9	0.57	100	0.49	0.9	0.62
Pre-monsoon	Sewage	5.7	0.8	1.43	10.2	334.55	159.7	70.25	126.86	2.4	256.4	6.6	29.2	1.5
Pre-monsoon	Sewage	5.76	0.82	1.45	10.22	340.55	159.68	70.27	126.84	2.5	256.6	6.7	29.3	1.7
Pre-monsoon	Sewage	5.68	0.76	1.39	10.16	342.55	159.74	70.23	126.9	2.2	256	6.4	29	1.1
Pre-monsoon	Sewage	5.74	0.74	1.37	10.14	336.55	159.76	70.21	126.92	2.1	255.8	6.3	28.9	0.9
Monsoon	Saline	2.7	0.009	0.15	9.66	19.03	10.88	17	0.9	0.8	210.88	0.33	2.85	0.9

Monsoon	Saline	2.8	0.01	0.17	9.68	19.05	10.89	16.5	0.8	0.9	210.92	0.35	2.87	0.8
Monsoon	Saline	2.5	0.007	0.11	9.62	18.99	10.86	15	1.1	0.6	210.8	0.29	2.81	0.89
Monsoon	Saline	2.4	0.006	0.09	9.6	18.97	10.85	15.5	1.2	0.5	210.76	0.27	2.79	0.9
Monsoon	Saline	4.2	0.29	0.18	16.03	24.69	18.3	18.1	34.03	1.07	291.34	0.58	1.5	1.8
Monsoon	Saline	4.3	0.31	0.17	16.05	24.71	18.5	18	34.05	1.09	291.36	0.6	1.51	1.8
Monsoon	Saline	4	0.25	0.2	15.99	24.65	17.9	18.3	33.99	1.03	291.3	0.54	1.48	1.1
Monsoon	Saline	3.9	0.23	0.21	15.97	24.63	17.7	18.4	33.97	1.01	291.28	0.52	1.47	1.6
Monsoon	Control	4.63	0.004	0.53	32.08	48.32	287.45	17.97	22	3.65	112.33	1.5	2.7	0.87
Monsoon	Control	4.65	0.005	0.54	32.1	48.33	287.47	17.99	22.02	3.67	112.35	1.52	2.72	0.6
Monsoon	Control	4.59	0.002	0.51	32.04	48.3	287.41	17.93	21.96	3.61	112.29	1.46	2.66	0.71
Monsoon	Control	4.57	0.001	0.5	32.02	48.29	287.39	17.91	21.94	3.59	112.27	1.44	2.64	0.9
Monsoon	Agriculture	4.3	0.008	1.23	18.33	2.5	126.4	19.59	11.63	5.29	401.73	2.1	3.25	0.65
Monsoon	Agriculture	4.31	0.01	1.25	18.35	2.6	126.38	19.61	11.65	5.31	401.75	2	3.27	0.72
Monsoon	Agriculture	4.28	0.004	1.19	18.29	2.4	126.44	19.55	11.59	5.25	401.69	2.3	3.21	0.62
Monsoon	Agriculture	4.27	0.002	1.17	18.27	2.5	126.46	19.53	11.57	5.23	401.67	2.4	3.19	0.67
Monsoon	Control	4.55	0.007	1.36	27.03	54.9	462.93	20.8	9.99	3.4	671.09	5.89	29.18	1
Monsoon	Control	4.57	0.006	1.38	27.05	54.91	462.95	20.82	10	3.6	671.11	5.91	29.2	0.9
Monsoon	Control	4.51	0.004	1.32	26.99	54.88	462.89	20.76	9.97	3	671.05	5.85	29.14	0.9
Monsoon	Control	4.49	0.003	1.3	26.97	54.87	462.87	20.74	9.96	2.8	671.03	5.83	29.12	1.2
Monsoon	Agriculture	4.38	0.008	2.38	72.37	41.69	95.4	20.19	19.4	4.8	732.1	8.95	9.9	1.2
Monsoon	Agriculture	4.4	0.009	2.39	72.39	41.71	95.38	20.2	19.41	4.82	732.11	8.97	9.91	1.4
Monsoon	Agriculture	4.34	0.006	2.36	72.33	41.65	95.44	20.17	19.38	4.76	732.08	8.91	9.88	1.1
Monsoon	Agriculture	4.32	0.005	2.35	72.31	41.63	95.46	20.16	19.37	4.74	732.07	8.89	9.87	1.1
Monsoon	Agriculture	4.44	0.007	0.7	37.98	38.1	81.58	19.67	33.39	6.96	570.65	3.48	14.86	1.5
Monsoon	Agriculture	4.46	0.008	0.72	38	38.11	81.6	19.69	33.42	6.94	570.67	3.5	14.9	1.1
Monsoon	Agriculture	4.4	0.005	0.66	37.94	38.08	81.54	19.63	33.33	7	570.61	3.44	14.78	1.4
Monsoon	Agriculture	4.38	0.004	0.64	37.92	38.07	81.52	19.61	33.3	7.02	570.59	3.42	14.74	1.2
Monsoon	Sewage	4.7	0.004	0.2	23.08	10.58	68.09	10.97	13.3	1.99	453.78	3.9	3.8	0.43
Monsoon	Sewage	4.9	0.003	0.21	23.1	10.6	68.11	10.99	13.5	2	453.8	3.91	3.4	0.3
Monsoon	Sewage	4.3	0.006	0.18	23.04	10.54	68.05	10.93	12.9	1.97	453.74	3.88	3.2	0.2
Monsoon	Sewage	4.1	0.007	0.17	23.02	10.52	68.03	10.91	12.7	1.96	453.72	3.87	4	0.5
Monsoon	Sewage	4.5	0.008	0.25	7.89	146.15	117.03	21.03	44	3	586.6	3.49	27	0.1
Monsoon	Sewage	4.7	0.009	0.26	7.91	146.17	117.05	21.05	44.05	3.02	586.8	3.51	27.1	0.11
Monsoon	Sewage	4.1	0.006	0.23	7.85	146.11	116.99	20.99	43.9	2.96	586.2	3.45	26.8	0.11
Monsoon	Sewage	3.9	0.005	0.22	7.83	146.09	116.97	20.97	43.85	2.94	586	3.43	26.7	0.9

Table S10 Result of two way-ANOVA showing variation in the mean for the sediment variables during different seasons in different zones

Tests of Between-Subjects Effects

Dependent Variable:pH

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	131.349[a]	11	11.941	27.524	.000
Intercept	5468.703	1	5468.703	12605.464	.000
SEASON2	102.760	2	51.380	118.432	.000
CATEGORY2	14.304	3	4.768	10.990	.000
SEASON2 * CATEGORY2	19.870	6	3.312	7.634	.000
Error	88.503	204	.434		
Total	5813.966	216			
Corrected Total	219.852	215			

Dependent Variable:ELECTRICAL CONDUCTIVITY

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	483.842[a]	11	43.986	489.534	.000
Intercept	165.808	1	165.808	1845.344	.000
SEASON2	89.029	2	44.515	495.421	.000
CATEGORY2	276.282	3	92.094	1024.951	.000
SEASON2 * CATEGORY2	130.990	6	21.832	242.974	.000
Error	18.330	204	.090		
Total	643.475	216			
Corrected Total	502.172	215			

Dependent Variable:ORGANIC CARBON

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	45.897[a]	11	4.172	15.480	.000
Intercept	105.029	1	105.029	389.673	.000
SEASON2	1.718	2	.859	3.187	.043
CATEGORY2	41.807	3	13.936	51.703	.000
SEASON2 * CATEGORY2	2.587	6	4.310	1.599	.149
Error	54.984	204	.270		
Total	231.112	216			
Corrected Total	100.881	215			

Dependent Variable:PHOSPHORUS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	19163.916[a]	11	1742.174	8.209	.000
Intercept	122519.275	1	122519.275	577.284	.000
SEASON2	3828.041	2	1914.020	9.018	.000
CATEGORY2	2978.671	3	992.890	4.678	.003
SEASON2 * CATEGORY2	12889.530	6	2148.255	10.122	.000
Error	43295.730	204	212.234		
Total	195689.487	216			
Corrected Total	62459.646	215			

Dependent Variable:POTASSIUM

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	807232.453[a]	11	73384.768	15.929	.000
Intercept	2010771.926	1	2010771.926	436.458	.000
SEASON2	492326.587	2	246163.293	53.432	.000
CATEGORY2	172698.783	3	57566.261	12.495	.000
SEASON2 * CATEGORY2	147451.562	6	24575.260	5.334	.000
Error	939832.430	204	4607.022		
Total	3685164.906	216			
Corrected Total	1747064.883	215			

Dependent Variable:CALCIUM

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.629E+06	11	148071.671	23.802	.000
Intercept	3.101E+06	1	3.101E+06	498.450	.000
SEASON2	68803.539	2	34401.769	5.530	.005
CATEGORY2	729978.880	3	243326.293	39.114	.000
SEASON2 * CATEGORY2	836434.678	6	139405.780	22.409	.000
Error	1.269E+06	204	6220.924		
Total	5.986E+06	216			
Corrected Total	2.898E+06	215			

Dependent Variable:MAGNESIUM

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	10455.608[a]	11	950.510	4.368	.000
Intercept	111588.359	1	111588.359	512.800	.000
SEASON2	8360.762	2	4180.381	19.211	.000
CATEGORY2	152.663	3	50.888	.234	.873
SEASON2 * CATEGORY2	1843.488	6	307.248	1.412	.211
Error	44391.664	204	217.606		
Total	170038.666	216			
Corrected Total	54847.272	215			

Dependent Variable:SULPHUR

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.839E+06	11	167159.151	17.802	.000
Intercept	1.852E+06	1	1.852E+06	197.266	.000
SEASON2	533335.222	2	266667.611	28.399	.000
CATEGORY2	964115.506	3	321371.835	34.225	.000
SEASON2 * CATEGORY2	401946.741	6	66991.124	7.134	.000
Error	1.992E+07	204	9389.891		
Total	5.453E+06	216			
Corrected Total	3.754E+06	215			

Dependent Variable:COPPER [ppm]

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	501.003[a]	11	45.546	98.790	.000
Intercept	606.709	1	606.709	1315.971	.000
SEASON2	195.087	2	97.543	211.574	.000
CATEGORY2	90.232	3	30.077	65.239	.000
SEASON2 * CATEGORY2	152.350	6	25.392	55.075	.000
Error	94.051	204	.461		
Total	1296.767	216			
Corrected Total	595.054	215			

Dependent Variable:IRON [ppm]

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.844E+06	11	440402.414	9.300	.000
Intercept	3.002E+07	1	3.002E+07	633.885	.000
SEASON2	1.449E+06	2	724303.342	15.296	.000
CATEGORY2	1.196E+06	3	398633.074	8.418	.000
SEASON2 * CATEGORY2	1.793E+06	6	298829.871	6.311	.000
Error	9.660E+06	204	47353.580		
Total	4.664E+07	216			
Corrected Total	1.450E+07	215			

Dependent Variable:ZINC [ppm]

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	856.046[a]	11	77.822	8.192	.000
Intercept	2957.248	1	2957.248	311.278	.000
SEASON2	400.372	2	200.186	21.071	.000
CATEGORY2	337.503	3	112.501	11.842	.000
SEASON2 * CATEGORY2	91.182	6	15.197	1.600	.149
Error	1938.071	204	9.500		
Total	5979.166	216			
Corrected Total	2794.117	215			

Dependent Variable:MANGANESE [ppm]

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5731.109[a]	11	521.010	6.022	.000
Intercept	22508.710	1	22508.710	260.151	.000
SEASON2	225.990	2	112.995	1.306	.273
CATEGORY2	4135.476	3	1378.492	15.932	.000
SEASON2 * CATEGORY2	1346.952	6	224.492	2.595	.019
Error	17650.401	204	86.522		
Total	47822.868	216			
Corrected Total	23381.510	215			

Dependent Variable:BORON(mg/kg)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	28.509[a]	11	2.592	6.607	.000
Intercept	233.466	1	233.466	595.140	.000
SEASON2	4.809	2	2.405	6.130	.003
CATEGORY2	12.923	3	4.308	10.981	.000
SEASON2 * CATEGORY2	11.149	6	1.858	4.737	.000
Error	80.027	204	.392		
Total	357.055	216			
Corrected Total	108.536	215			

Papers Published

1. Jyothi PV, Sureshkumar S (2014) Flora of medicinal significance in *Kole* wetlands of Ponnani, Kerala. Journal of Aquatic Biology and Fisheries 2:245-252.
2. Jyothi PV, Sureshkumar S (2016) Aquatic ornamental macrophytes in *Kole* wetlands: An untapped resource for sustainable utilization. Journal of functional and environmental botany 6(2):79-83. doi: 10.5958/2231-1750.2016.00013.5
3. Jyothi PV, Sureshkumar S (2018) Patterns of vegetation dynamics across mild disturbance gradient in a freshwater wetland system in Southern India. Wetlands 38:807–817.

Papers Presented in Seminars

1. A three-day international conference on ‘Towards a sustainable blue economy: Production, strategies and policies’ (TaSBE) . Presented the poster for TaSBE Entitled-Documentation of aquatic ornamental macrophytes in *Kole* wetlands for sustainable utilization. Organized by the Kerala University of Fisheries and Ocean Studies (KUFOS) on 04 -06 feb 2016.

2. Presented a paper entitled Dynamics of water quality parameters in Ponnani *Kole* wetlands, South India in 26th Swadeshi science congress held on 2016 on 7-9 November 2016.

3. Presented a paper entitled Seasonal variability in macrophytes assemblage pattern in Ponnani *Kole* wetlands , India in 4 th Indian Biodiversity congress held at Pondicherry university on 13-15 march 2017.