Final Project Report

STUDY ON THE IMPACT OF HEAVY FLOODS ON ENVIRONMENTAL CHARACTERISTICS OF VEMBANAD BACKWATER

Submitted to

KERALA STATE POLLUTION CONTROL BOARD
GOVERNMENT OF KERALA

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August, 2021

FINAL PROJECT REPORT

Title of the project	:	Study on the impact of heavy floods on environmental characteristics of Vembanad backwater
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Mode of project	:	Consultancy
Sanction order no. & date	:	PCB/HO/EE3/Vembanad wetland/2018 dated 27/12/2018
Duration of the project		
a. Date of commencement	:	27/12/2018
b. Date of completion	:	01/03/2019

സമർപ്പണം

മഹാപ്രളയത്തിൽ ജീവനും സ്വത്തും ഉപജീവനവും നഷ്ടപ്പെട്ടവർക്ക്...

ACKNOWLEDGEMENTS

I would express my sincere gratitude to the Kerala State Pollution Control Board (KSPCB), Govt. of Kerala for all the financial & technical support to accomplish the study.

My sincere thanks to the Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology for providing the necessary facilities to carry out the work.

I extend my special gratitude towards Chairman, Pollution Control Board for providing the lab facility for analyzing the water samples for heavy metal. I am also thankful to Dr. Harikumar P. S, Senior Principal Scientist, Centre for Water Resources Development and Management (CWRDM), Kozhikode for providing the lab facility for analyzing the sediment samples for heavy metals.

I am extremely thankful to the project staff, Mr. Aravind E. H. and Ms. Sruthy Sebastian for their valuable support for completion of the project. I will place on record the assistance rendered by Mr. Hari Praved P., Dr. Vineetha S., Ms. Neethu K. V., Ms. Aparna Suresh, Ms. Ganga Vijayaraghavan, Mrs. Krishnapriya P. P., Mr. Don Xavier N. D., Ms. Santu K. S., Mr. Athul Krishna N. G., Dr. Radhika R., Ms. Aswathy N. K., Dr. Lathika Cicily Thomas, Dr. Sreelekshmi S., Ms. Sreelakshmi M., Mrs. Suhaana M. Nazar, Mrs. Jima M., Dr. Jayachandran P. R. and Dr. Aneesh B. of the department of Marine Biology, Microbiology and Biochemistry.

My warm thanks to Mr. Anilajan for the help and co-operation in field sampling on board the vessel A.V.C. No. MB 171- CP.

Above all the blessing bestowed by almighty God is gratefully acknowledged.

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EXECUTIVE SUMMARY

Kerala has experienced an intense flooding due to multi-day extreme rainfall events during August 2018. This catastrophe was one of the worst floods to hit the state and resulted in heavy losses of lives and property. The region around Vembanad wetland system including Kuttanad - the 'rice bowl of Kerala' is severely affected by the flood. The Vembanad-Kol wetland is the largest tropical wetland ecosystem on the southwest coast of India. It is designated as a Ramsar site due to the international significance for its biodiversity values. The wetland system comprised of Vembanad backwater, the lower reaches of ten rivers (i.e. Pamba, Manimala, Achankovil, Meenachil, Periyar, Muvattupuzha, Chalakudy, Karuvannur, Keecheri and Puzhakkal) with a drainage area of 1,577,000 ha (ie. 15,770 km^2) and the adjoining low lying Kol lands spread over an area of 1,51,250 ha. It is an important resource area for local livelihoods and also an important tourist destination supports a highly productive agricultural system. The environmental integrity of the wetland system has become severely affected mainly due to the human interferences like construction of regulators, spillways, overexploitation, uncontrolled urbanization, drainage and filling, extensive land reclamation, conversion for polder rice cultivation and encroachment of rivers and backwaters for construction of infrastructure. This significantly alters the hydrology of wetland system and result in profound changes to wetland functions such as flood control. The drainage capacities of channels are affected by choking of main drainage channels and increased siltation. Hence, this low-lying region is susceptible to extreme flooding due to high monsoon discharges received from the major rivers. The absence of significant storage reservoirs in the upstream of the rivers, shrinkage of carrying capacity of Vembanad wetland, structural limitations of Thottappally spillway and Thanneermukkom barrage (TMB) may have worsened the flooding in Kuttanad region. This may be the reason for the heavy flooding experienced in the low-lying areas closer to the Vembanad wetland in the Alappuzha, Kottayam, Ernakulam, Thrissur and Pathanamthitta districts.

The terms of reference of the study was to conduct field work in the selected study stations in Vembanad wetland, covering the upstream, downstream and riverine areas of Alappuzha, Kottayam, Ernakulam and Pathanamthitta districts during the flood and post flood period to understand the status and changes on the water and sediment quality, productivity and biodiversity represented mostly by the plankton, benthos and fishery. The study also mandated to refer secondary data on rainfall, river discharge and dam storage and relate it to the observations and conclusions of the study. Because of its significance on biodiversity and the large number of people depending directly or indirectly on the wetland system, the impact of flood on the environmental quality is quite significant. In this context, the Kerala State Pollution Control Board (KSPCB) entrusted a study, to be conducted in the Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology (CUSAT) on the impact of flood and post flood scenario on the general ecology and biodiversity of Vembanad wetland ecosystem.

The salient findings are; the lack of appreciable storage reservoirs in the upstream of the major rivers, reduction of depth and shrinkage in carrying capacity of Vembanad wetland, the structural limitations of Thottappally spillway and the Thanneermukkom barrage that plays a major role in worsening the 2018 flooding in Kuttanad region. The overall degradation, pollution from numerous sources and accumulation of waste materials has led to the loss and reclamation in large areas of the rivers and wetland habitat significantly modifying the carrying capacity, causing serious flood condition in the area. The Vembanad wetland is a notable part of the Western Ghats and its ecological conditions. The floods in 2018 and the subsequent period have affected the river flow, storage capacity of dams and reservoirs in the Ecologically

Sensitive Zones (ESZ1, ESZ2 and ESZ3) of the wetland. So, it is inevitable to adopt a decentralized river basin planning for west-flowing rivers and maintaining environmental flow in these rivers. New scientific and development oriented initiatives should be proposed and implemented in the Western Ghats region considering the ESZ zones and its conservation strategies. The recent report of the IUCN (2020) has also highlighted the urgent need for implementation of the Gadgil and Kasthurirangan recommendations of the WGEEP (2011) report in total. At present due to various anthropogenic interventions and looming climate change issues, the Vembanad wetland area under the Western Ghats region has degraded miserably, also the 2018 floods and subsequent periods have worsened the situations in the area. The depth, transparency, pH, salinity, alkalinity and primary productivity values in the present study showed drastic decrease compared to pre flood period whereas BOD, sulphide and inorganic nutrients showed higher concentration. Intense rainfall and heavy river discharge during flood period influences most of the parameters in the study stations. Heavy metal contamination in water was lower compared to pre flood period, but cadmium was higher. The flood impact created on the water quality and primary productivity continued to be influencing the wetland even during the post flood period to a large extent. This suggests that, considering the prevailing flood and post flood conditions in 2018, environmental degradation of the wetland due to multiple anthropogenic factors inherently impacts the overall ecological status and well-being of the ecosystem. Nitrogen loading in Vembanad backwater also increased due to the extreme river and agricultural discharges during flood period. The sediment was also heavily polluted with the metals Cu, Zn and Pb, but an overall decrease in heavy metal accumulation was observed during flood compared to pre flood period. Due to very low salinity, stenohaline forms of phytoplankton (e.g. *Pediastrum* sp.), mesozooplankton and macrobenthic species prevailed in the wetland and generally, the abundance, diversity and distribution of species were also decreased. Biodiversity and its productivity have been affected by heavy land runoff and also by changing water quality conditions. Dominant opportunistic indicator forms survived well during the flood period (e.g. *Nitzchia* sp., *Dendronereis estuarina*). Swarming or mass occurrence of zooplankton like rotifers (*Keratella* sp., indicating eutrophication) and cladocerans (freshwater forms) were observed during post flood compared to pre flood period. The presence and occurrence of invasive opportunistic species of fish (i.e. *Arapaima gigas* and Alligator gar: *Atractosteus spatula*), mussels (*Mytilopsis sallei* and *Mytella strigata*) and ‘Acute bladder snail’ (*Physella acuta*) during the flood and the continuing post flood period can have far reaching repercussions on the biodiversity and food web structure of the wetland in future. These invasive species find their entry during flood from aquarium and other land based fishing activities that can significantly affect the trophic characteristics of the wetland ecosystem, which needs further studies. The impact of flood on biota continued to influence even during the post flood period due to the changing environmental conditions and human interventions. The inherent modification in the wetland posed to affect the biodiversity and distribution of the plankton, benthos and fishery without notably differentiating between the flood and post flood period.

From this study, it is concluded that, the water quality, productivity, sediment quality and biodiversity of Vembanad wetland system is seriously affected by the 2018 flood in Kerala. The degradation of wetlands is one of the major reasons for the devastating flooding observed in this region. Hence, as being a Ramsar site of international importance, implementation of better management remedies must be urgently developed in order to avoid future flood impacts.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	-	Percentage
~	-	Approximately
<	-	Less than
>	-	Greater than
≤	-	Less than or equal to
°C	-	degree Celsius
Anon	-	Anonymous
APHA	-	American Public Health Association Standard Methods
av.	-	Average
BCM	-	Billion cubic metres
BDL	-	Below detection limit
BOD	-	Biological oxygen demand
BW	-	Bottom water
cm	-	Centimetres
CPCB	-	Central Pollution Control Board
cumec	-	Cubic metre per second
CWC	-	Central Water Commission
day^{-1}	-	Per day
DO	-	Dissolved oxygen
E	-	East
ESA	-	Ecologically Sensitive Area
ESL	-	Ecologically Sensitive Localities
ESZ	-	Ecologically Sensitive Zone
et al.	-	And others
Fig.	-	Figure
FRL	-	Full Reservoir Level
ft	-	Feet
G & D	-	Gauging and discharge
$g\ kg^{-1}$	-	Gram per kilogram
g	-	Gram
$gCm^{-3}day^{-1}$	-	Gram carbon per meter cube per day
GDP	-	Gross Domestic Product
GPP	-	Gross primary productivity
GPS	-	Global Positioning System
ha	-	Hectares

hrs.	-	Hours
i.e.	-	that is
IBA	-	Important Bird Area
ICMR	-	Indian Council of Medical Research
IMD	-	India Meteorological Department
ind.m^{-2}	-	Individual per metre square
ind.m^{-3}	-	Individuals per cubic metre
IUCN	-	International Union for Conservation of Nature
KID	-	Kerala Irrigation Department
km	-	Kilometre
km^2	-	Square kilometre
km^3	-	Cubic kilometre
KSBB	-	Kerala State Biodiversity Board
KSDMA	-	Kerala State Disaster Management Authority
KSPCB	-	Kerala State Pollution Control Board
L	-	Litres
m	-	Metres
m^2	-	Square metre
m^3	-	Cubic metre
m^3s^{-1}	-	Cubic metre per second
MCM	-	Million Cubic Metres
MDDL	-	Minimum Drawdown Level
mg kg^{-1}	-	Milligram per kilogram
mg L^{-1}	-	Milligram per litre
mg	-	Milligram
Mha	-	Mega hectare
mha	-	Million hectare
million ty^{-1}	-	Million ton per year
ml	-	Millilitre
mm	-	Millimetres
Mm^3	-	Cubic megametre
mm^3/d	-	Cubic millimetres per day
MN	-	Monsoon
MoEF	-	Ministry of Environment and Forests
MSL	-	Mean sea level

MSSRF	-	M. S. Swaminathan Research Foundation
MT	-	Metric Tonne
MWL	-	Maximum Water Level
N	-	North
nm	-	Nanometre
No.	-	Number
NPP	-	Net primary productivity
NW	-	North-West
NW-SE	-	Northwest-Southeast
PDNA	-	Post Disaster Needs Assessment
PM	-	Post monsoon
ppt	-	Parts per thousand
PRB	-	Periyar River Basin
PRM	-	Pre monsoon
S	-	South
SAARC	-	South Asia Association of Regional Cooperation
SAC	-	Space Applications Centre
SE	-	South-East
sp.	-	Species
SQG	-	Standard Sediment Quality Guidelines
SRTM	-	Shuttle Radar Topographic Mission
St.	-	Station
SW	-	Surface water
SWM	-	South west monsoon
t	-	Tonnes
TMB	-	Thanneermukkom barrage
UNESCO	-	United Nations Educational, Scientific and Cultural Organization
US EPA	-	United States Environmental Protection Agency
v6	-	Version 6
WGEEP	-	Western Ghats Ecology Expert Panel
WHO	-	World Health Organization
wt	-	Weight
y^{-1}	-	Per year
µm	-	Micrometre
µmol L^{-1}	-	Micro mol per litre

1. INTRODUCTION

Floods are the most common disaster all over the world; their frequency, magnitude and the cost of damage are very high. Flooding is a temporary condition, where sudden water is accumulated from inland or tidal or from rapid runoff due to rain, causing complete inundation (Jeb and Aggarwal, 2008). The US National Oceanic and Atmospheric Administration (NOAA) defines flood as “an overflow of water into the dry land or the flooding of a usually dry region caused by rising water in an existing waterways such as a dam, stream or ditch for drainage. Usually, floods take hours or even days to develop, when excess rainwater above the carrying capacity of the channel spreads over the land next to it (floodplain) and giving resident’s time to prepare or evacuate. However, they can also happen very quickly with little or no warning, called flash floods that can be extremely dangerous causing huge loss of human lives. Flood is an extreme event, having major impact on humanity and also on the environment. As extreme events deviate beyond the threshold of tolerance, they build an increasingly greater catastrophe capacity. Depending on the vulnerability of the place of occurrence and the mitigation methods, the physical as well as socio-economic impacts of disaster are complex. According to Bryant and Allen Perry (1997), historically, floods have recorded the highest death tolls than any other natural hazards.

1.1 Flood-prone regions of India

An average of around 40 million hectares or 12 % of the total land is flood-prone in India, as per South Asia Association of Regional Cooperation (SAARC) Disaster Management Centre (Rai, 2017). In India, around 8 million hectares is affected by floods in every year, several hectares of crops lost, along with a few hundred lives, and million rendered homeless. The Indo-Gangetic plains are some of the most susceptible areas prone to flooding. The vast alluvial plains of the rivers Ganga, Indus and Brahmaputra and their tributaries constitute the Indo-Gangetic plains and differentiate the Himalayan ranges from Peninsular India. These plains are the largest quaternary alluvial sediment areas in the world derived from the largest orogen, i.e. Himalaya (Jain and Sinha, 2003). The basin of the Himalayan Rivers, covering parts of Punjab, Haryana, Himachal Pradesh, Delhi, Rajasthan, Uttar Pradesh, Bihar and West Bengal are the most flood-prone regions in India. The Kosi and Damodar are the main rivers causing floods here. Bihar is India’s most flood-prone state, with 76 % of the population in north Bihar living under the recurring threat of flood devastation. A recent analysis indicates that over the past 30 years, the plains of north Bihar have reported the highest number of floods. The north-western river basin is another flood-prone region, covering the states of Jammu and Kashmir, parts of Punjab, Haryana, western U.P and Himachal Pradesh. Rivers such as Jhelum, Beas, Ravi and Chenab are also flood-prone. Further, the central and peninsular river basins of the Narmada, Tapi, Chambal and Mahanadi are also flood-prone. Heavy floods often occur in the Godavari, Krishna, Penna and Kaveri. Every year, the rivers of Gangetic plains cause wide spread destruction due to severity of floods. The 2008 flood occurred in Kosi (Bihar), 2009 flood in Krishna (Andhra Pradesh), 2010 flood in Leh and Ladak (Jammu & Kashmir) (Sudheer *et al*., 2019) are some examples of flood events occurred in these flood-prone regions of India. Owing to their peculiar geographical positions and physical characteristics, the northeast India and west coast are India's two main disaster prone areas, experiencing the wrath of the monsoon. From June to September, the summer (southwest) monsoon affects both of these regions, contributing more than 80 % of the annual rainfall. Major floods occur during this season that often leads to disaster.

The rivers of the southern part of the Indian peninsula are also monsoonal in nature. Studies suggest that the hydrological characteristics of these rivers vary significantly from those of the Himalayan Rivers. With extreme variability in discharge and sediment load, the Himalayan Rivers inhabit a highly dynamic environment. From time to time, earthquakes and landslides also have a great influence on these rivers. The rivers are therefore characterised by regular changes in shape, scale, location and platform. In contrast, the fluctuations in peninsular rivers are less frequent and much smaller in nature. These rivers are subjected to severe floods during the monsoon season. According to Kale (2003), all large rivers of the Indian peninsula are subjected to high magnitude floods at intervals of several years to decades. Such floods create large hydrodynamic forces, and are likely to be geomorphologically efficient if they are long-lasting and if power consumption is strong (Costa and O'Conner, 1995). Several large-magnitude floods (peak floods between 10,000 and 80,000 m^3s^{-1}) have been reported in the last few decades. The study of the systematic, historical and pale of flood records reveals that, the frequency of high magnitude floods has increased dramatically in recent decades. Usually chances of prevalence of high floods were observed when monsoon rainfall was high in the country viz., 1988, 1989, 1993, 1995 and 1998. However, there were occasion of floods even during the drought years e.g. 1972, 1974, 1979, 1982, 1985, 1987, 2000 and 2002. This might be due to the spatio-temporal variations in southwest monsoon in India. The increase in flood frequency during the recent years is associated with heavy rain spell from cyclonic circulations, sea level troughs, off shore troughs, active to vigorous monsoon conditions, low-pressure areas, low-level troughs, mid-tropospheric cyclonic circulations and east-west oriented troughs.

1.1.1 Flood events and fatalities in India and other regions

Several countries were affected by the disasters generated by various weather conditions that caused the loss of many lives; many properties were destroyed, especially overall economic activities. According to the study conducted by Wahlstrom and Guha-Sapir (2015), among the weather-related disasters that happened from the year 1995 to 2015, 47 % were due to flooding in which 2.3 billion people were suffered from Asia. Mainly, the cities in southern Asian regions are most vulnerable to flood-related disasters. These regions are the most typhoon and cyclone prone in the world and most populous, with their slum population comprising 43 % of the city population. The alarming examples of flood-related disasters in the past in the region are Cyclone Sidr (Bangladesh), Cyclone Nargis (Myanmar) and Typhoon Fengshen (Philippines). Besides this, statistics show that over 45 % of water-related disaster fatalities and 90 % of affected people since 1980-2006 are from Asia, and the damage to property is ever-escalating (Adikari and Yoshitani, 2009; Hoyois *et al.*, 2007). Hence, the rise in casualties and economic losses are related to increase in flood frequency. This result is similar to that obtained by Dutta *et al.* (2003) indicating that economic loss and human casualties from flood events have shown increasing trend in Asia. Increased urban population, economic migrants to the cities, their socio-economic status and the poor management of these groups of population are placing the population at a high risk during flooding or any other water-related disaster. Countries such as Bangladesh, India and Vietnam are highly regarded as densely populated countries in the world (Nation Master, 2009). And these countries are also in the most flood-vulnerable list of World Water Development Report 2 (WWDR2) of World Water Assessment Programme (WWAP), 2006. Bangladesh is the most flood-affected country in the world and India is on the next position. Out of 28 states in India, 23 states are liable to floods. India accounts almost one-fifth of worldwide death rate because of floods. According to Sengupta and Kakran (2011), around 4 lakh sq. km or about one-eighth of India's topographical territory is flooding inclined.

In India, the Himalayan Rivers account for nearly 60 % of the flood damage. The chronic flood-prone basins are the Ganga and Brahmaputra covering northern and north-eastern parts of country. Flood in these rivers occur during rainy season and usually in the months of August or September. The most flood-prone states are Uttar Pradesh, Bihar, West Bengal, Orissa and Assam represents a highly flood-prone region of the country. Around 30 million people in the country are affected by floods and more than 1500 lives are lost each year (Devrani *et al.*, 2015; Gupta *et al.*, 2003). Frequent occurrence floods have been annual phenomenon in the riverine areas. Every year unprecedented floods takes place in one state or the other state in the country. At a rate of 0.014 million hectares per year, flood-prone regions in India have risen significantly over time.

In India, flood events and human fatalities increased during 1978-2006 (Rai, 2017; Sreekesh, 2009; Shrestha, 2008). This is mainly due to land-use or cover change, deforestation and overgrazing. In addition, the harmful effects of rapidly increasing population, urbanization, massive economic growth, environmental degradation and climate change also accelerate the trend of the violent natural disaster erupting in the form of floods (Shrestha, 2008). According to Singh and Kumar (2013), 75 % of flood events in the country occurred after 1990. During 1978-2006 period, the maximum flood events were recorded in Maharashtra (12 %), followed by Karnataka (9 %) and West Bengal (8 %). But in Uttar Pradesh (17 %), human lives lost were the largest, followed by Maharashtra (13 %) and Bihar and Gujarat (10 % each). On an average, about 60-80 % of flood damages occur in the state of U.P, Bihar, West Bengal and Assam.

Recent monsoon floods July 12th – 15th in 2021 in Europe was intense and Germany, Belgium and the Netherlands were the worst affected nations. Several rivers burst from their banks inundating large areas. Reports also suggest that, the death toll from the flood fury crossed 214 in Germany and Belgium. Many of the towns were submerged and people were evacuated in large number even the flood waters breached the dikes and entered the town of Meerssen in the Netherlands and the administration had to close the breach by sandbags. This shows the impact of climate change on the environment. Also, with advanced facilities and early warning systems in these European countries, the flood has not spared their life and property. However, the early warning systems for possible floods and forecast of rains that can affect larger populations is well in place in these developed nations. Therefore, the vulnerability of such floods is not only exposed in these European nations but also in Kerala floods 2018 and also in 2019. But, the spirit of eternal vigilents and disaster management measures of such floods is most important for any country.

1.1.2 Impacts of flood in Peninsular India

In many rivers of the Indian region in general and the Indian peninsula in particular, massive floods are important formative events. Such large floods are important, not only from the stand point of geomorphic work, but also in terms of social impact. Being an agrarian economy, the economic development of India has always been under the caprices of the weather, especially extreme weather events (De *et al.*, 2005). Floods in the peninsular region are responsible for colossal loss of human life, crops, property and disruption to economic activities, especially when highly urbanized and populated regions of the country are in the eye of the extreme weather events. In the recent past, India has witnessed some of the most unprecedented extreme precipitation events that caused flooding and loss of lives. Among which the prominent ones are the events which occurred in Mumbai (Maharashtra in 2005) affected more than 20 million people and caused more than 1000 deaths (Gupta and Nair, 2011). The 2013 extreme rainfall and flood event in Kedarnath (Uttarakhand) resulted in the death of more than 6000 people and caused an economic loss of more than $3.8 billion (Sati and Gahalaut, 2013; Kumar, 2013). Furthermore, extreme precipitation in Chennai (Tamil Nadu) in November 2015 resulted in the economic loss of over $3 billion (Boyaj *et al*., 2018; van Oldenborgh *et al*., 2016). In India, the total estimated loss due to the damages incurred during floods between 1953 and 2016 was estimated to be approximately INR 347,581 crores (www.cwc.gov.in/main/downloads/statewiseflood data damage statistics.pdf).

In India and other regions of the globe, extreme rainfall and flooding have become among the costliest natural disasters (Anon, 2015). Human loss from flooding are projected to increase by 70-80 % if the global mean temperature increases above 1.5 °C from the pre-industrial level (Dottori *et al*., 2018). According to Dottori *et al*. (2018), future flood effects are likely to have unequal geographic distribution, with the highest losses are to occur in Asia. Hence, the recent extreme rainfall event and widespread flooding in Kerala exemplify the enormity of extreme rainfall and large-scale floods in India. In August 2018, persistent and heavy rainfall in Kerala affected all aspects of human life, including socio-economic conditions, transportation, infrastructure, agriculture, and livelihoods. The 2018 Kerala flood has drawn attention from the media, scientists and politicians, which is potentially the worst flood in a century.

1.2 Kerala - Physiographical features

Kerala, a relatively small state with an area of 38,863 km^2, with a population of over 3.3 crore, located in the south-western part of the Indian peninsula (08°17' - 12°48' N and 74°51' - 77°20' E) and is confined between the Western Ghats in the east and the Arabian Sea in the west. It is globally recognised for its impressive achievements in human development. Kerala is blessed with 44 rivers, originate from the Western Ghats which judiciously used by the people, who have a significant impact on the livelihood of the population, which includes agriculture, fisheries, poultry, livestock, and small scale industries. Apart from these 44 rivers, their tributaries and distributaries, around 48 backwaters and a countless number of ponds, streams and rivulets crisscross the land making it green and fertile and also serve as inland waterways. Hence, all these receive rainwater and other water runoff from the terrestrial mass and debouch to Arabian Sea through West Coast canal system. Kerala, characterized by all three physiographic divisions, namely highland (>75.0 m), midland (7.5-75.0 m) and lowland or coastal plain (<7.5 m), exhibits diverse geomorphic features, such as tall mountain peaks of

Anaimudi (2695 m), 41 short-run west-flowing rivers (debouches to Arabian Sea) and 3 east-flowing rivers (debouches to Bay of Bengal), and a coastline (590 km) studded with several lagoons and barrier systems. For example, according to the study conducted by Sajinkumar *et al.* (2017) and Joseph and Thrivikramji (2002), several parts of the coastal plains (Vembanad backwater, Kuttanad, and the Kol lands of Thrissur) have their floor below the mean sea level. Many of the short run rivers have multi-purpose water storage reservoirs and dams located in the highland and/or midland, which is predominantly, designed for hydroelectric power generation as well as irrigation purposes.

The state is unique as the onset of the Indian summer monsoon rainfall (ISMR) normally starts over the Kerala coast, and the state belongs to one of the highest monsoon rainfall regions in India, along with the northeast India. Normally, the state's annual rainfall is around 3000 mm, with considerable spatial variability across the state, and the months of June and July contribute to the dominant share of annual precipitation (~50 %) (Thomas and Prasannakumar, 2016; Nair *et al.*, 2014). The width of the state i.e. mainly the distance between the ridgeline of the Western Ghats and the coastal line ranges between 15 and 120 km. The state's gentle coastal plains are heavily populated, and the midland and highland areas are primarily used for different agricultural activities and commercial plantations. The narrow width of the state between the ridgeline of the Western Ghats and the coastal line along with dense population means, that the river basins have shorter response time to extreme rainfall event (ERE) and are thus vulnerable to severe flooding (Sudheer *et al.*, 2019).

1.3 Unique position of Kerala in India

According to the Human Development Index (HDI), Kerala ranks first among the Indian states. In 2015-2016, in terms of per capita state domestic product, Kerala was among the top five Indian states and among the top four in terms of per capita revenue growth. In Kerala, several other indices of human growth can be equated with those of developed countries. For example, in 2011, the state registered a literacy rate of 94 % (as against the national average of 73 %), life expectancy at birth between 2011-15 of 75.2 years (the highest among Indian states and higher than the national average of 68.8 years) and infant mortality of 10 per thousand live births (the lowest among Indian states). In comparison to the national average of 22 %, the state also recorded the lowest proportion of the population below the poverty line (7 %). Throughout 2015-2016, 94 % of households had access to improved sources of drinking water, 98 % of which used improved sanitation facilities and 99 % of households had electricity. Considering the other Indian states, human development has been more equitable in Kerala. Also, it is the 12th largest economy in India with 11.3 % GDP contribution in Agriculture. While Kerala is highly vulnerable to natural disasters and changing climate patterns, it is located along the coast of the sea and along the slopes of the Western Ghats with a steep gradient. The Kerala State Disaster Management Plan describes 39 hazards identified as naturally triggered hazards (natural hazards) and anthropogenically triggered hazards (anthropogenic hazards) that can become catastrophic in the absence of sufficient preparedness and risk mitigation preparation (KSDMA, 2016) (Table 1.1). Kerala is also one of the most heavily populated Indian states, making it more vulnerable to disaster damage and losses (i.e. 860 people per square kilometre).

Table 1.1 Area vulnerable to hazards in Kerala

Hazards	No. of Taluks prone	Susceptible area (km^2)	Population exposed
Landslides	50	5619.7	2799482
Floods	75	6789.5	7795816
Coastal Hazards	24	289.7	313205

(Source: KSDMA, 2016)

In Kerala, natural calamities like flood and coastal erosion are common events in many regions in the lowlands during the monsoon season (Kalayathankal and Singh, 2010). Among this, floods are the most common of natural hazard in the state. Around 14.5 % of the land area of the state is vulnerable to flooding and in some districts; the proportion is as high as 50 %. In Idukki, Wayanad, Malappuram, Kozhikode and Kottayam districts, landslides are a major hazard along the Western Ghats region. During the summer months, seasonal drought-like conditions are also frequent. Kerala experienced 66 drought years between 1881 and 2000. In summer, dry rivers and declining water tables have contributed to water shortages in both urban and rural areas. Lightning, forest fires, soil piping, coastal erosion and high wind speed are other significant environmental hazards. The state also lies in seismic zone III.

In the form of monsoon rain and thundershowers, Kerala usually experiences rainfall for nearly 6 months in any given year. The variation in the annual rainfall in Kerala is small when compared with other parts of the Indian sub-continent. However, there had been at least one, uncharacteristically wet years when the historians have observed that a total of 3368 mm of rain was recorded during a period of three weeks in 1924. Specifically, this rainfall event in 1924 occurred during the southwest monsoon (SWM) season.

1.4 Historical aspects of floods in Kerala

1.4.1 Kerala flood - 1924

In 1924 (Kollavarsham 1099, traditional Malayalam calendar), unprecedented and massive floods observed in almost all the rivers in Kerala. The rainstorm was caused by the southwest monsoon, which occurred from 16-18th, July 1924 and that extended to the south of peninsula on 15th July and caused rainfall in Malabar. During the monsoon season, Kerala received 3,368 mm of rain (64 % higher than normal) possibly triggered by offshore vortices along the west coast and disturbances higher up in the troposphere and are not due to any depression or cyclonic disturbances in the Arabian Sea or Bay of Bengal. Under its influence, heavy rainfall obtained in almost the entire state. The area under the storm recorded 1-day maximum rainfall on 17th of July 1924, 2-day maximum rainfall on 16-17th, July 1924 and 3-day maximum rainfall on 16-18th, July 1924. Devikulam in Kerala was the centre of the 1-day and 2-day rainstorm, which recorded 484 mm and 751 mm of rainfall respectively. The 3-day rainstorm centre was located at Munnar in Kerala, which reported a 3-day rainfall of 897 mm. As a result of these flood, heavy losses to life, property and crops had been reported (Plate 1.1). As per the reports, the weeks of rain brought down an entire hill called Karinthiri Malai and completely destroyed the Ernakulam-Munnar road due to the catastrophic landslide at Karinthiri. A natural reservoir in the hills above Pallivasal was destroyed, as a result hydroelectric power station supplying electricity to Munnar town was buried off and Pallivasal town was no more. Kundala Valley Railway which was the first monorail system in India was also completely destroyed. Many districts of present-day Kerala were deeply submerged by the flood from Thrissur, Ernakulam, Idukki, Kottayam even up to Alappuzha and Kuttanad. While the worst affected were Munnar and Idukki, other districts also suffered massive damage. It is said that, the central Kerala was submerged up to 20 feet under water for days. The human cost of the flood of 1924 still remains an unsolved question as no accurate record of the lives lost in the disaster.

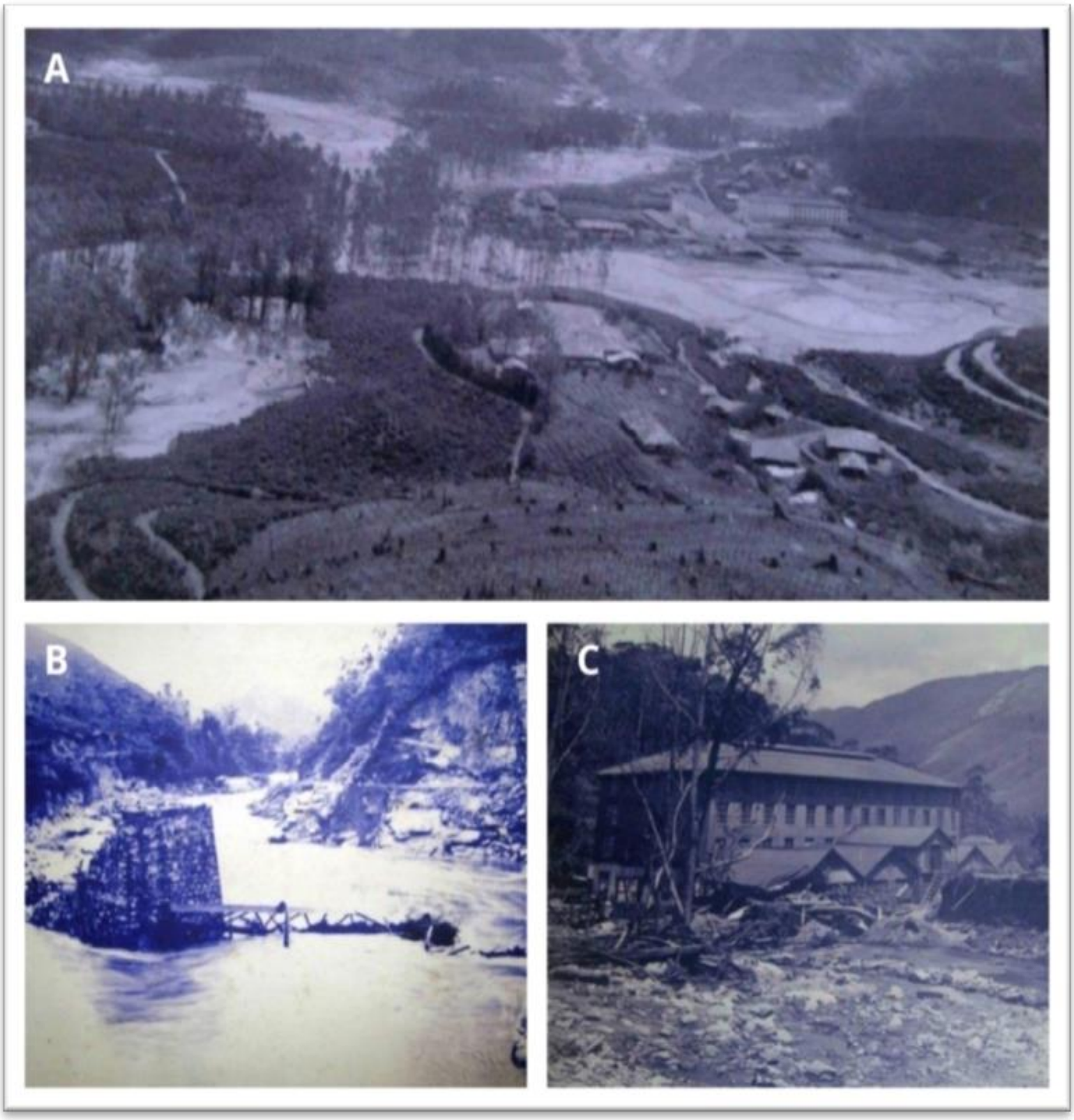

Plate 1.1 Impacts of flood, 1924 in Munnar (Source: Indiatimes.com)
(A) Munnar (B) Munnar railway station (C) Madupatty factory, Munnar

1.4.2 Kerala flood - 1961

In 1961 also, Kerala witnessed another heavy floods and rise in the water levels of reservoirs. Normally, heavy precipitation is concentrated over a span of 7 to 10 days during the monsoon season in the state, when the rivers rise above their formed banks and flood the low lying areas. But in 1961, not only in duration, but also in the rate of precipitation, floods were abnormally high. In 1961, in the last week of June, the monsoon began to turn violent and the precipitation was concentrated in most parts of the southern area of Kerala in the early days of August. By the first week of July, the severity steadily spread to other parts of the state and by the second week of July, the whole state was reeling under an extreme flood. The Periyar sub-basin was the worst affected region and other sub-basins were also affected by it. Many of the important infrastructures like highways were submerged. The monsoon became more violent by the middle of July after a short interval, affecting the northern parts of the state. The average rainfall was 56 % above normal. The maximum daily intensities recorded at four districts in 1961 are given in Table 1.2. The damage caused by the floods had been severe and varied. Nearly 115 people lost their lives due to floods and landslides. Over 50,000 houses were completely and partially damaged and around 1,15,000 acres of paddy were seriously affected (Anon, 2018).

Table 1.2 Rainfall (one day) recorded in 4 major districts of Kerala in 1961

Sl. No.	District	Rainfall(mm)
1	Calicut	234
2	Trivandrum	136
3	Cochin	189
4	Palakkad	109

(Source: CWC report, 2018)

1.5 Kerala flood - 2018

Kerala suffered the worst ever floods in its history since 1924, Between June 1 and August 26, 2018. The extreme abnormal spell of rainfall began on 8th August 2018. Initially, the rainfall was active in the northern districts of Kerala causing widespread flooding in Wayanad, Kannur and Malappuram. The rainfall was intense in these districts on 8th and 9th August. After a relatively low spell of rainfall from 10th to 13th August, the precipitation increased substantially over the entire state attaining its peak on 15th, 16th and 17th August. This rain spell was wide spread and affected the entire state. According to India Meteorological Department (IMD), during the southwest monsoon (SWM) rainfall events in 2018, the amount of rainfall was 50 % less than the 1924 event but was still 42 % more than the normal rainfall. During 2018, torrential rains coupled with release of excess water from 35 dams across the state, resulted in severe flooding in the state. Almost all 41 west-flowing rivers originating in the Western Ghats were in spate. The reservoirs of all 81 dams on these rivers were at maximum capacity by 10th August, 2018. The Kerala flood was triggered by the above seasonal rainfall, multi-day extreme precipitation, above normal reservoir storage and extreme precipitation in the catchments upstream of the reservoir (Mishra *et al*., 2018).

1.5.1 Impacts of Kerala flood 2018

During August 2018, continuous rain with heavy rainfall (e.g., 177.5 mm on 17th August 2018 at Idukki) in the catchments of Western Ghats caused reservoirs to cross Full Reservoir Level (FRL) and resulting in the release of excess water via flood gates (Duncombe, 2018). Hundreds of cities, inundated large built-up areas and small towns in the downstream of the basins have been devastated by the floodwaters that resulted from the dam release, destroying the lives of hundreds of thousands of people, warranting relocation to safe shelters. Inundation in the Achankovil, Pamba, Manimala, Meenachil, Moovattupuzha, Periyar and Chalakudy River basins led to uprooting of river shore trees, partial or complete destruction or water-logging of houses (over 50,000), shops, bridges (around 221), agricultural crops (about 1,15,000 acres of paddy were seriously affected), around 83,000 km of roads including 10,000 km of major roads, and other civil infrastructure and caused heavy siltation over the affected land. According to the reports of the state government, 1,259 out of 1,664 villages spread across its 14 districts were affected. The seven worst hit districts were Pathanamthitta, Alappuzha, Ernakulam, Idukki, Kottayam, Thrissur and Wayanad. The release of excess water from the dams inundated parts of these districts, where the whole district was notified as flood affected (Plate 1.2). The devastating floods and landslides occurred between 22nd May - 29th August 2018, affected 5.4 million people, displaced 1.4 million people, about a million people were evacuated mainly from, Chengannur, Pandanad, Edanad, Aranmula, Kozhencherry, Ayiroor, Ranni, Pandalam, Thiruvalla, Eraviperoor, Vallamkulam, Kuttanad, North Paravur, Vypin Island, Chellanam, Aluva, Chalakudy, Thrissur, Palakkad and Malappuram. Inundation in the Achankovil, Pamba, Manimala, Meenachil, Moovattupuzha, Periyar and Chalakudy River basins led to more than 483 deaths. Around 140 went missing (Anon, 2018). More than 3 lakh farmers affected out of 12 districts. Incidences of suicide were reported. In between 16th July to 28th August, 65,188 hectares of the land area was inundated [Post Disaster Needs Assessment (PDNA), 2018; Khan & Ahmad, 2018]. Nearly 341 landslides were reported from 10 districts. Idukki, the worst hit district, was devastated by 143 landslides. A number of water treatment plants, especially in northern districts of the state, have been forced to cease pumping water, resulting in poor access to clean and potable water. As a result of the severe flooding, the Kerala State Disaster Management Authority placed the state on a red alert. (Anon, 2018). One-sixth of Kerala's total population was directly affected by the floods and related incidents, according to the Kerala government (Anon, 2018). The Indian government had declared it a Level 3 calamity, or "calamity of a severe nature". The Central Water Commission (CWC) report, 2018 noted that the rainfall of August 15-17th, 2018 in Kerala was “almost of the same order as that of rainfall which occurred during July 16-18th, 1924”. The sector wise impact of 2018 flood is shown in Table 1.3 (Anon, 2018).

On 8th August 2018, most of the major reservoirs in Kerala had more than 90 % of its capacity and almost all the districts were under red alert. So, in any case, it was essential to make releases from reservoirs. Shutters of 54 dams had to be opened by 21st August 2018, and the gates of about 35 out of these 54 dams within the state were opened for the first time in history. All five overflow gates of the Idukki dam were opened at the same time, and 5 gates of Malampuzha dam of Palakkad were also opened for the first time in 26 years. Inadequate management of water resources might have played a major role in the severe damages incurred by the recent floods in Kerala. Poor watershed management in hilly areas and loose soil from land not covered by vegetation, loss of natural systems and floodplains along with the unusually high rainfall rate over a very short span, contributed to the landslides in the hilly areas.

Plate 1.2 Impacts of flood, 2018 in different parts of the State

(A) Kuttanad flooded with water | **(B) Flushing flood water from fields**
(C) Kainakary flooded with water | **(D) Submerged houses in Alappuzha**
(E) Submerged houses in Cochin | **(F) Submerged Shops & homes in Aleppey**
(G) Aluva Sivarathri Manappuram | **(H) Submerged homes in Alappuzha**
(I) Evacuation in Pandalam | **(J) Rescue operation in Idukki**

1.5.2 Rapid response and mitigation strategies

A number of relief camps were opened to save the people from the vagaries of flood. Schools, churches, temples, universities, commercial complexes were converted to temporary relief camps in almost no time. The situation was regularly monitored by the State Government, Central Government and National Crisis Management Committee. The state government responded quickly with rescue and relief operations and saved many lives by rapidly mobilising the following national forces: Kerala Fire and Rescue Services, National Disaster Response Force (NDRF), Navy, Coast Guard, Air Force, Central Reserve Police Force and Border Security Force. The fisherfolk were an invaluable link in Kerala's rescue efforts as they rendered phenomenal voluntary assistance towards search and rescue in the flood affected areas. Survivors, long before government agencies were able to reach flood victims, beginning to conduct relief operations in Kerala. Much before the Navy and the Coast Guard came to rescue, the locals joined together to save people. The information on people who were missing or stranded and location-based requirements of essential items was circulated on multiple platforms with social media proving to be the cornerstone of probably the world's largest such citizen-led rescue and relief operation. Then the state government began centralizing all efforts through various public and private forums and approved websites that enabled effective coordination and communication between the public, rescue volunteers and government authorities at different levels. In order to assist with the distribution of aid, provide medical assistance and support in rescue operations, volunteers poured in from all over the state and the country. The success of rescue and relief operations were the coordination between the multitude of civil actors from government officials to fisherfolk, white collar professionals to school kids, all of whom turned up when they were needed the most.

Additional assistance of INR 600 crore (USD 85 million) including ex gratia payment of INR 2 lakh (USD 2,800) (i.e. per person to the relatives of the deceased and INR 50,000 (USD 700) per head to those seriously injured) was declared by the Government of India. Furthermore, an additional INR 1,800 crore (approximately USD 260 million) was sanctioned by the Ministry of Rural Development under the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) for 2018-19 for 5.5 crore person days of work. Relief assistance has also been offered to individuals in camps, instant food supply, drinking water, kerosene and other life-saving items. An assistance of INR 10,000 per family to clean flooded houses and food packets were also disbursed.

The devastating floods and landslides caused large-scale damages to houses, roads, railways, bridges, power supplies, communications networks, and other infrastructure; washed away crops and livestock and affected the lives and livelihoods of millions of people in the state. The loss suffered by the state in various sectors and the total recovery needs are estimated at INR 31,000 crore (USD 4.4 billion) (Table 1.3). The assessment done across social, productive, infrastructure and cross-cutting sectors, estimates both private and public loss (Kerala Flood 2018, PDNA).

Table 1.3 Overall summary of impacts of Kerala flood, 2018 (Damage, Loss &recovery needed)

Sector		Damage (INR Crores)	Loss (INR Crores)	Total effect D+L (INR Crores)	Recovery needed (INR Crores)
Social Sectors	Housing land and settlement	5027	1383	6410	5443
	Health and Nutrition	499	28	527	600
	Education and child protection	175	4	179	214
	Cultural Heritage	38	37	75	80
Productive sectors	Agriculture fisheries and live stocks	2975	4180	7155	4498
Infrastructure sectors	Water sanitation and hygiene	890	471	1361	1331
	Transportation	-	-	-	10,046
	Power	-	-	-	353
	Irrigation	-	-	-	1,483
	Other infrastructure	-	-	-	2,446

Cross-cutting sectors	Environment	26	0.04	26	148
	Livelihoods	881	9477	10358	3896
	Disaster risk reduction	17	583	599	110
	Gender and social inclusion	0.9	0	0.9	35
	Local Governance	28	0	28	32
	Integrated water resource management	0	0	0	24
Grand Total					31,000

(Source: PDNA, 2018)

The percentage of estimated total disaster effects among the main sectors of social and economic activity reveals that, the infrastructure sectors are most affected (38 % of the total effects), which includes transportation, water sanitation and hygiene along with power, irrigation, and other infrastructure sectors. This is followed by the cross-cutting sectors (27 %), social sectors (18 %), and productivity sector (17 %). The percentage of estimated recovery needs among the main sectors of social and economic activity reveals that infrastructure sectors have highest recovery needs (51 % of the total recovery needs), followed by the social sectors (20 %), productive sectors (15 %) and cross-cutting sectors (14 %).

1.6 Impacts of recent flood in Vembanad wetland and associated coastal ecosystem

1.6.1 Wetlands

Wetlands are one of the most productive ecosystems of the earth (Ghermandi *et al*., 2008) and provide countless valuable services to the human society. It cover approximately 5-8 % of the global land area. These are ecotones or transitional zones between dry lands and open water where the water level remains near or above the surface of the ground for most of the year. It has the unique characteristics of their own and also possesses the properties of both terrestrial and aquatic ecosystems. It play crucial role in hydrological cycle. Wetland ecosystems are accompanied with a diverse and complex array of direct and indirect uses depending on the type of wetlands, soil and water characteristics, and associated biotic influences. Direct uses of wetland include water supply source and harvesting of wetland products such as fish and plant resources. Indirect uses are obtained from environmental functions such as floodwater retention, groundwater recharge or discharge, climate mitigation, and nutrient abatement. As they support a variety of plant and animal life, biologically they are one of the most productive systems in world. It is unique in having rich nutrient status and carrying capacity with immense production potential, hence considered as food and fodder resources for the entire community. The key factor that distinguishes wetlands from other land forms or water bodies is the characteristic vegetation that is adapted to its unique soil conditions. Ramsar Convention (1971), defines wetlands as (Article 1.1) "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres". Furthermore, the Convention (Article 2.1) appends that wetlands "may incorporate riparian and coastal zones adjacent to the wetlands, and Islands or bodies of marine water deeper than six meters at low tide lying within the wetlands". Cowardin *et al.* (1979), classified wetlands into marine (coastal wetlands), estuarine (including deltas, tidal marshes, and mangrove swamps), lacustrine (lakes), riverine (along rivers and streams), and palustarine ('marshy' - marshes, swamps and bogs) based on their hydrological, ecological and geological characteristics. Wetlands are important part of the ecosystem and are among the most threatened of all environmental resources.

The coastal zones play a vital role in maintaining the ecological balance between marine and inland ecosystems. They have an important position in the landscape as they are sinks and sources of organic matter in the trophic system and repositories of unique and specified biotic resources. They are among the most productive ecosystem component in the world which influence the nutrient loadings and serve as regulators of pelagic productivity. They have key role in sustaining human wellbeing due to its enormous biological resources and the life-supporting services (WRI, 2001; UNISDR/UDNP, 2012). The different types of coastal ecosystems include coral reefs to sea grass meadows, sand dunes, mangroves, salt marshes, tidal flats, lagoons and estuaries. Each of these ecosystems harbours a variety of species and maintains a range of ecosystem services essential for humans. In which coastal lagoons and estuaries deliver significant ecosystem goods and services to society and so most of the world's population live in coastal regions (Michael and Paerl, 2010). The coastal ecosystems occupy 8 % of the global surface area, accounts for about 25 % of global primary production. 90 % of the current world fishery production comes from the exclusive economic zone (i.e. from within 200 miles (321.87 km) of the coast), and most of what is caught comes from within 5.59 miles (9 km) of the shore. The loss of coastal wetlands is of particular importance to the fishing industry. Such wetlands are important breeding grounds for coastal fish species but are currently being lost at rates of more than 1 % per annum in some areas [Intergovernmental Panel on Climate Change (IPCC), 1995]. According to Bigford (1991), a 50 % reduction in wetland productivity would lead to a 15-20 % loss in estuarine dependant fish harvests.

Coastal wetlands in their natural state provide a wealth of values to the society. They play a key role in nutrient recycling, oxygen production, microclimate regulation and world climate. They are an important habitat to a variety of biologically and economically important resident and migratory aquatic fauna (Bijoy Nandan, 2008). They provide a temporary or permanent diverse habitat for plants, fishes, shell fishes, water fowls and other wildlife (homes to much wildlife i.e. many species of wildlife rely on wetlands provide mammals, plants, amphibians reptiles, birds and fish with food, habitat, breeding grounds and shelter). In addition, coastal wetlands play an important role in maintaining the environmental quality of the aquatic habitat. They act as natural filters, helping to purify water by trapping pollutants of lakes, rivers and streams. The natural filtration mechanism of wetlands will remove contaminants such as sewage, nitrogen based fertiliser, phosphorus and heavy metals from industrial waste. The water leaving a wetland is often purer than the water which enters the wetland. Wetlands are capable of efficiently purifying water and are therefore of great importance as filters for potential drinking water. Besides, they prevent flooding by holding water much like a sponge. Wetlands, therefore, help to maintain regular river levels and filters and purify the surface water. They accept water during storms and whenever water levels are high. When water levels are low, they slowly release water. They also release vegetative matter into rivers, which helps feed fish in the rivers. They help to counter balance the human influence on rivers by rejuvenating them and surrounding ecosystems. They have an important influence on the recharge or discharge of groundwater. They offer many recreational opportunities including boating, fishing, swimming, bird watching, white baiting and hunting. Also wetlands play a major role in erosion control. Mostly the erosion control efforts in aquatic areas often include the planting of wetlands plants. Although wetlands are truly unique, they should not be considered as an isolated and independent habitat. To the contrary, wetlands are vital to the health of all other biomes and to wildlife and humans everywhere. Unlike most other habitats, wetlands directly improve other ecosystems. Because of its many cleansing benefits, scientists often refer to wetlands as the "kidneys" of the earth.

Many areas in global coastal zones are very rich in biodiversity. Such biologically rich, endangered regions are identified as biodiversity hot spots. Among the 25 biodiversity hot spots of the world, 23 of them are at least partially within coastal zones from which 10.45 % of these coastal zones are designated as protected. But high population pressure in and around the coastal systems threaten the biodiversity within the ecosystem (Shi and Singh, 2003). During the last century, great concern and attention have been given to the effects of human activities on the stability and sustainability of coastal ecosystems. The land based anthropogenic activities are strongly reflected in the ecological quality of coastal wetlands. Therefore, effective policies are urgently required for the management of these biodiversity hot spots.

1.6.1.1 Flood control

By serving as natural buffers, soaking up and storing a large amount of flood water, wetlands may play a significant role in reducing the frequency and severity of floods. The capacity to store flood water is one of the most important advantages of wetlands. Wetlands absorb heavy rain, gradually releasing water, thereby minimising flooding. Throughout times of low rainfall, downstream water flows and ground water levels are also maintained. Wetlands help stabilize shorelines and riverbanks. They soak up rain and snowmelt as they occur and slowly release this water in drier seasons. Wetlands act as temporary storage basins, reduce erosion and limit the destruction caused by severe floods.

1.6.2 Coastal wetlands in India

India has long coast line and large area of wetlands coming under the coastal wetlands. The area estimates of various wetland categories for all the coastal states and Union Territories showed a total of 120019 wetlands (NWIA, 2011). In addition, 289459 ha small wetlands (< 2.25 ha) have also been identified. The estimated total wetland area is 9.70 Mha, which is around 6.94 % of the geographic area. Total inland wetlands are 5.58 Mha and coastal wetlands are 4.12 Mha. Inter-tidal mud flats (2.39 Mha) occupying around 24.7 % of total wetland area is the most dominant type of coastal wetland. The other important coastal wetlands are mangrove (471407 ha), aquaculture pond (287232 ha), lagoon (248277 ha), creek (206698 ha) salt pan (148913 ha) and coral reef (142003 ha) (MoEF&CC, 2013). There are 178 lagoons having area about 2,46,044 ha which is around 1.61 % of total wetland area of the country. Orissa has an area of 89023 ha followed by Andhra Pradesh (47407 ha) and Kerala (38442 ha) under lagoons. In all the coastal states, except Lakshadweep and Kerala, inter-tidal mud-flats are observed. Gujarat has a broad inter-tidal mud-flats area (2,260,365 ha) followed by Tamil Nadu (33,164 ha) and Andhra Pradesh (31,767 ha) (Sarkar, 2011).

1.6.3 Wetlands of Kerala

The total wetland area in Kerala is 160590 ha. Kerala has the largest proportion of land area under wetlands among all the states of India. The Govt. of India spots nearly 1762 wetlands in Kerala. In addition, 2592 wetlands smaller than 2.25 ha has also been identified. The major wetland types are marine (including coastal lagoons, rocky shores, and coral reefs; 38442 ha), riverine (wetlands along rivers and streams; 65162 ha), reservoirs (26167 ha) and waterlogged areas (20305 ha) (MoEF&CC, 2010). Among the 14 districts of Kerala, four districts can be grouped to be rich in wetland habitat. Alappuzha district covering more wetland area with 26079 ha, is represented mostly by the Vembanad-Kol wetland, the remaining three districts are Ernakulam (25065 ha), Kollam (13703 ha) and Thrissur (13285 ha). Wayanad district has the lowest area under wetland (3866 ha) (MoEF&CC, 2010). International Convention on wetlands designated three wetland ecosystems in Kerala - The Vembanad-Kol, Ashtamudi and Sasthamkotta, as Ramsar sites for the conservation of biological diversity for sustaining human life through ecological and hydrological functions they perform (Bijoy Nandan, 2008; http://www.kerenvis.nic.in). Among these, Vembanad-Kol wetland system is the largest brackish, tropical wetland ecosystem and typical of large estuarine system in Kerala (Fig. 1.1) which plays a vital role in the ecology and economy of the southwest coast of India. Moreover, the Ministry of Environment, Forests and Climate Change (MoEF&CC), Govt. of India recognized two more wetlands i.e. Kotturi in Kozhikode district and Kadalundi in Kozhikode and Malappuram districts under National Wetland Conservation Programme (Kokkal *et al*., 2007).

1.6.4 Importance of conservation of wetlands

Globally the wetlands have declined from 64-71 % in the 20th century and its degradation continues worldwide and is extreme in Asia (Davidson, 2014). For several years, humankind has been draining, in-filling and converting both coastal and inland wetlands. This conversion and degradation of wetlands continues with increasing economic and human population growth and it abruptly causes alteration from extensive and intensive agriculture and aquaculture, water abstraction and major hydro-engineering projects, increasing urbanization and infrastructure development, spread of invasive species, sea defences, port and industrial developments (Asselen *et al*., 2013). Changes in wetland areas may significantly affect ecosystem processes. Concerns about changes in the size and quality of many of the world's wetland systems have been growing because an increasing number of wetlands are being transformed to agricultural or urban uses or are being impacted by natural factors like drought. In the beginning of the 18th century, wetland conversion and loss in the long term was in excess of 50 % later as much as 87 % in 20th century, further the loss of wetland was four times faster than earlier, with loss of up to 70 % of wetlands existing in 1900 AD, the transformation of coastal natural wetlands increased more than that of inland natural wetlands in the 20^{th} century; and the alteration and loss was on-going in all parts of the world, quickly in Asia and so the fate of the world's remaining wetlands is doubtful (Davidson, 2014). So contracting parties and their policymakers have been urged to take urgent measures to meet the Ramsar Convention's objective to stop and reverse the loss and destruction of wetlands and services to people (Ramsar Briefing Note, 2015).

In case of Indian wetlands, the poor, economic, social and environmental effect of declining water quality was a major concern. According to Central Pollution Control Board, 2008, many fresh water wetlands in India are in a threatened state and several are in a declining condition due to increased urbanization, population expansion and economic activities. Wetland tourism contributes a major share to Gross Domestic Product (GDP) and employment in India (Government of India, 2012). An average of seven million tourists visit backwaters, beaches and wildlife sanctuaries of Kerala annually; three million visit Uttarakhand's lakes and other natural wetlands; one million visit Dal lake; and 20,000 visit lake Tsomoriri. Similarly wetlands in India play a significant role in fish production and its production increased from 0.2 million tonne in 1950-1951 to around 5.1 million tonne in 2010-2011 (Bassi *et al*., 2014). Wetlands act as a net sequesters or producers of greenhouse gases based on the biogeochemical processes and hydrology. The coastal wetlands in India have a great role in carbon sequestration and the Vembanad wetland releases up to 193.2 $mg/m^2/h$ of CH_4 (Verma *et al*., 2002). Poor governance and management is also a major problem in deteriorating these water bodies (Kumar *et al*., 2013). Most of the Indian wetlands were polluted due to agricultural runoff and untreated sewage discharges and other waste from urban areas. In India, the urban population has risen eightfold over the 90 year period from 1901 to 1991 due to the population explosion (Bassi and Kumar, 2012). This level of increase created great pressure on wetlands and flood plain areas, which formed large water and food demand for growing population in India. Water is seriously polluted in most Asian rivers, lakes, streams and wetlands, primarily due to the drainage of pesticides and fertilizers from agriculture fields, untreated industrial and municipal wastewater discharges, all of which caused widespread eutrophication (Prasad *et al*., 2002). It is estimated that, due to the climate change related sea level rise of up to 1 m will possibly decline around 84 % of coastal wetlands and 13 % of saline wetlands in India (Blankespoor *et al*., 2012). This will adversely affect the wetland and migratory species which utilize the wetland habitats for completing their life cycle. Even though India is included as a signatory to Ramsar Convention on Wetlands and also for enforced Wetland (Conversation and Management) Rules in 2010, but no significant improvement has occurred on the conservation and wise use of wetlands. It is complained that only few wetlands get the consideration from the national conservation policy process such as National Wetland Conservation Programme, National Lake Conservation Plan, etc. (Bassi *et al*., 2014).

In Kerala, wetlands and hills are under threat because of developmental activities. Wetlands are being reclaimed with soil extracted from reclaiming the hills and valleys. The indiscriminate activities will have a significant adverse effect on the entire ecological system. In the past few years, it has become a common phenomenon in Kerala and many educated people continue to believe that hills and wetlands are wastelands. Currently, Kerala's wetlands are subjected to acute pressure from rapid construction activities. Most government sponsored projects, especially in urban areas, find space in wetland areas where extensive reclamation activities continue unabated. Unauthorized encroachment of wetland areas for non-wetland purposes are still continuing in the state particularly areas adjacent to low land paddy fields, mangrove areas and other backwater areas. Much of the encroachments were initially for agriculture purposes; later on, for many other purposes, these areas have been reclaimed and used. In addition to deforestation in uplands and in wetlands, unscientific land use and agricultural activities place tremendous pressure on wetlands, contributing to soil erosion. This causes siltation, resulting in vertical shrinkage and related concerns such as salinity intrusion, habitat change and loss of biodiversity. The eroded soil contain large amount of nutrients which causes eutrophication. Use of low-lying lands for purposes other than the originally envisaged, like paddy lands for vegetable cultivation and aquaculture, reclamation of the private owned low land areas for construction purposes, for industries are common practices in many places, which lead to the changes in the ecosystem. Furthermore, some areas are excavated for clay and soil for making country bricks. The destruction of wetlands due to various anthropogenic activities has brought countless species of medicinal and economically valuable plants and animals to the brink of extinction. Wetlands and hills are two significant water storing systems that play an important role in maintaining the hydrological cycle of the tropical and subtropical regions. Water is normally preserved in hills at higher elevations either in the sedimentary deposits or in the soil or weathered horizons. The gradient helps in groundwater flow. Rivers and lakes will be fed during summer by the stored water in the hills and hillocks. Therefore the hills are called 'Thanneer kudangal (water pots)' and wetlands as 'Thanneer thadangal (water reservoirs)'. Scientists often refer to wetlands as the "kidneys" of the earth and forests as the "lungs" of the earth. These two systems function as unique ecosystems that provide significant environments for many ecologically and economically important plants and animals. Therefore, wetlands reclamation and demolition or levelling of hills means degradation of our hydrological cycle that sustains life and greenery of the Earth.

1.6.5 The Vembanad-Kol wetland

Vembanad-Kol wetland, the largest brackish humid tropical wetland ecosystem in the state of Kerala, lies between 09°00’ - 10°40’ N and 76°00’ - 77°30’ E (Fig. 1.1). It consists of Vembanad backwater bordered by Kuttanad on south and Kol lands of Thrissur on north, which are interlinked by rivers, estuaries and mangrove marshes, all interconnected by a complex network of natural and manmade channels spreading over an area of 1,51,250 ha (MoEF&CC, 2020). The Vembanad wetland system spread across four districts of Kerala viz., Thrissur and Ernakulum in the north, Kottayam in the east and Alappuzha in the south. Four canals - Thottappally, Andhakaranazhi, Kochi and Azhikode connect the Vembanad backwater to the sea. It is unique in terms of physiography, geology, climate, hydrology, land use and flora and fauna. The Vembanad backwater has a total surface area of ~36,500 ha and contributes over 50 % of the total area of backwaters in the state. The width of the backwater varies from 0.5 to 4.5 km and the depth from <1 to 9 m. Situated in the humid tropics, this positive wetland system with semidiurnal tidal cycle experiences fairly uniform temperature ranging from 21 °C to 36 °C. Rainfall is obtained during two distinct rainy seasons, southwest monsoon (June-August) and northeast monsoon (September-November). The average annual rainfall in the area is 3200 mm and salinity ranges from 10 to 22 ppt at surface during pre-monsoon. The wetland is fed by ten rivers flowing from the Western Ghats: Pamba, Manimala, Achankovil, Meenachil (in the south), Muvattupuzha, Periyar, Chalakudy, Keecheri, Karuvannur and Puzhakkal (in the north) with a drainage area of 1,577,000 ha (i.e. 15,770 km^2). River basins of Vembanad receive 32 million tonnes of sediments annually, which is mainly contributed by the human interference that occurred in the catchments of Western Ghats. Chitrapuzha, a small stream, also drains into the central part of Vembanad wetland.

Fig. 1.1 IRS LISS-III FCC - 5 km buffer area of a) Vembanad wetland system

(Source: National Wetland Atlas, 2013)

Vembanad wetland is an ecologically sensitive transitional zone between the marine and terrestrial ecosystems. The site is ecologically significant owing to vanishing mangrove patches and many animals that live in other habitats use this wetland for migration or reproduction. The Vembanad wetland ecosystem is identified as an Important Bird Area (IBA) by Birdlife International. *Horadandia atukorali* an endangered fish species (tending to be most common in flood plains and other lowland areas) listed in IUCN red-data book is also reported from the Pathiramanal Island in the Vembanad wetland. Based on the fulfilment of criteria 4, 5 and 6 of Ramsar convention, Vembanad-Kol wetland has been designated as a Ramsar site (Ramsar site no. 1214), a wetland of international importance on 19^{th} August 2002. The Criterion 4 states that, a wetland should be considered internationally relevant if it supports plant and/or animal species at a critical stage in their life cycles, or provides shelter during adverse conditions. Criterion 5 encompass that, a wetland should be regularly supporting 20,000 or more water birds. Criterion 6 states that a wetland should be regularly supporting 1 %

of the individuals in a population of one species or subspecies of water bird (www.ramsar.org). Vembanad backwater, along with the adjacent Kol lands, is the second largest Ramsar site (1,51,250 ha) in India and supports the third largest wintering waterfowl population of the country. It is one of the 15 mangrove areas that have been identified by the Ministry of Environment, Forests and Climate Change (MoEF&CC) for intensive conservation and management (Rajan *et al.*, 2008). It also supports a highly productive agricultural system - Kuttanad the 'rice bowl of Kerala', spread over 1,100 km^2, which is a reclaimed portion of the backwater. The Vembanad wetland helps to contain flood waters and prevent submersion of densely populated areas, recharges coastal aquifers, filters and flushes out contaminants.

1.6.5.1 Kuttanad wetland system

Kuttanad is part of the Vembanad-Kol wetland system and is a deltaic trough like formation shaped by the confluence of five major rivers of the state, Pamba, Manimala, Achankovil, Meenachil and Muvattupuzha (Velupillai, 1996). The Achankovil-Pamba-Manimala River system feeds south and south-western parts of Kuttanad and the Meenachil feeds the eastern parts of Kuttanad. The Muvattupuzha River and the smaller Kariyar River feeds the Vaikkom area, which are in the north-eastern parts of Kuttanad wetland system. These rivers join into the Vembanad backwaters through a network of water ways and canals, and flow in a south to north direction, and then travel further north towards Cochin barmouth and empty into the Arabian Sea (MSSRF, 2007). Kuttanad comprises of marshy low lying area below mean sea level (1.5 to 2 m), coastal alluvial belt, uplands of higher elevation, river networks and backwaters, contributing to a unique ecology. The ecological character of the Kuttanad wetland is the capacity to provide a wide range of naturally occurring ecosystem services (MSSRF, 2007). Kuttanad, 'the rice bowl of Kerala', also commonly known as Kuttanad wetland system, comprises of paddy fields; a marsh, lakes and rivers located around the Vembanad Lake, and includes 304 km^2 of garden lands and 524 km^2 of low lying rice fields, the rest being aquatic systems (Thampatti and Padmakumar, 1999). The region extends from 9°17' - 9°40' N and 76°19' - 76°33' E and most of the region lying 0.6 - 2.2 m below mean sea level (Sreejith, 2013), water logged throughout the year, that is facing flood submergence during monsoon period and salt water intrusion during summer. Kuttanad region comprises of 79 revenue villages, 10 taluks: Cherthala, Ambalapuzha, Chengannur, Kuttanad, Karthikappally and Mavelikkarataluks in Alappuzha districts, Thiruvalla taluk in Pathanamthitta District and Changanassery, Vaikom and Kottayam taluks in Kottayam districts covering an area of 870 km^2 (Hazard Centre and People's Science Institute, 2006).

Kuttanad has an area of 1,10,000 ha and is divided into four ecological zones. It include Garden or dry land (~31,000 ha), wetlands (11,000 ha), reclaimed land having 55,000 ha which is situated below sea level and water bodies including lake and canals having area of 13,000 ha. Garden land is an important area for plantation crops situated above MSL of 0.5 to 2.5 m and the dry lands were not facing floods or from saline water intrusion. The major portion of wetland areas (66,000 ha) are reclaimed from the backwater for paddy cultivation, which is situated either above MSL or below MSL. From this, 55,000 ha of reclaimed area situated below MSL are called as *punja* lands including cluster of fields are called “padashekarams” (paddy lands). Remaining 11,000 ha of wetland is part of Upper Kuttanad, where no influence of floods and salinity intrusion is reported. Agriculture is the main economic activity employing about 40 % of the population. The United Nation's Food and Agriculture Organisation declared Kuttanad as a Globally Important Agricultural Heritage Systems for its below sea-level farming system (Anon, 2013a). *Punja* lands of Kuttanad are categorized as Karappadam lands having 33,000 ha area, Kayal land with 13,000 ha area and Kari land with area of 9000 ha. Karappadam lands having alluvial soils are situated along the waterways, canals and included the lower reaches of eastern and southern boundary. During the flooding period, large amount of silt was deposited in the area. Kayal lands mainly included the padashekarams situated between 1.5 to 2.2 m below MSL. The area is situated in the revenue villages Chennenkari, Kainakary, Pulimkunnu of Kuttanad taluk and Thiruvarppu and southern regions of Kumarakom of Kottayam taluk. Kari lands having black peaty soils is situated at or below MSL of north (Vaikom) west (Cherthala) and southwest (Purakkad) of Kuttanad. The soil in Kuttanad is a mixture of silt and clay in varying proportions. The sediment of the area is highly acidic, saline and high in organic carbon content. Several parts of this delta have subsoil layers containing pyrites which on oxidation produces severe acidity (Thampatti and Jose, 2000).

1.6.5.1.1 Kuttanad agro-ecological zones

Based on the agro-ecological and climatic features, Kuttanad is classified into six agro-ecological zones (Fig. 1.2). The distinctiveness includes mean sea level range, river influence, flooding, salt water intrusion, soil characteristics, fertility and cropping pattern.

Upper Kuttanad: It is situated on the south eastern side of Kuttanad which includes comparatively high lands and covering 10,576 ha. The elevation varies from 0.5 to 6 m above MSL and bund levels vary from 0.3 m to 5.0 m above MSL. The zone experiences low risk of saline intrusion and flood. Rivers such as Achankovil, Pamba and Manimala enter in this zone before flowing into Vembanad backwater.

Purakkad Kari: Situated on the western side of Upper Kuttanad having an area of 3,500 ha and spread across 43 padashekarams over four panchayaths of Ambalappuzha and Karthikappally. This zone is close to the sea and located 1.5-2.0 m below MSL. This zone is undergoing the risk of floods and salt water intrusion through Thottappally spillway and Ambalappuzha - Thakazhy canals. Water and sediment of the area are highly acidic due to peaty soil (partially decomposed organic matter).

Lower Kuttanad: It is the main part of Kuttanad, having 16,280 ha area and situated on the south-eastern side of Vembanad backwater. The elevations of padashekarams vary from 1.5 m below to 1.0 m above MSL and the bund levels at 0.3 to 1.3 m above MSL. This zone experiences a high risk of flood and salt water intrusion and also noticeable with the presence of small islands with human habitation.

Kayal lands: Located on the north of Lower Kuttanad having 9,464 ha area at elevations 1.0 m to 2.0 m below MSL with bund levels ranging from 0.6 to 1.1 m above MSL. Most of the lands were reclaimed from the shallow portion of south eastern part of Vembanad backwater. More than 600 padashekarams are included in this zone and is experienced with the risk of flood and saline water intrusion.

North Kuttanad: This zone is having an area of 6,556 ha, located on the north and eastern side of Vembanad Kayal falling in Kottayam district, including the Kumarakom town. The land is formed by deltaic formation of Meenachil River and its distributaries. The elevation of the western side was 0.5 m below MSL and the eastern side was 1 m above MSL. Salt water intrusion was the major risk faced by this zone.

Vaikkom Kari: It is located on the northernmost part of Kuttanad, i.e. northern side of Thanneermukkom barrage, spreading an area of 7,748 ha. The western portion having an elevation of 0.5 m below MSL and in eastern portions it reaches up to 6 m above. The zone is experienced with high risk of salt water intrusion during summer. Due to the presence of high organic carbon content, the soil of the area is black in colour. The soils of the area are highly acidic, heavy texture, hypoxic and low fertile in nature. Partially decayed (peat logs) wood is seen in this area.

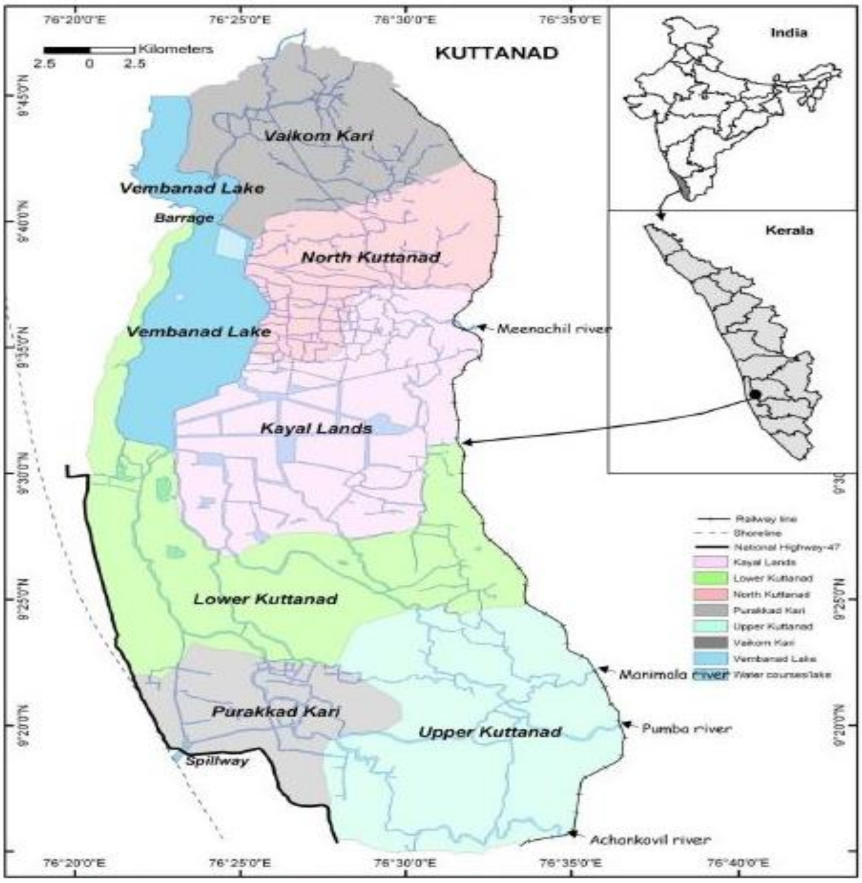

Fig. 1.2 Divisions of Kuttanad wetlands (Source: Narayanan *et al.*, 2011)

Based on the topography and the rivers, Kuttanad divide into three major ecological zones - highlands, lowlands and backwaters. Sandy beach ridges close to the sea have an elevation of 1.5 to 5 m above MSL. Upper Kuttanad has elevations of -0.5 m to +6.0 m MSL and elevations in lower Kuttanad areas range from -1.5 m to +1.0 m MSL. The backwaters or the Kayal lands are at elevations -1.0 m to +2.2 m MSL (MSSRF, 2007). According to MSSRF (2007), the rainfall and evapo-transpiration study in Kuttanad showed that the actual wet season in Kuttanad is only about 3-4 months, from mid-May to mid-August; whereas a water deficit condition occurred in the remaining months. During this period, the tidal entry increases and reduces the water level in Kuttanad by 1.22 m within 6 hrs and this causes saline water intrusion into the lake. The intermixing of saline and fresh water in Kuttanad was varied annually and it mainly depends upon the rainfall and inflow of rivers. During January to April-May a brackish water condition was prevailed in Kuttanad.

Agriculture is the major economic activity in Kuttanad and other parts of Alappuzha. Rice and coconut are major crops contributing to about 80 % of agricultural income. Area occupied by paddy and coconut is 38 and 45 % of the cropped area, respectively. Other crops include banana, tubers and vegetables. Dairying is not common in Kuttanad due to shortage of fodder, forages, and high price of concentrates. Kuttanad has highest number of ducks in the State and duck farming is also constrained with non-availability of paddy fields for foraging and affliction of serious diseases. Increased pesticide load in the water caused immune-suppression in ducks. The local duck breeds, 'Chara' and 'Champally' having better resistance (MSSRF, 2007). While capture fishing from water bodies is a major livelihood, culture fishing is not common, despite availability of water bodies. The culture fishing in paddy fields of wetland and *Pokkali* area under 'one paddy-one fish' system appears to have potential in limited areas for enhancing the farm income. There are two distinct paddy season in Kuttanad; *Punja* (main summer crop - Rabi crop) and *virippu* (additional crop - Kharif crop). *Punja* crop sown in November or December and harvested by the end of March whereas the additional crop grown from May to the end of June and harvested in September or October (http://www.kuttanadpackage.in). The cultivated *punja* lands of Kuttanad are having an area of 40000 ha and that of additional crop cultivated approximately 10000 ha area consists of several padashekarams or polders separated by channels and bunds. The area is important in maintaining the food security of the state contributing 20 % of the state rice production. Major part of the Kuttanad paddy lands are the reclaimed portion of the lake, as reclaimed on the basis of state policies for expanding the rice production due to Second World War and Bengal famine. Due to state policies and private involvement, a large portion of the shallow area of lake was converted for rice cultivation and reduces the lake area by 65 %. In high ranges large portion of forest area were reclaimed for agriculture crops and cause silting up of the lake.

In Kuttanad, rice cultivation faced several problems mainly because of the annual flooding and salt water intrusion during monsoon and summer respectively. Kuttanad experienced annual flooding and during the period majority of the areas get submerged under water. Vast areas of paddy fields get submerged for one or two weeks and the annual monsoon flood caused severe damage into the whole Kuttanad area. During monsoon floods, the bunds getting breached and lead to crop damage or result in complete loss of cultivation costs of farmers. The flood water enters the Vembanad backwater, from where the water is washed out to Arabian Sea through the Cochin barmouth. During the flood period, communication and transportation facility of the area become worst and the whole area gets isolated as an island with no connection to the mainland. Flooding is worst where the rivers from the upper catchments enter the area in upper Kuttanad, and the least near the backwater. The flood storage capacity of the wetland in turn is closely related to the land use pattern, mainly the extent of rice cultivation in polders. Kuttanad area and the community associated with the region are facing extreme agrarian distress over the last few decades from multiple factors. Based on the request of Government of Kerala to address the perennial problems faced in Kuttanad, the Union Government entrusted Dr. M. S. Swaminathan Research Foundation (MSSFR), Chennai to conduct a detailed scientific study of the region and to suggest suitable measures to mitigate agrarian distress in Kuttanad. The MSSRF recommended a variety of intervention to be executed as a Kuttanad Package with a total outlay of 1,840 crore which was accepted by Govt. of India. Thus Kuttanad package was implemented by the Kerala Govt. in 2008 on a time bound-manner, but was probably a big failure.

The objective of the package was to propose measures for strengthening ecological security of Kuttanad and for expanding sustainable livelihood opportunities for the local people through work and income security (http://www.kuttanadpackage.in/). The report contains a malady-remedy analysis of the problems and potential solutions and the suggestions include - creation of Special Agricultural Zone (SAZ), restoration of natural drainage systems, minimizing ecological damage caused by TMB, functional restoration of Thottappally spillway, reducing pollution of Kuttanad waters, improving logistics of padashekarams, revitalization of fisheries, promoting environmentally sustainable water tourism, promoting group farming, enhancing income from coconut farming system, improving productivity and profitability of rice farming. The main tasks recommended in the package are: (1) protection and ecological restoration of the water spread area; (2) measures for salinity and flood management in Kuttanad; (3) measures for pollution control; (4) total elimination of aquatic weeds; (5) measures for augmenting biodiversity in the backwaters; (6) improving health and sanitation; (7) declaring Kuttanad a Special Agricultural Zone; (8) provide infrastructure support to paddy cultivation; (9) enforce crop calendar; (10) strengthening of research and extension; (11) strengthening economic viability of farming; (12) coconut-based enterprises and integrated farming; (13) actions to promote fishery wealth of Vembanad lake; (14) promoting fish infrastructure and (15) infrastructure support to facilitate responsible tourism (under water tourism and local ecology) (MSSRF, 2007).

The package aimed at ‘Mitigating Agrarian Distress in Alappuzha and Kuttanad Wetland Ecosystem,' may destroy the environment and ecology of Kuttanad and inflict severe damage to the midland and highlands of the state from where huge volumes of granite would be quarried for the construction of bunds. Criss-cross roads have come up in the State's granary by reclaiming paddy fields and canals. In the name of development, Kuttanad has been subjected to indiscriminate human interventions and the carrying capacity of Kuttanad has already reached its peak. Expressing his dissatisfaction over the implementation of the Kuttanad package M. S Swaminathan admitted the fault in the implementation of the Kuttanad package in a time bound-manner. He said that lack of time bound implementation and some kind of criteria/standards affect the productive nature of the project accomplishment. He added that the failure to set a time schedule and the lack of coordination among various government departments were the major factors that adversely affected the implementation of the package (Anon, 2013b). Poor research and development support for package lead to its failure of implementation and the lack of right resources with the right skills also increases the impact. Lack of establishment of professional implication trigger the complete failure of the package.

The Vembanad wetland is a lifeline for the villages situated on its bank (nearly 1.6 million people in 38 panchayaths spread across three districts). Directly or indirectly, a large population residing in the drainage basin is dependent upon this wetland ecosystem for their livelihood. Major livelihood activities are dependent on the Vembanad wetland are agriculture, fishing, tourism related activities, inland navigation, coir retting, harvesting live clams, lime shell collection, shrimp/crab farming, sand mining and fodder collection for livestock. More than 20,000 fishermen are directly dependent on the aquatic resources of this wetland fetching over 7000 tons of fish and shellfish annually. Surrounding land mass is used for rice cultivation, plantation crops, housing, tourist resorts and industries. All these 'water based activities' depend upon environmental integrity of the Vembanad wetland and the surroundings. The commercial nature of many of these activities leads to uncontrolled resource use which poses grave threats to the ecosystem. At present, the environmental condition of the wetland system is in a steady decline due to severe anthropogenic pressures.

1.6.5.2 Thottappally Spillway

Due to the accumulation of floodwaters from the river systems in Kuttanad, water level used to rise beyond manageable limits soon after the onset of the southwest monsoon. The entire low lying areas of the region used to remain flooded till the end of north east monsoon making it impossible to raise a second crop during the autumn season. Detailed hydraulic surveys conducted from the early 1930's had shown that this problem could be mitigated by diverting the floodwaters directly to the Arabian Sea at the extreme south of the flood limit itself. Accordingly, the construction of a spillway was started in 1951 at Thottappally located 20 km south of Alappuzha town. A 368 metre long outlet to the sea was constructed. The regulator-cum-bridge has 40 spans of 25 ft. (KDP, 1972). It was designed to discharge 64,000 cusecs of water to the sea and to control floods in Kuttanad and the spillway was designed to discharge more than 90 % of it directly to the sea (George, 1984). However, while designing the spillway the problem of piling up of water due to the raising sea level during the monsoon months and the consequent formation of sand bar on the seaward side of the spillway were not taken into account. Therefore after the spillway was completed in 1955, the realized capacity of it is found to be less than one - third of the estimated capacity and hence fails to serve its purpose to some extent (Thomas, 2002). So the remaining flood water in the Kuttanad area makes least salinity in the upper part of the wetland system (Nayar, 1998).

1.6.5.3 Alappuzha-Changanassery (AC) Canal

Alappuzha town is connected with Changanassery by Alappuzha-Changanassery road (AC road), which was opened for traffic in 1958 and passing through Kuttanad area. The AC road was created in an east-west direction right across the direction of floodwater movement. Along its 42 km length is the AC canal was envisaged to remove the block caused to the water flow by the AC road, and cuts across all the three north flowing rivers and some of their branches. This canal was envisaged along as a 50 m wide canal. But the anticipated role of AC canal for controlling the flood water was not accomplished due to the incomplete construction work. Now the paddy fields get water-logged soon after a heavy downpour in the upper Kuttanad area. There is no progress in expanding the Alappuzha-Changanassery (AC) Canal, a project under the Kuttanad Package, mostly due to the delay in the eviction of traders and families residing on either side of the canal. The construction of AC canal from Manackachira to Onnamkara (Phase I - 11.72 km) tendered and the construction work is started now.

1.6.5.4 Thanneermukkom Barrage (TMB)

The Thanneermukkom barrage was built (1975) as a part of Kuttanad Development Scheme to prevent salinity intrusion in the dry season and retain a freshwater condition into the Kuttanad region so as to make possible the *punja* cultivation (KWBS, 1989). The barrage is located at Thanneermukkom, 25 km north of Alappuzha considered the largest mud regulator in the country, which was built across narrowest region of backwater between Vechoor in east and Muhamma in west. It has a length of 1400 meters and includes a 470 m long reclaimed portion in the middle of the estuary. The plan was to build the TMB in three phases. The first phase at Muhamma end comprising 31 shutters and two locks for navigation was completed in 1968. The second phase at Vechoor-end with 31 shutters and one lock was completed in 1974. When the work on the third phase with 31 shutters was delayed, a cofferdam was erected in 1975 to stop the saltwater flow. However, some of the reports states that the barrage was commissioned in 1976 (Anon, 2001). Another important issue associated with TMB is the deviation in the construction from its original design with the erection of the cofferdam at central section. This has changed the cross section of the Vembanad backwater at its deepest central part. The anticipated benefit from TMB was safe *punja* paddy and intensification to a second crop (*virippu* crop) in about 18,500 ha of Kayal land, Lower Kuttanad. The barrage closure extended from three month period of December - March to even May. The barrage was operational and retaining a fresh water condition in the south of Thanneermukkom barrage and additional cropping was taking place during dry seasons in the Kuttanad area. The barrage has been relatively successful in ensuring freshwater conditions in Kuttanad and enabling cropping additional areas during dry seasons. However, there have been several ecological consequences triggered by changes in salinity regimes and impeded circulation and mixing patterns. There has been a decline in brackish water fisheries. Elimination of tidal flushing has impacted pollution levels in Kuttanad, further aggravated by increasing use of fertilizers and pesticides which also contributed to proliferation of invasive, water hyacinth affecting the light penetration in the southern zone of TMB. The fishery resources of the southern part of Vembanad backwater suffering a decline due to the construction of TMB, mainly its haphazard opening and closing and resultant ecological changes (MSSRF, 2007). The shutters have remained closed for a period up to six months invariably creating conflicts between farmers and fishers. Based on the expert committee constituted by Govt. of Kerala to settle the conflicts regarding the opening and closing of the barrage, to assess the environmental, ecological and socio-economic imbalances arising out of barrage operations, proposed to reduce the annual period of closure of barrage to mid-December to mid-March and also suggested for implementing entire environmental monitoring programme and a participatory structure for barrage operations. Measures recommended include modernization of TMB with efficiently operable shutter, replacement of middle cofferdam with barrage, operation of TMB at scheduled time and appropriate enforcement new crop (*punja*) calendar and exploration of opportunity for reducing the scheduled time. It is also important to note that, based on the recommendations of M. S. Swaminathan Commission’s Kuttanad package, as a recent development in 2014, Govt. of Kerala initiative the cofferdams and other obstructions along the TMB were suitably replaced by sluice gates (barrages) for overall rejuvenation of the ecology of the backwater, for the continuity of the water body on the south and northern sides and also for the effective management for salinity regulation in the low lying paddy fields of the wetland. But such modifications could again lead to other ecological implications on the ecosystem which is to be further probed.

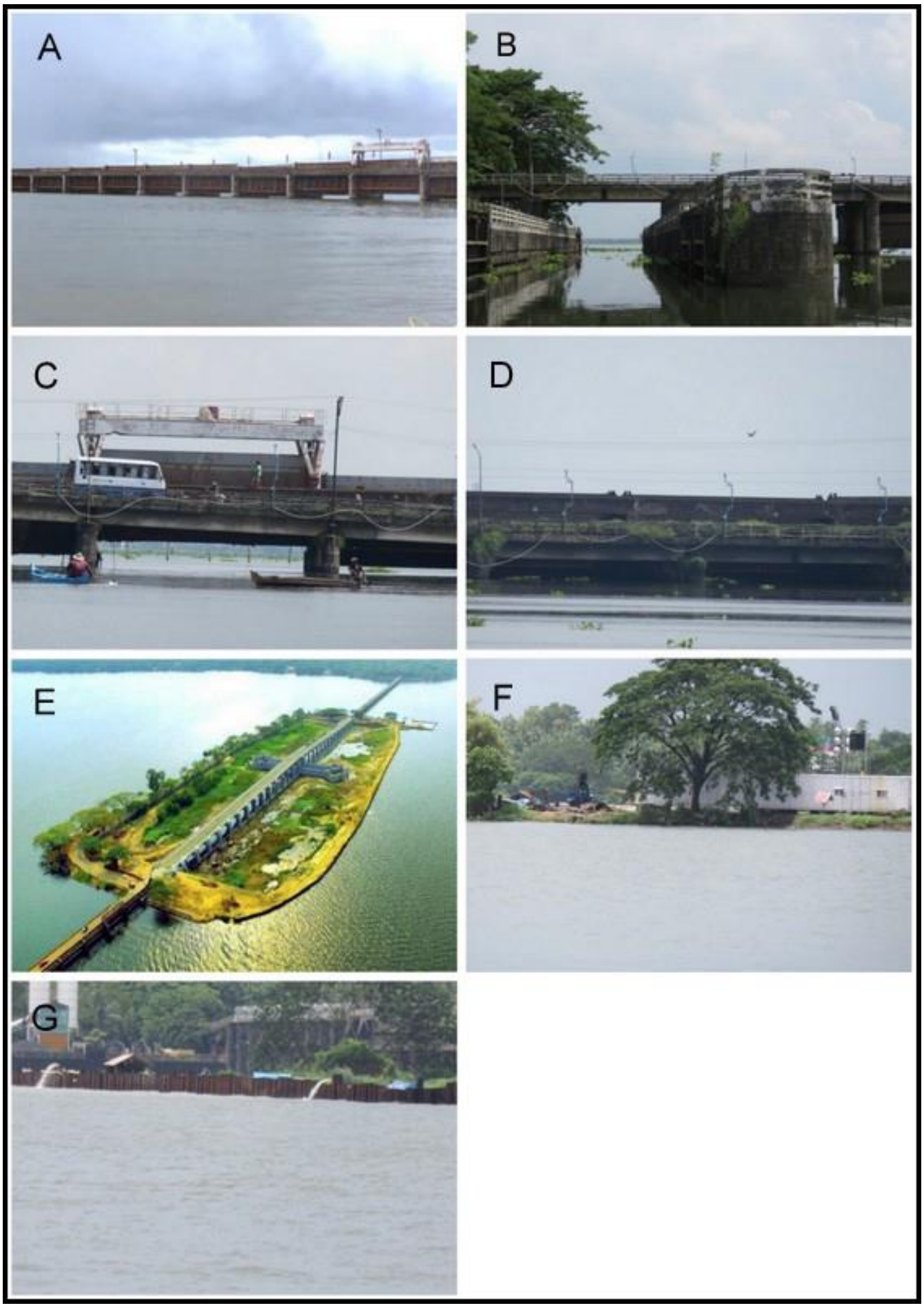

Plate 1.3 Different views of Thanneermukkom barrage
a) Thanneermukkom Barrage b) National Water Highway crossing the barrage
c) TMB: Open period d) TMB: Closed period e) Cofferdam
f) and g) Recent reclamation activities in the middle cofferdam
(Source of Picture E: http://epaper.mathrubhumi.com/21.03.2017)

1.6.5.5 Major interventions in Vembanad wetland system

Among the human interventions in Vembanad wetland, the earliest one was the dredging of a natural harbour at Kochi and creation of a new island for harbouring port facilities. Later, in order to solve the flooding problems and salinity issues, a spillway was built at Thottappally with a clear span of 304 m, to divert flood water from Vembanad wetland into the sea., but a long term solution to the issues were not achieved. Yet another intervention was the construction of Thanneermukkom barrage (TMB) across the Vembanad backwater in 1976 (which is 1250 m long with 93 sluice gates each 12.2 m wide and 5.5 m high), to prevent salinity intrusion to the Kuttanad agrarian system during dry seasons (Bijoy Nandan *et al*., 2014; Government of Kerala, 2002**)** and retain a freshwater condition into the Kuttanad region so as to make possible the *punja* cultivation. But the operation of TMB transformed the wetland into two distinct ecosystems, a fresh water zone on the south and a brackish water zone on the northern side of the barrage, resulting in gross changes in the physical, chemical and biological entities of the wetland system. Incomplete construction of the barrage, having an earthen zone in middle portion of the estuary intensified the situation of Kuttanad by reducing flood water receding during monsoon and tidal intrusion in all the seasons. Instead of earthen bunds, the reinforced granite bunds used for facilitating the additional crop of rice during monsoon created severe damage to the upper reaches of Kuttanad. Several minor spillways cum regulators were also constructed in the Kol wetlands for controlling flood water and to prevent salinity intrusion. Interventions in the river basins of the wetland system include three completed irrigation projects and nine hydel projects.

1.6.5.6 Alterations of Vembanad wetland system

Significant alterations have taken place in the morphology and ecology of Vembanad wetland in the sequence of its history can be congregated as a combination of natural processes and human interferences of which latter has contributed much serious alterations in the system. Reclamations in the name of agriculture and aquaculture have been in its peak in the Kuttanad resulting in its shrinkage both horizontally and vertically (Gopalan *et al*., 1983). According to MSSRF (2007), the water spread area of Vembanad has decreased over the years both in square area and cubic area. In 1834, the Kayal having 36,329 ha area and this was reduced to about 23,750 ha in 1983. It further declined to 13,224 ha in 1992 and 12,504 ha in 2000 and its rate of decline has increased over the years. The reclamations and economic activities in the Cochin estuary catalyzed with the development of the Cochin Port Trust in 1938, presently ending with Vallarpadam International Container Trans-shipment Terminal, Kochi (2011) and Liquefied Natural GasTerminal (LNG) (August, 2013). The annual rate of decline during the first phase (1834-1983) was 0.23 %, which during the second phase (1983-1992) increased to 4.93 % and to 0.68 % during the third phase (1992-2000). Along with the depth, the water carrying capacity of the wetland system has reduced to 78 %, i.e. from 2.4 km^3 to a mere 0.6 km^3 (MSSRF, 2007). The depth of the backwater is decreasing and its rate increased after the construction of Thanneermukkom barrage particularly its cofferdam situated in the middle of the backwater. Reduced flow in the southern part cause the deposition of silts and ultimately reduces the depth of the system and it leads to decline in the carrying capacity of the water body (Rajan *et al*., 2008). According to Nair and Suresh Babu (2016) the total area wise loss of the Vembanad backwater was 12.28 km^2 between 1972 and 2015.

Besides, pollution from a multitude of sources deteriorating the water quality of the wetland system. Industrial and agro-chemical residues, municipal sewage, domestic wastes, waste discharge from houseboats and resorts and coir retting to open water bodies are the major sources of pollution. The retting of coconut husk for the production of coir is one of the most extensive and damaging pollution affecting the entire backwater ecosystems of the region (Bijoy Nandan, 2008). Water quality degradation is apparent in high concentration of nutrients, heavy metal contamination, high incidence of waterborne diseases and reduction in fish diversity and fish catch (Kuttanad Water Balance Study, 1989). Also, numerous seafood exporting units functioning in the banks of Vembanad backwater, dumps their effluents directly in to the Lake. The chemical industries near the Vembanad backwater release nearly 260 million litres of trade effluents/day to the wetland system. Sixteen major industries around Cochin discharge nearly 0.104 mm^3/d of waste containing organic load into the Cochin estuary (Balachandran *et al*., 2006).

1.6.5.7 Vembanad wetland: Flood scenario

Coastal wetlands play a significant role in the protection of coastal settlements by attenuating floods and tidal surges. Anthropogenic interferences such as drainage and filling alter wetland hydrology and result in profound changes to wetland functions such as flood control (Yang, 2003). The drainage capacities of channels are affected by choking of main drainage channels and increased siltation. As a result, flash floods are common in low-lying areas even during very early phases of monsoon. Post flood sedimentation and unregulated disposal of solid waste in rivers resulted in a reduced carrying capacity and increased flood occurrence. Extensive land reclamation and conversion for polder rice cultivation and construction activities significantly impacted the hydrology of Vembanad wetland system. Hence, this low-lying region susceptible to extreme flooding due to high monsoon discharges received from the major rivers originating from the Western Ghats. In recent decades, augmentation of flood risk became a major issue in the Vembanad wetland and associated coastal ecosystem.

Several canals and drains draining the paddy fields are seriously compromised with encroachments. Unscientifically constructed roads, bridges, silting and aggressive spread of waterweeds also added to the problem. They block the free flow of rivers and canals resulting in water logging, accumulation of wastes, breaching of bunds, promotion of prolific breeding of predator fishes and deadly pathogens, degrading water quality and obstructing the navigation. Three major obstructions to be rectified on priority for regulating flood in Vembanad backwater and Lower Kuttanad area for protection of paddy fields are those between the C and D Blocks in Pulinkunnu panchayath and Rani and Chithira blocks in Kainakary and in the AC 11 canal flanking the AC road. Even though many new roads have a good impact on communication and life of people in Kuttanad, they are creating many ecological problem in the manner in which they are laid out. For a better future, it is very necessary to remove several roads built by PWD and local panchayaths by violating environmental norms essential in Kuttanad. Encroachment of rivers and backwaters for constructing homes and establishments and for farming activities, destruction of paddy fields, illegal quarrying activities and sand mining in rivers have deep ecological impacts, as they reduces the water carrying capacity of soil and thereby depleting the ground water level. Excessive withdrawal of groundwater in the plains is also reducing the inflows into the wetlands. The management of wetlands for sustainable fisheries, tourism and transportation is inadequate. Degrading ecosystem due to extensive exploitation of the natural resources and deforestation, coastal erosion, monsoon storm surges, sea level rise and land subsidence due to tunnel erosion or soil piping (a creeping slow hazard that emerged from analysis of landslides) etc. accelerated flooding in Kerala.

1.7 Significance of the study

The Vembanad-Kol wetland system is one of the largest estuarine system and a designated Ramsar site, on the southwest coast of India. It is a wetland of global importance for its biodiversity values and ecosystem services, fed by ten rivers covering an area of 1,51,250 ha. It is one of the massive and vibrant coastal wetland ecosystem of international importance with unique priceless ecosystem values. The Vembanad wetland ecosystem and associated backwaters have been considered as subservient to water needs for the developmental sectors and therefore heavily fragmented. The Kol region is home to over 90 species of resident birds and 50 species of migratory birds. The wetland supports vulnerable species spot-billed pelican (*Pelicanus philippensis*), habitat for variety of finfish, shellfish and a nursery of several species of aquatic life and renowned for its live clam resources and sub-fossil deposits. This wetland ecosystem comprises not only the Vembanad Lake but also a huge network of rivers, canals and drains. The canals provide the local people with tremendous navigational facilities. The

Vembanad-Kol wetland system has several functions and values. It regulates and manages the flood water and saves around 3500 km^2 of densely populated coastal region covering five districts (i.e. Thrissur, Ernakulam, Alappuzha, Kottayam and Pathanamthitta) in Kerala from flood damage. It has a significant role to play as a sink for ten rivers, serves as an efficient aquifer for the excavated wells in the neighbouring areas that provide people with drinking water. The region is regularly facing floods during the southwest monsoon season, becoming one large sink between the Arabian Sea and main land and acts as the flood control system for the entire area in the four districts. In addition, the Vembanad wetland act as a sink and transformer for the agricultural and municipal wastes discharged into it. It also acts as a giant filter and flushes out mechanism of the pollutants and subsistence resource for a very large number of fishermen and coir processors. In order to sustain optimum subsistence activities, the region around the Vembanad wetland ecosystem is one of the most heavily inhabited areas of Kerala and a single ecosystem next to Arabian Sea. Therefore degradation of this wetland system poses a major threat to the sustainability of the economic growth for the entire region.

Due to human intervention and ever increasing pollution, the Vembanad wetlands and associated backwaters are facing an acute environmental and ecological crisis. The Vembanad wetland, which is a protected Ramsar site, into which several rivers drain, has been encroached on and its capacity to hold water has been drastically reduced because of the huge urbanization that has taken place around it. Consequently, it did not have the capacity to hold the huge runoff received during the 2018 flood that overflowed and submerged the areas around it. The unauthorized encroachment and reclamation of wetland areas for non-wetland purposes are still continuing in the state especially areas adjacent to low land paddy fields, mangrove areas and other backwater areas. Floods, intensive sedimentation, decrease in the depth of the backwater, decline in fishery, avifauna and mangrove vegetation and degradation of water quality are the major impacts on the wetland ecosystem. Unregulated disposal of solid waste and massive sedimentation reduced the carrying capacity of the Vembanad wetland and increased flood occurrence.

The combination of above normal seasonal rainfall, state-wide extreme rainfall conditions, high reservoir storage, unprecedented extreme rainfall in the catchments upstream of major reservoirs and reservoir release might have played a significant role and worsened the large-scale flood occurred in Kerala during 2018. The Vembanad wetland and associated coastal ecosystem had critically affected and ravaged the general ecology of the wetland habitat by the heavy flood accompanied by the extreme rainfall event. The terms of reference of the study was to conduct field work in the selected study stations in Vembanad wetland, covering the upstream, downstream and riverine areas of Alappuzha, Kottayam, Ernakulam and Pathanamthitta districts during the flood and post flood period to understand the status and changes on the water and sediment quality, productivity and biodiversity represented mostly by the plankton, benthos and fishery. The study also mandated to refer secondary data on rainfall, river discharge and dam storage and relate it to the observations and conclusions of the study. Because of its significance on biodiversity and the large number of people depending directly or indirectly on the wetland system, the impact of flood on the environmental quality is quite significant. So, in view of this, the Kerala State Pollution Control Board (KSPCB) entrusted the major task of assessing the changes in water quality and general environmental scenario along the biodiversity changes and productivity of Vembanad wetland system during flood and post flood period of 2018.

1.8 Objectives of the study

- To assess the flood situation in the Vembanad wetland system based on the field condition and secondary data.
- To assess the environmental quality and biodiversity changes of the various sectors of the Vembanad wetland system (extending from the north to southern regions covering three districts viz., Ernakulam, Kottayam, Alappuzha and Pathanamthitta including the Cochin estuarine zone) during flood and post flood scenario.
- To propose management strategies for maintaining the environmental quality during such intense floods.
- To propose proper control measures for reducing the future flood impacts.

2. MATERIALS AND METHODS

2.1 Study area

Wetlands are unique, productive ecosystems where terrestrial and aquatic habitats meet, sustaining many natural cycles and also supporting wide range of biodiversity entities. The Vembanad-Kol wetland system, Ashtamudi and Sasthamkotta, are the three designated Ramsar sites of Kerala. Among which Vembanad-Kol wetland (09°00'-10°40' N and 76°00'-77°30' E) constitutes the largest brackish humid tropical wetland ecosystem in Kerala on the southwest coast of India. It consists of Vembanad backwater bordered by Kuttanad on south and Kol lands of Thrissur on north, which are interlinked by rivers, mangrove marshes and water fowl habitats all interconnected by a complex network of natural and manmade channels spreading over an area of 1,51,250 ha (MoEF&CC, 2020). The Vembanad backwater is bordered by Alappuzha, Kottayam and Ernakulam districts of Kerala having an average depth of <1 m to 9 m. The major city of Kochi, 12 municipal towns and 100 villages are located on the bank of this wetland system. It supports unique assemblage of marine, brackish water and freshwater species and well known internationally for its unique, endemic biodiversity and livelihood opportunities. It is an important tourist destination and supports a highly productive agriculture system including the ‘rice bowl of Kerala’. It has two permanent openings into the Arabian Sea; at Cochin and Azhikode. The backwater opens to the Arabian Sea at Cochin (Cochin gut) that 450 m wide and another opening at Azhikode (Azhikode gut) has 100 m width and fairly deep. Rivers such as Pamba, Manimala, Achankovil and Meenachil flow into the wetland through the south of Thanneermukkom barrage whereas Periyar and Muvattupuzha rivers flow into the wetland through the north of Thanneermukkom barrage. The other four rivers i.e. Chalakudy, Karuvanur, Keecheri and Puzhakkal are also drain into the wetland through the northern part.

2.2 Study stations

Thirty nine different stations were identified for field sampling based on ecological importance (Table 2.1). The geographic positions of study stations were fixed using GPS (Global Positioning System). The study stations, selected were St.1 - Aroor, St.2 - Perumbalam, St.3 - Varanad, St.4 - Thanneermukkom North, St.5 - Thanneermukkom South, St.6 - Pathiramanal, St.7 - Aryad, St.8 - Sports Authority, St.9 - Munnattinmugham, St.10 - Nehru trophy finishing point, St.11 - Pangankuzhipadam, St.12 - Punnamada, St.13 - Pallathuruthy, St.14 - Meenappally, St.15 - Meenappally Vattakayal, St.16 - Meenappally Neendakayal, St.17 - Kainakary, St.18 - Kuttamangalam, St.19 - Kuppapuram, St.20 - C Block Cherukayal, St.21 - C Block 2, St.22 - R Block, St.23 - Kizhakke Vattakayal, St.24 - H Block, St.25 - Ranikayal, St.26 - Marthandam, St.27 - Chithirakayal, St.28 - Kumarakom, St.29 - Kumarakom Centre, St.30 - Vembanad Centre, St.31 - Marine Science Jetty, St.32 - Bolgatty, St.33 - Chittoor, St.34 - Cheranelloor, St.35 - Methanam, St.36 - Eloor, St.37 - FACT, St.38 - Kadamakudy, St.39 - Cochin Barmouth (Plate 2.1). The map showing the study stations are given in Fig. 2.1.

Table 2.1 Study stations selected for flood and post flood survey in Vembanad wetland system during August and November 2018

Sl. No.	Station	Geographic Position
1	Aroor	09° 55' 05.96" N and 76° 18' 39.52" E
2	Perumbalam	09° 49' 48.59" N and 76° 21' 56.22" E
3	Varanad	09° 41' 586" N and 76° 22' 185" E
4	Thanneermukkom North	09° 40' 41.47" N and 76° 23' 36.25" E
5	Thanneermukkom South	09° 40' 32.72" N and 76° 23' 36.45" E
6	Pathiramanal	09° 37' 18.76" N and 76° 22' 30.55" E
7	Aryad	09° 32' 35.23" N and 76° 21' 17.92" E
8	Sports Authority	09° 31' 31.88" N and 76° 21' 32.65" E
9	Munnattinmugham	09° 30' 30.98" N and 76° 18' 18.11" E
10	Nehru Trophy finishing point	09° 29' 59.71" N and 76° 21' 22.66" E
11	Pangankuzhipadam	09° 30' 23.30" N and 76° 21' 55.74" E
12	Punnamada	09° 30' 18.41" N and 76° 21' 19.39" E
13	Pallathuruthy	09^0 48' 695" N and 76° 36' 491" E
14	Meenappally	09° 29' 50" N and 76° 23' 02" E
15	Meenappally Vattakayal	09° 29' 23.12" N and 76° 22' 46.87" E
16	Meenappally Neendakayal	09° 29' 18.66" N and 76° 23' 04.95" E
17	Kainakary	09° 31' 32" N and 76° 22' 35" E
18	Kuttamangalam	09° 29' 37.25" N and 76° 23' 04.83" E
19	Kuppapuram	09° 41' 586" N and 76° 22' 185" E
20	C Block Cherukayal	09° 31' 17.47" N and 76° 23' 34.60" E
21	C Block 2	09° 32' 28.83" N and 76° 24' 12.84" E
22	R Block	09° 32' 47.45" N and 76° 24' 55.66" E

23	KizhakkeVattakayal	09° 31' 39.21" N and 76° 24' 16.75" E
24	H Block	09° 31' 42.25" N and 76° 26' 01.98" E
25	Rani Kayal	09° 32' 10.91" N and 76° 22' 54.45" E
26	Marthandam	09° 53' 560" N and 76° 40' 500" E
27	Chithirakayal	09°32' 35" N and 76°24' 19" E
28	Kumarakom	09° 35' 55.33" N and 76° 25' 30.24" E
29	Kumarakom Centre	09° 35' 55.39" N and 76° 24' 43.11" E
30	Vembanad Centre	09° 35' 48.91" N and 76° 23' 50.51" E
31	Marine Science Jetty	09° 57' 50.57" N and 76°16' 49.67" E
32	Bolgatty	09° 58' 58.89" N and 76°15' 42.94" E
33	Chittoor	10° 02' 17.24" N and 76° 16' 8.37" E
34	Cheranelloor	10° 04' 20.07" N and 76° 16' 49.01" E
35	Methanam	10° 05' 33.41" N and 76° 17' 43.12" E
36	Eloor	10° 04' 52.47" N and 76°17' 57.45" E
37	FACT	10° 04' 34.78" N and 76°18' 10.97" E
38	Kadamakudy	10° 03' 10.70" N and 76° 15' 05.12" E
39	Cochin Barmouth	09° 58' 9.05" N and 76° 14' 1.62" E

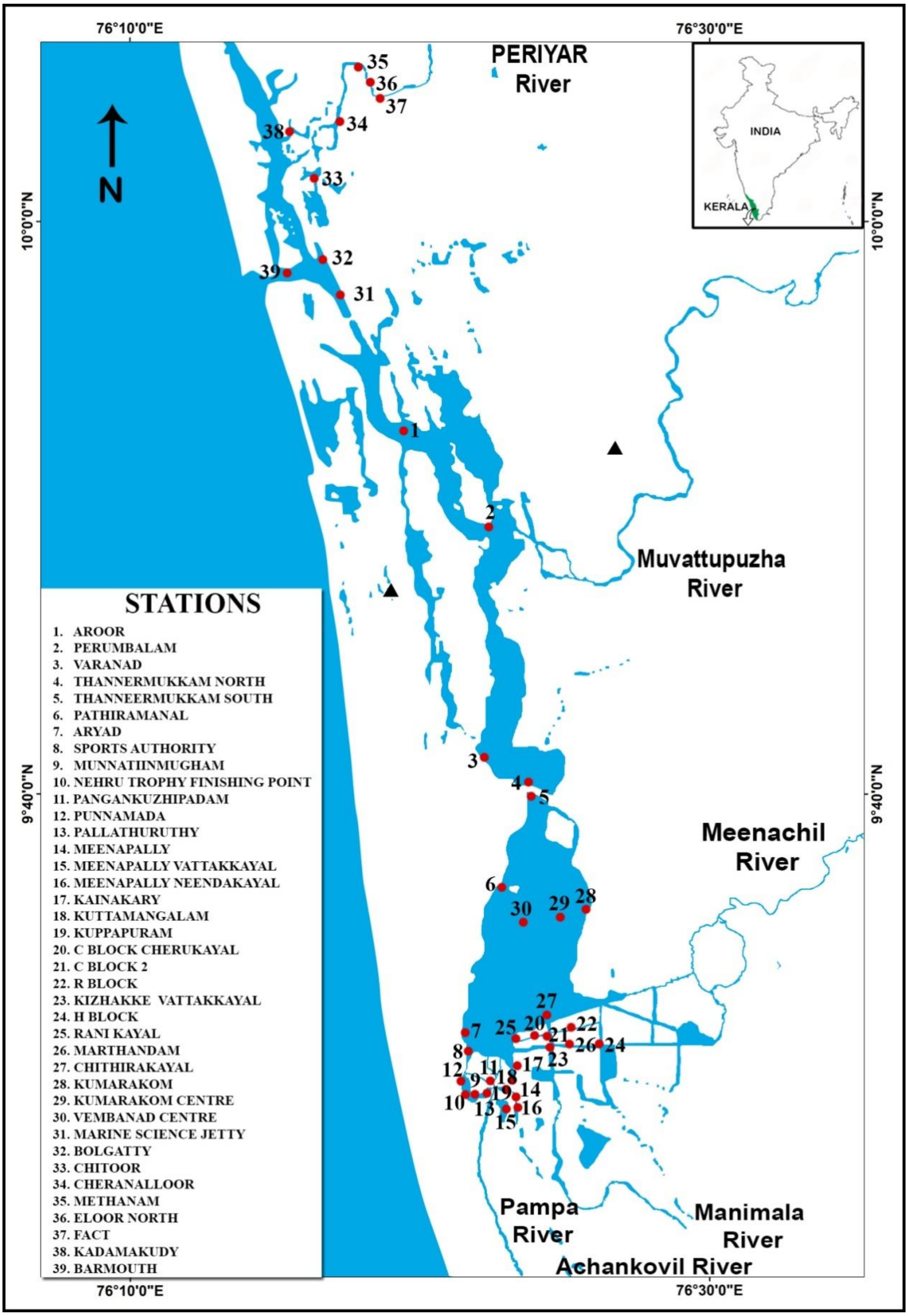

Fig. 2.1 Map of Vembanad wetland system showing the study stations

Station 1: Aroor (09° 55' 05.96" N and 76° 18' 39.52" E)

The station is situated near to barmouth (about 9 km) and is highly influenced by the tidal action, currents and saline water intrusion from the nearby Lakshadweep Sea. It is a seafood related industrial area located at the south of Kochi. The abundance of marine wealth and logistical advantages has helped the seafood export grow especially around Aroor. Thus the station is also affected by the discharges from seafood industries situated in the banks of the estuary. Sewage wastes from the Kochi city is also a major threat to the station. The Cochin Shipyard and the Cochin Port are releasing sizable quantities of waste oil, metal and paint scrapings into the station. Fishing activities with stake nets and cast nets by traditional fishermen could be observed here. The heavy movement of motor boats was observed across the station.

Station 2: Perumbalam (09° 49' 48.59" N and 76° 21' 56.22" E)

Perumbalam is an island, located in the central part of the Vembanad wetland, which is wedge shaped, pointing towards the barmouth. It is bordered by Ernakulam district on the north and Kottayam district on the south. Most beautiful attraction in this island is backwater and traditional fishing. Perumbalam is also famous for its coir products and a land of lush paddy fields. The station is about 14 km away from Cochin barmouth and is highly influenced by anthropogenic interventions like encroachment, land filling and construction activities in the small islands of the water body. Mining by local fishermen for clam fishery was widely observed in the area and fishing by cast nets, stake nets could also be seen here. There was a number of illegal construction activities in the lake especially in small private Island Nediyanthuruthu situated near to the Perumbalam Island.

Station 3: Varanad (09° 41' 586" N and 76° 22' 185" E)

This station is influenced by discharge from Mc Dowell and Company’s distillery unit situated on the western side of the water body. Both raw and treated effluents from the distillery are being directly discharged into this station with high organic load causing severe fouling of the atmosphere. It is about 34 km away from Cochin barmouth and 5 km from the barrage. Fishing activity by local fishermen using cast nets and traps could be seen around. Continuous dredging for clam shell beds by the Travancore Cements Ltd. (TCL) for the production of white cement was evident in the area, which adversely affects the water quality and benthic biodiversity.

Station 4: Thanneermukkom North (09° 40' 41.47" N and 76° 23' 36.25" E)

This station is located on the northern side of the Thanneermukkom barrage, at a distance of about 150 m north of the barrage and 40 km from the Cochin barmouth. The station acts as a transition zone between north and south of the wetland system. This station experiences the action of tides and currents arising from the barmouth at Cochin. Intense fishing activity, sand mining and inland water transport activities were seen actively in this zone. The station is a major source of clam, *V. cyprinoides,* which provides livelihood for thousands of fisherfolk.

Station 5: Thanneermukkom South (09° 40' 32.72" N and 76° 23' 36.45" E)

This station is located on the south of Thanneermukkom barrage, about 400 m away from barrage and on the narrowest part of Vembanad wetland. This station is influenced by tides and currents arising from the Cochin barmouth on the northern side of the water body. It is also part of the main basin of the estuary and is almost the central part of the water body extending from Alappuzha to Cochin. Intense fishing activity, sand mining and inland water transport activities were observed in this zone. The unscientific operations of the Thanneermukkom barrage have blocked the connectivity of the water body to the sea for a good part of the year. Thanneermukkom barrage severely affects the ecological characteristics of this zone and restrained the seasonal intermixing of fresh and saline water and thereby interfering with natural cleansing mechanisms of wetland and threatening accelerated loss of habitats and biodiversity.

Station 6: Pathiramanal (09° 37' 18.76" N and 76° 22' 30.55" E)

The study station is a small island (28.505 ha.), in Muhamma panchayath of Alappuzha district, harbouring rich biological diversity which is the fresh water zone of Vembanad wetland. The island is fringed by mangroves and associates and is around 7.5 km away from the barrage. It emerged as an important roosting site for water birds due to availability of food and negligible human habitation was observed in the surrounding areas. Oriental darter, a near-threatened bird species and the vulnerable spot billed pelican *Pelicanus philippensis*, is known to visit here. It is the home for 91 local species of birds and 50 migratory birds from different parts of the world. The island stands out in terms of species diversity, 24 species of dragonflies and damselflies, 23 spiders, 34 butterflies, 88 birds, 58 fishes and 7 reptiles have been recorded from here. Land drainage from the island could be observed particularly during the monsoon period. The island has been beautified by State Tourism Department by laying road ways and planting trees that has probably altered the topography of the area. Fishing activity, clam fishery mining and tourism related activities are seen in the area. Operation of Thanneermukkom barrage, have altered the natural ecological characteristics of the station.

Station 7: Aryad (09° 32' 35.23" N and 76° 21' 17.92" E)

It is the widest point and the main basin of the Vembanad wetland system. It's around 26 km away from the barrage. Shorelines of the study station have also been reclaimed for development of infrastructure for tourism. Live clam fishing by traditional fishermen was a prominent activity in the station, providing livelihood and full time employment to over thousands of fishermen. Rich sources of live clam as well as sub fossil deposit of clam are the characteristic feature of this station. *Villorita cyprinoides* were the major clam species observed here. The rate of sand mining is higher than natural replenishment in the station and has resulted in the development of pits of various dimensions in the estuarine beds, affecting the water quality and depth of the station. Houseboat tourism and related activities were also influencing the station. Thanneermukkom barrage plays a critical role in influencing salinity pattern of this station. Closure of Thanneermukkom barrage during the summer months lead to a significant reduction in tidal flushing in this zone which affects the water quality of the region.

Station 8: Sports Authority (09° 31' 31.88" N and 76° 21' 32.65" E)

This station is located near the Water Sport Centre under the Sports Authority of India and is highly influenced by the houseboat tourism activities. Human settlements and resorts are situated near the station. The water quality of the station is highly affected by the sewage discharge from houseboats and nearby resorts. The station is received freshwater discharge from Pamba River.

Station 9: Munnattinmugham (09° 30' 30.98" N and 76° 18' 18.11" E)

This is the station near to the controversial luxury backwater resort, Lake Palace resort in Alleppey. Kollam - Kottappuram waterways is passing through this area and is also an alluring tourist spot where houseboats ply the waters.

Station 10: Nehru Trophy Finishing Point (09° 29' 59.71" N and 76° 21' 22.66" E)

The station is situated on the southern region of the wetland which is the finishing point of the famous Punnamada boat race. The station is influenced by the river discharge from Pamba, Manimala and Achankovil. Temples, resorts, boat jetties are seen around the station. Sewage discharge from houseboats, resorts and Alappuzha town seriously affects the station. Fishing activities by local fishermen can also be observed.

Station 11: Pangankuzhipadam (09° 30' 23.30" N and 76° 21' 55.74" E)

Most of the land in this area is used for paddy cultivation and people living in this area are engaged mainly in agricultural practices and fishing. Agricultural runoff including pesticide residues and fertilizers from these paddy fields and domestic sewage are major factors which affects the hydrology of this zone.

Station 12: Punnamada (09° 30' 18.41" N and 76° 21' 19.39" E)

Punnamada is the southern region of the Vembanad wetland. This portion of the Vembanad wetland is located in Kuttanad region in Alappuzha district. Punnamada is one of the leading tourist destinations in the world. The well-known Nehru trophy boat race is annually being conducted in Punnamada Lake. This station is severely influenced by houseboat tourism activities and sewage disposal from Alappuzha city. Schools, churches, temples, big and small resorts and home stay are seen on either side of the station. The Water Sport Centre under the Sports Authority of India is also located in this station. The unrestricted operation of houseboats in Punnamada Lake has caused serious environmental pollution. Fishing activities are also active in Punnamada region. The riverine inflow from Pamba, Achankovil and Manimala plunge into Vembanad wetland is through Punnamada. Organic and inorganic fertilizers from the Kuttanad paddy fields directly get drained into this station.

Station 13: Pallathuruthy (09° 48' 695" N and 76° 36' 491" E)

This station is situated on the south eastern side of the wetland with low lying paddy fields bordering it. It is about 45 km away from the Thanneermukkom barrage. It is a water bound region surrounded by the Vembanad backwater and the Pallathuruthy canal passes through the region. Pallathuruthy has become an inevitable tourist spot, vital vein for houseboats as well as artisanal fishing activity. Like the rest of Kuttanad, most of the land in Pallathuruthy is used for paddy cultivation. Riverine inflow from Pamba, Achankovil and Manimala influence the station. Human disturbances, mainly by large scale tourism developments in Pallathuruthy are increasing; and have a negative impact on its natural beauty. Agricultural runoff from the polders (padasekharams), sewage disposal from houseboats, human settlements and floating weeds around seems to be affecting the station. Agrochemicals including fertilizers, insecticides, domestic sewage and urban wastes from Alappuzha town severely affect the water quality of Pallathuruthy. Usage of these polluted waters for domestic purposes has led to several waterborne epidemics.

Station 14: Meenappally (09° 29' 50" N and 76° 23' 02" E)

This is a small village on the southernmost part of the wetland. The station is influenced by the discharges from Pamba River. Increased houseboat tourism and boat jetties around the station have negative impacts on the water quality. Church, temple and other human settlements are also seen on either side of the station. The major income is agriculture and fishing.

Station 15: Meenappally Vattakayal (09° 29' 23.12" N and 76° 22' 46.87" E)

The station is situated on the southern region of the Vembanad wetland. Paddy and coconut are the main agricultural crops in this area. The solid waste from houseboats and leachates from agricultural fields probably influences the station. The station is received freshwater discharge from Pamba and Manimala River.

Station 16: Meenappally Neendakayal (09° 29' 18.66" N and 76° 23' 04.95" E)

This station is situated on the southern region of the Vembanad wetland. Houseboat tourism activities are common in this region. Churches, temples and resorts are seen around the station. The agricultural runoff from nearby paddy fields and sewage discharge from houseboats and nearby human settlements influence the water quality of this station.

Station 17: Kainakary (09° 31' 32" N and 76° 22' 35" E)

The station is famous for its pristine scenic beauty. It is situated on the eastern side of the wetland. The lush green coconut trees and paddy fields surrounded by blue water make this area an attractive tourist spot. The station is influenced by the river discharge from Pamba and Manimalayar. Kainakary is synonymous with ‘Kettuvallam’ or houseboats. It is famous for its snake boat race rowers. The major income is from agriculture and fishing. Human settlements and large scale tourism activities have negative impacts. Sewage discharge from houseboats and domestic wastes also affects the station.

Station 18: Kuttamangalam (09° 29' 37.25" N and 76° 23' 04.83" E)

The station is situated on the eastern side of the wetland, which is a small village; the green paddy fields were boarded by coconut trees. This station is influenced by the riverine inflow from Manimala and Pamba River. The solid waste from houseboats and runoff from agricultural fields probably influences the station. Churches and temples are also seen around the station.

Station 19: Kuppapuram (09° 41' 586" N and 76° 22' 185" E)

This is a small village situated on the southern part of the wetland. Most of the land in Kuppapuram is used for paddy cultivation and people living in this area are engaged mainly in agricultural practices and fishing. Field discharge, including pesticide residues and fertilizers and domestic sewage are major factors which affects the hydrology of this zone. This area is influenced by the discharges from Pamba River. Church, temple, boat jetties are seen around the station.

Station 20: C Block Cherukayal (09° 31' 17.47" N and 76° 23' 34.60" E)

The station is situated on the eastern side of the estuary. It is influenced by the field discharge from nearby padasekharams and riverine inflow from Pamba and Manimala. R block is the nearest padasekharams situated on the eastern side of the station.

Station 21: C Block 2 (09° 32' 28.83" N and 76° 24' 12.84" E)

This station is situated in the middle of C Block and R block. It is the place where Marthandam Kayal and the Manimala River intercept. It is influenced by the Pamba River and field discharges from the nearby padasekharams.

Station 22: R Block (09° 32' 47.45" N and 76° 24' 55.66" E)

The R block is also known for its picturesque vast paddy fields. It is situated near to the C Block. It is influenced by field discharges and riverine inflow from Kodoor River and Marthandam Kayal as well.

Station 23: Kizhakke Vattakayal (09° 31' 39.21" N and 76° 24' 16.75" E)

This station is situated in between North Kainakary and Kuttamangalam regions. The Alappuzha-Veliyanadu ferry is passing through this area. This Vattakayal is influenced by discharges from both Pamba and Manimala Rivers.

Station 24: H Block (9° 31' 42.25" N and 76° 26' 01.98" E)

H Block is also a place known for its vast paddy fields. It is situated in between Pallikayal and Marthandam Kayal, near to the R Block. It is influenced by field discharges and riverine inflow from Kodoor River.

Station 25: Rani Kayal (09° 32' 10.91" N and 76° 22' 54.45" E)

The station is influenced by the riverine inflow from Pamba and Manimala. Field discharge from nearby R and C block padasekharams affects the station. Increased houseboat tourism and related activities have negative impact on the hydrology of the zone. This station is situated on the eastern side of the wetland.

Station 26: Marthandam (09° 53' 560" N and 76° 40' 500" E)

This station is situated on the eastern side of the wetland and is influenced by the discharges from Pamba and Manimala River. The station is about 32 km away from Thanneermukkom barrage. The R Block and C Block are the nearest padasekharams situated on the eastern side of this station. Agricultural runoff including pesticide residues and fertilizers from these padasekharams is a major factor which affects the hydrology of this zone. It is also a major area of clam (*V. cyprinoides*) fishery. The station is a major site for night halting of majority of the houseboats apart from Punnamada and Kainakary. The station gives way for the inland water way for transport boats. All these boating activities trigger fuel emissions from boat motors, suspension of bottom sediments, decreased water transparency, shoreline erosion, destruction of fish spawning areas and loss of valuable fish. Uncontrolled houseboat tourism in the peak of tourism season subjects this station to indiscriminate exploitation beyond its carrying capacity. The solid waste from boats and runoff from agricultural fields probably influences the station**.**

Station 27: Chithirakayal (09° 32' 35" N and 76° 24' 19" E)

The station is situated on the eastern side of the wetland which is influenced by the field discharge from R and H block padasekharams. Agricultural runoff including pesticide residues and fertilizers from these padasekharams and riverine inflow from Pamba and Manimala are the major factors affecting the hydrology of this zone. Houseboat tourism and related activities also affects the station.

Station 28: Kumarakom (09° 35' 55.33" N and 76° 25' 30.24" E)

Kumarakom, which is situated in Kottayam district, is one of the foremost travel destinations in Kerala. Kumarakom is home to a wide variety of tropical flora and fauna. The destination is most popular for its backwater boathouse rides. Kumarakom is habitat for many marine and freshwater fish species. The place is fertile and most suitable for cultivation of rice and coconut trees.

Station 29: Kumarakom Centre (09° 35' 55.39" N and 76° 24' 43.11" E)

This station is situated in between the centre of Vembanad Lake and Kumarakom west. The station is situated near to Kollam - Kottappuram waterways.

Station 30: Vembanad Centre (09° 35' 48.91" N and 76° 23' 50.51" E)

The station is in the Centre of the Vembanad backwater where a large number of houseboats used to wander off. It is also near to the Muhamma - Kumarakom waterway. The station was selected to study the impact of the flood in the centre part of the Vembanad Lake.

Station 31: Marine Science Jetty (09° 57' 50.57" N and 76° 16' 49.67" E)

The station is situated in the northernmost region of wetland system. Oil and ballast water discharge is of primary concern in this area, as it is a major factor threatening the organism distribution structure in the region. Several oil tankers/ships are observed to be filling or refilling crude oil in the area. Huge pipelines are seen in the periphery of this zone used for transporting crude oil to the Cochin crude oil refinery for processing. Oil spillage into the water body occurs during the loading and unloading of crude oil from the ships and vessels in this area. The area is highly infested with different aquatic weeds such as *Eichhornia crassipes* and *Salvinia molesta*. A large number of tourist boats and research vessels are also docked in the jetty.

Station 32: Bolgatty (09° 58' 58.89" N and 76° 15' 42.94" E)

This area has undergone extensive reclamation and construction activities due to various developmental projects such as the Goshree project opened in 2004, the International Container Trans-shipment Terminal (ICTT) commissioned on 11th February 2011, construction of new residential complexes and other industrial activities. Cochin international Marina started in 2010 is the only marina in India of International standard. The marina provides berthing facility for yachts that offers services like fuel, water, electricity and sewage pump-outs for boats.

Station 33: Chittoor (10° 02' 17.24" N and 76° 16' 8.37" E)

Fishing is widely prevalent in and around this region. Chinese dip net fishing is one of the types of fishing seen here. In addition, integrated fish farming - farming of fishes along with ducks are also seen in this region. The aim is to harvest fish that find shelter in these structures for the purpose of feeding and breeding. The State Department of Fisheries has banned this method of fishing in the inland waters of Kerala.

Station 34: Cheranelloor (10° 04' 20.07" N and 76° 16' 49.01" E)

Cheranelloor is a suburb of Kochi city and lies on the Periyar River. Fishing activities are widely practiced in and around the study area. Large numbers of Chinese nets are also deployed in the area. The Cheranelloor ferry connects Eloor, Mannamthuruth and Cheranelloor.

Station 35: Methanam (10° 05' 33.41" N and 76° 17' 43.12" E)

The station is situated near to the Eloor - Methanam Bridge in the Periyar River. Fishing activities are seen around the place. The Ongithod River is joining the Periyar River in this area. The station is also near to the industrial belt in Kochi.

Station 36: Eloor (10° 04' 52.47" N and 76° 17' 57.45" E)

Eloor is the largest industrial belt in Kerala. On observation, the water in the region appears to be dark and turbid, and contains oil residue. Fish kills have been known to occur frequently in this zone. Twenty five percent of the industries of the state are located along the banks of River Periyar and the concentration of these industries is within a stretch of 5 km in the Eloor - Edayar area, which is only 10 km north of Cochin port. These industrial complexes depend on the river for intake of process water and disposal of effluents. The river also provides water for irrigation and domestic use all along its course, besides supporting a rich fishery. The Cochin Corporation, in the vicinity of river mouth has an intake point upstream of Aluva to meet its water supply; this point is generally free from salinity intrusion.

Station 37: FACT (10° 04' 34.78" N and 76° 18' 10.97" E)

The factories, FACT (Fertilizers and Chemicals Travancore Ltd.), IRE (Indian Rare Earths), Merchem and HIL (Hindustan Insecticides Ltd.) are located near to the study station. The effluents possibly from these industries are discharged into the estuary. The effluent treatment systems in these industries are not always effectively operated. FACT that manufactures phosphatic and ammonium sulphate fertilizers is one of the major industries in this region.

Station 38: Kadamakudy (10° 03' 10.70" N and 76° 15' 05.12" E)

Kadamakudy is an Island suburb of the Kochi city and is a less populated area. This station is located on the northern branch of Cochin estuary. It’s a cluster of scenic islands and this countryside is a live gallery of agricultural activities, fishing and toddy tapping. These islands are also famous for prawn farming.

Station 39: Cochin Barmouth (09° 58' 9.05" N and 76° 14' 1.62" E)

Barmouth is the permanent wide opening of the estuary to Lakshadweep Sea. Strong variations in tidal flux are observed in this area. It is a hub for shipping activities, fishing operations as well as commercial boating. Dredging is frequently done in this area, as part of maintenance of channels required for the passage of international and national shipping vessels. Dredging destroys the much of the habitat heterogeneity supported by the natural water body. Stake nets and Chinese dip nets are widely operated in the area during the high tide phase of the estuary. Cochin Port Trust, International Container Trans-shipment Terminal (ICTT), several boat jetties and the fishing harbour at Kalamukku, are located close to the study area. The intense boating activities cause noise pollution and acts as potential source for waste disposal. The station is located approximately 2.7 km from the mouth of the estuary.

S1. Aroor

S2. Perumbalam

S3. Varanad

S4. Thannermukkom North

S5. Thannermukkom South

S6. Pathiramanal

S7. Aryad

S8. Sports Authority

S9. Munnatiinmugham

S10. Nehru Trophy Finishing Point

S11. Pangankuzhipadam

S12. Punnamada

S13. Pallathuruthy

S14. Meenapalli

S15. Meenapalli Vattakayal

S16. Meenapalli Neendakayal

S17. Kainakary

S18. Kuttamangalam

S19. Kuppappuram

S20. C Block

S21. C Block 2

S22. R Block

S23. Kizhake Vattakkayal

S24. H Block

S25. Ranikayal

S26. Marthandam

S27. Chithirakayal

S28. Kumarakom

S29. Kumarakom Centre

S30. Vembanad Centre

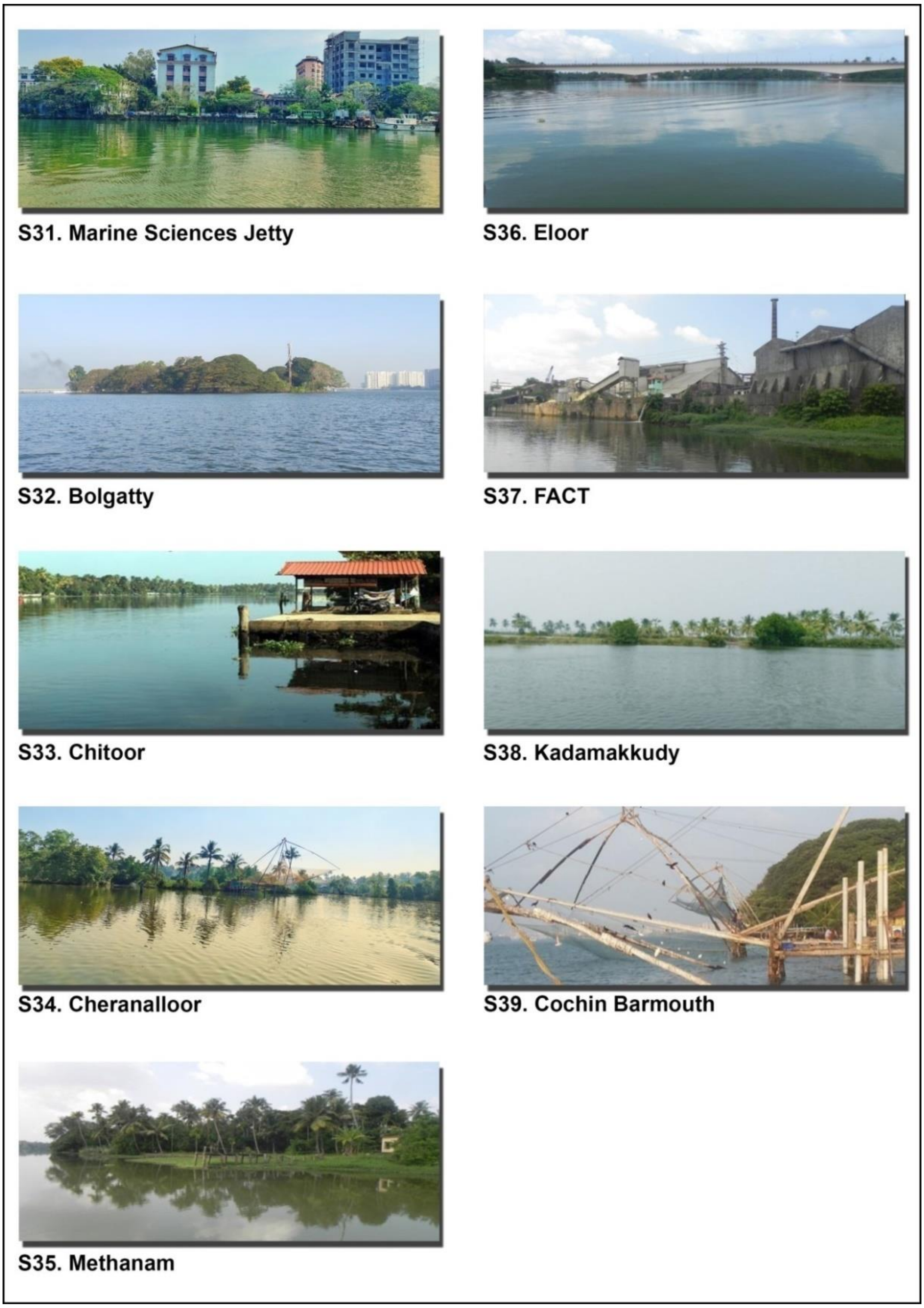

Plate 2.1 Study stations selected for flood and post flood study during August 2018 and November 2018

2.3 Field sampling

Field sampling was carried out on board a hired research vessel A.V.C No. MB171-CP. The study locations were selected based on the impact of flood on the Vembanad wetland system extending from the Cochin to Alappuzha district. Some areas of the districts Kottayam and Pathanamthitta were also covered during the sampling. Also, the rivers, canals, dams, and backwaters that ultimately join the floodplain zones of the wetland were considered for the site selection for the study. The field collections and analysis of various physico-chemical and biological parameters for the flood period was conducted during August, 2018, and the post flood sampling was done during November, 2018.

2.4 Methodology

2.4.1 Rainfall and river discharge data

Rainfall data, river flow data and river discharge data were obtained from Central Water Commission (CWC), Govt. of India web site (http://www.india-wris.nrsc.gov.in/). Dam discharge data was collected from Dam Safety Organisation, Kerala State Electricity Board Limited. The monthly discharge data of river flow from rivers such as Muvatupuzha, Meenachil, Achankovil, Manimala and Pamba into the backwater were collected from the gauging stations situated at Ramamangalam, Kidangoor, Thumpamon, Kalloopara and Malakkara respectively.

2.4.2 Water quality - physico-chemical characteristics

Water quality parameters are important for the survival of aquatic flora and fauna. Some important physical and chemical factors which are influencing the aquatic environment such as depth, temperature, transparency, pH, salinity, dissolved oxygen and major inorganic nutrients like phosphate-phosphorus, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen and silicate-silicon were analysed.

The surface and bottom water samples were collected using a standard Niskin sampler (General Oceanics, 5 L capacity). Preservation and transportation of the water samples to the laboratory for analysis are based on standard methods (Grasshoff *et al.*, 1999). The water temperature, water depth and transparency were measured at each site. Water temperature was measured on-board using a standard 0-50 °C precision alcohol based thermometer with an accuracy of ±0.01 °C. Depth was measured in the field by lowering a graduated weighted rope until it touches the bottom of the estuary. Water transparency was measured with the Secchi disc (20 cm in diameter) and expressed in metres (Strickland and Parsons, 1972). pH measurements were made using a digital pH meter (MODEL alpha 01). Salinity was measured from the field using a calibrated analogue handheld refractometer (Model-EW-81150-20, accuracy ±1.00 ppt, and range 0-100 ppt) and counter checked by Mohr-Knudsen titrimetric method (Grasshoff *et al*., 1999) and expressed in parts per thousand (ppt). The water samples for dissolved oxygen (DO) and biological oxygen demand were collected in DO glass bottles. The samples for dissolved oxygen were fixed on-board the boat and estimated using the modified Winkler's method (APHA, 2005; Strickland and Parsons, 1972). This method depends on the oxidation of manganese dioxide by the oxygen dissolved in the samples, resulting in the formation of a tetravalent compound, which on acidification liberates iodine equivalent to the dissolved oxygen present in the sample. The quantity of iodine liberated was determined by titration with sodium thiosulphate. The results were expressed in milligram/litter (mg L^{-1}). Biological oxygen demand (BOD) was measured by APHA (2005) and was expressed in milligrams per litre (mg L^{-1}). The remaining water samples for the analysis of other parameters were collected in thoroughly washed 1 litre polythene bottles and stored in containers with ice. The preserved samples were brought to the laboratory at the earliest and the analysis was completed soon.

The inorganic nutrients were analysed immediately after filtering through Whatman No-1 filter paper, following standard procedures (Strickland and Parsons, 1972; Grasshoff *et al*., 1983) and using a spectrophotometer (Systronics UV-VIS spectrophotometer, Model No.117), after proper calibration. The values are expressed in the unit of micromole per litre (µmol L^{-1}). Dissolved inorganic phosphate-phosphorus (PO_4-P) was measured by ascorbic acid method (Strickland and Parsons, 1972; Grasshoff *et al*., 1983). In an acid solution containing molybdic acid, ascorbic acid and trivalent antimony, inorganic phosphate forms a reduced phosphomolybdenum complex and the absorbance was measured at 880 nm; that of silicate-silicon (SiO_4-Si) in the water was estimated by molybdosilicate method (Grasshoff *et al*., 1983). When an acid sample is treated with a molybdate solution, a yellow coloured silicomolybdic acid is formed. This is further reduced by ascorbic acid in presence of oxalic acid (to prevent interference from phosphate) to form a blue coloured complex (molybdenum blue). The absorbance was measured at 810 nm. Ammonia-nitrogen (NH_4-N) was measured by the phenate method (Grasshoff *et al*., 1983). In a moderately alkaline medium, ammonia reacts with hypochlorite to form monochloramine, which forms indophenol blue in the presence of phenol, a catalytic amount of nitroprusside ions and excess hypochlorite. The blue colour was measured at 640 nm. Nitrite-nitrogen (NO_2-N) was measured using the diazotised method (Strickland and Parsons, 1968; Grasshoff *et al*., 1983). In this method, the nitrite in the water samples was allowed to react with sulphanilamide and later with N-(1-Naphthyl) ethylene diamine dihydrochloride. The absorbance was measured at 543 nm. Nitrate-nitrogen (NO_3-N) was measured by cadmium reduction method (Grasshoff *et al*., 1983). Nitrate-nitrogen in the water sample was quantitatively reduced to nitrite by passing through a reduction column filled with copper coated cadmium granules and measured as nitrite using diazotized method and the absorbance was measured at 543 nm.

2.4.2.1 Primary productivity

The primary productivity (gross and net production) was estimated by *in situ* incubation method employing the Light and Dark bottle method (Strickland and Parsons, 1972). This method is based on the principle that photosynthesis is complemented by the release of oxygen and the liberated oxygen is considered as a measure of primary production. The rate at which oxygen is released was converted into carbon units, assuming a photosynthetic quotient of 1.2. In this method, both surface and bottom water samples were collected before sunrise and immediately passed through a 200 µm sieve to remove large sized zooplankton and transferred to 125 ml capacity DO bottles. Each set of experiments contain three sets of bottles (two initial, two light and two dark bottles for both surface and bottom water). The light and dark bottles were incubated for 3-4 hours (APHA, 2005). The initial bottle containing water samples were immediately fixed with fixatives normally used in Winkler's method. After the incubation period, the light and dark bottles were taken out and fixed with similar fixative used in initial bottle. All the bottles were brought to the laboratory in cold condition for analysis. The oxygen content in each bottle was determined by modified Winkler's method and calculated on an hourly rate of primary production multiplied by the number of day light hours (~12 hours) and it was expressed in the unit gram Carbon/metre cube/day ($gCm^{-3}day^{-1}$). The difference in oxygen concentration between the light bottle and the dark bottle as well as the light bottle and the initial bottle provides gross and net productivity respectively (APHA, 2005; Strickland and Parsons, 1972).

2.4.2.2 Analysis of heavy metals in water samples

The heavy metals copper (Cu), cadmium (Cd), nickel (Ni), lead (Pb), zinc (Zn) and iron (Fe) were analysed from the study. Copper (Cu), zinc (Zn), nickel (Ni) and iron (Fe) are required in trace amounts but their higher dose causes toxic effects. Metals that are not suitable for biological function such as lead (Pb) and cadmium (Cd) are analysed to study its impact.

For heavy metal analysis, the samples were filtered using 0.45 µm Millipore filter paper and stored in pre-cleaned, acid washed polyethylene bottle. The sample was acidified with supra-pure nitric acid to a pH between 2-3. Samples were stored at low temperatures (-10 to -40 ºC) to avoid evaporation. 400 ml of the sample was taken in a separating funnel and ammonium acetate buffer was added to adjust the pH of the sample to 4.5. 10 ml of 2 % Ammonium pyrrolidine dithiocarbamate (APDC) solution was added to the sample followed by 15 ml of Methyl Isobutyl Ketone (MIBK). The funnel was shaken well using reciprocating shaker (Model: RS M1) and the 2 phases were allowed to separate, the lower aqueous layer was drained to another separating funnel. The extraction process was repeated by adding 5 ml of APDC and 10 ml of MIBK 2 or 3 times. The MIBK layer was shaken well after adding 0.1 ml of conc. HNO_3 and 9.9 ml of distilled water. The layers were separated and the aqueous layer collected in 25 ml standard flask and made up to mark with Milli-Q (Brooks *et al.*, 1967).

During the study period, water samples were pre-concentrated by APDC-MIBK method in laboratory facility at CUSAT and the metal analysis was done at KSPCB (Central lab, Kerala State Pollution Control Board, Kochi) using Atomic Absorption Spectrophotometer Model Perkin Elmer A Analyst 700.

2.4.3 Sediment quality

The sediment samples were collected using a standard van Veen grab of size 0.04 m^2. Sediment temperature was determined using standard degree centigrade thermometer in the field. A separate core sample of sediment was taken for further analysis of sediment parameters.

2.4.3.1 Total nitrogen

Total nitrogen was analysed using automated Kjeldhal digestion method and Nitrogen distillation unit (Anderson, 1993). 0.2 g of sediment is weighed and transferred to a digestion tube. Add 10 ml of concentrated H_2SO_4 and 1 g of digestion mixture (Selenium- 3 g, $CuSO_4$- 20 g, K_2SO_4- 200 g) into it. Pre-warm the Kjeldhal digestion unit up to 200 °C. Then place the digestion tubes and digest for 2 hrs in 420 °C. After digestion keep the tubes for cooling for 30 min. Transfer the digested material into a conical flask and make up to known volume (25 ml). 10 ml of sample is transferred to digestion tube. Take 20 ml of boric acid in a conical flask and add 4 drops of mixed indicator to it. Add 20 ml of NaOH to the sample in the digestion tube. Run the instrument for 9 min. Then the solution is titrated against the 0.01 N H_2SO_4 in the burette.

$$TN = \frac{\text{Titrated value x Normality of H2SO4 x 14 x 25}}{\text{Value taken for distillation x Weight of soil}}$$

2.4.3.2 Analysis of heavy metals in sediment samples

Heavy metals such as copper (Cu), nickel (Ni), cadmium (Cd), lead (Pb) and zinc (Zn) were analysed in sediment samples. The sediment samples were oven dried to a constant weight at 80 ˚C and then crushed using a mortar and pestle until the sediment was homogenous and thensieved through 2 mm sieve. Approximately 0.5 g of homogenized dry sediment samples were accurately weighed and transferred to boiling tubes which were then placed into a Kjeldhal digestion block [KEL PLUS digester (Model: KES 04 L)] and samples were digested by diacid 1:5 ($HClO_4$:HNO_3) treatment at 180 ºC for 4.5 hr and the supernatant solution was filtered in Whatmann filter paper grade No-1 and made up to 50 ml using Milli-Q for measurement (Grasshoff *et al*., 1983).

During the study period, acid digested sediment samples were filtered at CUSAT lab and analysis was done at CWRDM (Centre for Water Resources Development and Management, Calicut) using M series Atomic Absorption Spectrophotometer (AAS).

2.4.3.2.1 Pollution indices

a. Sediment Quality Guidelines (SQG)

Ecological risk and toxicity of the metals were analysed by comparing metal concentration with reference values that were developed by the U.S National Oceanic and Atmospheric Administration (NOAA). The reference table uses three standards, non-polluted, moderately polluted and heavily polluted that considers all adverse biological effects associated with elevated metal concentrations (MacDonald *et al*., 1996; Long *et al*., 1995). The concentrations that comes in non-polluted range represent a minimal effects range, concentration that comes in moderately polluted range represent a possible effect range within which adverse biological effects would occasionally occur and concentrations that comes in heavily polluted range represent adverse biological effects would frequently occur (Buchman, 2008).

Table 2.2 Concentration of heavy metals and its pollution status based on the sediment quality guidelines (SQG)

Element (mg/Kg)	SQG		
	Non-polluted	Moderately polluted	Heavily polluted
Cu	<25	25-50	>50
Zn	<90	90-200	>200
Cd	<1	1-6	>6
Pb	<40	40-60	>60
Ni	<20	20-50	>50

The degree of heavy metal pollution in sediments was assessed by means of sediment quality indicators like geoaccumulation index (Igeo) and contamination factor (CF) based on the average crustal abundances from Turekian and Wedepohl (1961). The results of sediment quality evaluation data for heavy metals generated using Igeo and

CF demonstrates their usefulness in the monitoring and assessment of sediment metal contamination. Furthermore, this data is essential for an environmental forensic investigation, because it allows the sources and impacts of contaminants to be traced to various human activities. This provides a more accurate appraisal of environmental pollution from anthropogenic inputs. The advantage of determining reference concentration of metals in sediments for different aquatic environments is to assess whether the detected metal concentrations are elevated above the background levels. On the other hand, these reference concentrations are heeded to provide the regulators and managers with a scientific database to establish the available criteria to control the overlying water quality.

b. Geoaccumulation index (Igeo)

The geoaccumulation index (Igeo) described by (Salomons and Forstner, 1984) are considered as a measure of the contamination by metals. This index is acquired by means of computing the base two logarithm of the quotient of the total concentration of the element obtained in each sample (Cn) over the average of the total concentration measured in the uncontaminated zone (Bn) multiplied by 1.5 (a correction factor for background values), this is:

$$I_{geo} = \log_2 (C_n) / 1.5 B_n$$

Where: C_n - concentration of metal in sediment, B_n - geochemical background value in average shale (Turekian and Wedpohl, 1961).

Muller (1969) has determined seven classes of Igeo: uncontaminated (<0; class 0), uncontaminated to moderately contaminated (0-1; class 1), moderately contaminated (1-2; class 2); moderately to strongly contaminated (2-3; class 3), strongly contaminated (3-4; class 4), strongly to extremely strongly contaminated (4-5; class 5), extremely contaminated (>5; class 6).

c. Contamination Factor (CF)

To assess the extent of metal contamination, contamination factor was calculated for sediments using measured concentration of metals and respective world shale average reported by Turkian and Wedephol, 1961.

$$CF = \frac{\text{Metal content in sediment}}{\text{Back ground value of metal}}$$

According to Hakanson, 1980; CF values are interpreted as CF < 1 indicates low contamination factor, 1 < CF <3 refers to moderate contamination factor; 3 < CF <6 means considerable contamination factor and CF > 6 indicates very high contamination factor.

2.4.4 Biodiversity analysis

2.4.4.1 Phytoplankton

Samples for microphytoplankton were collected by filtering ~100 litres of sub-surface water through 20 µm mesh size plankton net made of bolting silk (Tait, 1998; Santhanam, 1980). Replicate samples were collected simultaneously and samples were preserved using 3 % formalin and Lugol's iodine. The samples were concentrated to 15 ml for further studies (Tait, 1998). Standing crop was estimated by enumeration in Sedgewick-Rafter counting cell. 1 ml of sample was transferred into a Sedgewick-Rafter counting cell and left for about half an hour for proper sedimentation. The counting was started from one corner of the counting cell to the other end and the total number of plankton was expressed in $ind.m^{-3}$ (APHA, 2005; Santhanam, 1987). For getting an error free result, replicate count were done and take the average values to study composition, distribution, abundance and community structure of phytoplankton. The enumeration and identification of plankton was done using a binocular microscope - Leica DM 500 and standard identification keys (Tomas *et al*., 1997; Gopinathan, 1974; Davis, 1955; Cupp, 1943; Venkataraman, 1939).

2.4.4.2 Mesozooplankton

Samples for mesozooplankton was collected by towing plankton net made of bolting silk with half metre diameter and the speed of the boat maintain in uniform speed, 1 km for ten minutes. Standard nets with a mesh size of 200 µm were used for the collection of mesozooplakton (Pansera *et al*., 2014; Vidjak *et al*., 2009). The volume of water filtered was measured by a calibrated flow meter (General Oceanics Model number - 2030 R, 2012) mounted at the mouth of the net. The samples were transferred into a 100 ml polythene bottles and preserved in 4 % buffered formalin. Magnesium chloride (7-10 %) used as narcotizing agent (Omori and Ikeda, 1984; Steedman, 1976). Sorting was carried out in laboratory using stereo microscope Magnüs-No. 7OT. The total number of mesozooplankton present in the sample was calculated using the formula proposed by Harris *et al.* (2000) and abundance was expressed as individuals per cubic meter ($ind.m^{-3}$). The identification of zooplankton was done using a binocular microscope - Leica DM 500 with standard identification keys (Al-Yamani, 2011; Goswami, 2004; Raymont, 1963).

$$\mathbf{V = a \times N_R \times A}$$

Where; V = volume of water filtered (m^3)

a = Flow meter calibration factor

N_R = no of revolutions

A = area of the mouth of the net (m^2)

$$D = \frac{\underline{n \times Vs \times S}}{Na \times V}$$

Where; D = Number of organisms per cubic meter

n = number of organisms counted

N_a = Volume of aliquot examined

V_s = volume of subsamples concentrate

S = split factor

V = volume of water filtered

2.4.4.3 Macrobenthos

Grabs are generally used for quantitative sampling of macrofauna. For macrofauna, samples were taken at each site by using standard van Veen grab of size 0.04 m^2 and the sediment samples were sieved onboard through a 0.5 mm mesh sieve. The sieved macrobenthos with residual sediment samples were then preserved in 4 - 7 % neutral buffered formaldehyde containing Rose Bengal, which facilitate sorting of the organisms from other components of the soil in the laboratory (APHA, 2005; Eleftheriou and Mclntyre, 2005; Holme and Mclntyre, 1984). The sieved samples were then labelled and stored for further examination. For qualitative enumeration, each sample was examined under a binocular microscope. The organisms were separated into different taxonomic groups and then enumerated and expressed as ind.m^{-2}.

2.4.4.4 Data Analysis Tools

The software programmes viz., SPSS (Statistical Programme for Social Sciences Version 20) was employed for statistical analysis of three way ANOVA (Analysis of Variance), standard deviation and correlation analysis among parameters. ORIGIN 8 software was also used for the graphical representation of data. PRIMER Vs.6.1.9 (Plymouth Routines in Multivariate Ecological Research, Version 6.1.9) was used for univariate and multivariate statistical analysis and plotting of data (Clarke and Gorley, 2006). Principal Component Analysis (PCA) was performed using PAST V. 2.17c software.

I. Univariate analysis

Diversity indices:

i) Species diversity - Shannon-Wiener index - (H')

It explains both abundance and evenness of species present in the community. In the present study, the data were analysed for diversity index (H') using the following Shannon-Wiener's formula (1949):

H' = -ΣS Pi log 2 Pi.....

i = 1

Where,

H' = Species diversity

S = Number of species

pi = Proportion of individuals of each species belonging to the species of the total number of individuals (number of individuals of the i^{th} species).

ii) Species dominance - Simpson's index (D) (Simpson, 1949)

The Simpson's index is a measure of both the richness and proportion (percentage) of each species. It is calculated by the formula:

$D = 1/\lambda$

Where,

$\lambda = \sum Pi^2$

Pi = ni/N

ni = Number of individuals of i, i^2 etc.

N = Total number of individuals

iii) Species richness - Margalef index (d)

It is a measure of the number of species present for a given number of individuals (Margalef, 1958). It is given by:

d = (S-1) / log N

Where,

d = Species richness

S = Total number of species

N= Total number of individuals

iv) Species evenness - Pielou's index (Pielou, 1966)

The index measures equitability and allows comparison of Shannon Weaver index with the distribution of individuals in the observed species that would have the maximum diversity. It is calculated as:

j' = H'/log2 S or H'/ln S

Where

J' = Evenness,

H' = Species diversity

S = Total number of species

II. Multivariate analysis

i) Bray-Curtis similarity index

Multivariate analysis consisted of estimating Bray-Curtis similarity after suitable transformation of sample abundance data. The similarity matrix was subjected to both clustering (hierarchical agglomerative method using group average linking) and ordination (Non-metric Multidimensional Scaling, NMDS). Cluster analysis was done to find out the similarities between groups. Hierarchical clustering methods are commonly used. The Bray-Curtis similarity measure was used to produce the similarity matrix and the similarity percentage was used to determine the degree of similarity. The dendrogram with the X-axis representing the full set of samples and the Y-axis defining the similarity level at which the samples or groups are fused.

ii) Non-metric Multidimensional Scaling (NMDS)

It is used to graphically display the two-dimensional ordination plots representing the similarity ranking of groups/species composition between different stations. A stress value of <0.2 gives a useful representation of results (Clarke and Warwick, 2001). In NMDS "stress coefficient" showed the extent to which the relationship between the samples was adequately represented in the resulting 2-D ordination. The red lines represent 80 % similarity contour, blue line 40 % and green 20 %.

iii) Principal Component Analysis (PCA)

It is a powerful tool that tries to elucidate the variance of a large dataset of intercorrelated variables with a smaller set of independent variables (Simeonov *et al*., 2003). This analysis was performed using PAST V. 2.17c software (Paleontological Statistic software package) (Hammer *et al*., 2001). PCA was conducted on environmental data to detect trends of variation of ecological characteristics across the study area. The assessment of the index was done using a Pearson correlation between the scores in PCA axis and the environmental variables. The most significant variables in the components represented by high loadings are taken into consideration for evaluating the components. This analysis uses an ordination plot to project the points of higher similarities closer together while samples more dissimilar are further apart. In this study, significant environmental variables measured have been included for the PCA.

iv) Regression analysis

Multiple regression analysis was carried out to determine the effect of rainfall and dam discharge (fixed factors) on the environmental variables (independent variables) of the Vembanad estuary during the study period using SPSS v16 software.

3. RAINFALL, RIVER DISCHARGE AND INFLUENCE OF MAJOR RESERVOIRS DURING FLOOD, 2018

3.1 Introduction

Kerala is known for its abundant natural resources, especially water. There are 44 rivers, 27 backwaters (mostly in the form of lakes and ocean inlets), 7 lagoons, around 18,681 ponds and over 30 lakh wells in the state (KID, 2020). Out of 44 rivers originating from Western Ghats, 41 are west-flowing rivers and the remaining 3 rivers are east-flowing. The Kerala backwaters are a network of brackish lagoons and lakes lying parallel to the Arabian Sea. The Vembanad-Kol wetland is the largest brackish humid tropical wetland ecosystem in the state of Kerala. It is a complex system of backwaters, marshes lagoons, mangrove forests, reclaimed land and an intricate network of natural and manmade canals. Vembanad wetland obtains freshwater discharge from ten short, west-flowing rivers namely; Pamba, Manimala, Meenachil, Achankovil, Periyar, Muvattupuzha, Chalakudy, Keecheri, Karuvannur and Puzhakkal.

Being the largest backwater lake in Kerala, Vembanad backwater is influenced by the discharges from most of the dams and reservoirs in the state. Reservoirs play an important role in the local community's fishing and livelihood security and also play a major role in the country's development process. From generation of electricity to irrigation, reservoirs have many uses. The effect of reservoirs on the quality of the original river water has been a subject of long discussion. The three factors which affect the quality of water are natural and water-management conditions of the runoff occurrence in the catchment area; quantities and qualities of waste waters discharged into the reservoir; and processes occurring in the reservoirs themselves. Quintessential operation of dams plays a vital role in flood control. A storage reservoir which is at least slightly emptied before the onset of monsoon can have a big control over the flood wave. Normally, reservoir operation uses upper and lower rule curves to consider the release of water from the reservoir. The main purpose of these rule curves is to avoid the risk of floods and water shortages. To reduce the water levels to the upper rule curve, it is necessary to release water from the reservoirs. During the rainy season, it can sustain the precipitation and inflow that flows into the reservoir. The rule curve ensures that the storage capacity is partly emptied in a certain period of the year. This practice makes it possible to lower the risk of flood and it should be given prior importance.

Since the Indian Ocean is under the influence of annually occurring monsoons (the seasonally reversing wind systems that are propelled by a pair of low (high) and high (low) pressure zones over the land and the sea, respectively during winter or summer), the seasons are mainly classified as the following. The south west monsoon (summer monsoon;

June to September), north east monsoon (winter monsoon; December to March) and spring inter-monsoon period (transition period from winter to summer; March to May) and fall inter-monsoon period (transition period from summer; March to May) and fall inter-monsoon period (transition period from summer to winter; September to October) (Madhupratap *et al*., 2001).

Kerala enjoys two monsoon seasons - the southwest monsoon, the main rainy season (provides almost 85 % of the rains) of Kerala and the north east monsoon, the retreating or reverse monsoon. The south west monsoon or *Edavappathy* (means in the middle of the Malayalam month Edavam) that arrives towards the end of May or early June, which is characterised by torrential rains. As Kerala lies on the windward side of the Western Ghats and is the first state to get hit by the monsoon winds, the state receives heavy rainfall. The average temperature ranged from 20 °C to 30 °C during the season. This monsoon season goes away by mid-August, leaving a pleasant weather with occasional rainfall. Monsoon returns again in October with heavy downpours, accompanied by thunder and lightning. It is the retreating monsoon season, and it is known as the north east monsoon or *Thulavarsham* (rains during the Malayalam month Thulam). The main feature of this season is heavy rains during afternoon together with lightning and thunder. And even with heavy rainfall, the days remain hot and humid.

The major scenario that led to Kerala flood, 2018 are the high seasonal rainfall, high reservoir storage, unprecedented extreme rainfall in the catchments upstream of major reservoirs and reservoir release. These are also plays a significant role in worsening the Kerala flood, 2018 as well. There are numerous instances of flood-induced changes in the channel dimension, position and pattern in some areas. The annual floods appear to be geo-morphologically more effective than the occasional large floods in the Ganga-Brahmaputra plains. Whereas, the rivers of the Indian peninsula are, by and large, stable and the geomorphic effects of floods are modest. Only large-magnitude floods that occur at an interval of several years to decades are competent to modify the channel morphology in a significant way. Large floods are important geomorphic agents in the tropical monsoonal environment that temporarily affect the forms and behavioural features of some rivers, but leave a lasting impact on others.

3.2 Major rivers draining into Vembanad wetland system

Vembanad wetland receives freshwater discharge from six major west flowing rivers. They are short, steep, fast flowing and monsoon fed which originate from Western Ghats - the 'Biodiversity Hotspot' drain to the Vembanad wetland and eventually join the Arabian Sea. Rivers such as Pamba (176 km), Manimala (90 km), Meenachil (78 km) and Achankovil (128 km) drain directly into the southern part of Vembanad wetland and finally into the Arabian Sea while a southern branch of Periyar (244 km) and Muvattupuzha (121 km) drains into Cochin estuary and finally into the Arabian Sea through Kochi outlet (Anon, 2008; www.nio.org). Pamba, Manimala, Meenachil and Achankovil flows into the wetland on the south of Thanneermukkom barrage while, Periyar and Muvattupuzha Rivers flows into the Cochin estuarine region on the north of Thanneermukkom barrage (Fig. 3.1). Besides these rivers, four other rivers flow in to the wetland at different points including Chalakudy (130 km), Karuvannur (40 km), Keecheri (51 km) and Puzhakkal (29 km). Kuttanad is the marshy delta in the southern part of the Vembanad wetland, formed by four river networks namely, Pamba, Manimala, Achankovil and Meenachil around the Vembanad backwater. Discharge of these rivers varies seasonally and maximum input observed during monsoon season. Major parts of the wetland lie below sea level to a depth of about 2.5 m, waterlogged for much of the year, prone to flood and inundation during the monsoon and salt water intrusion during the summer months.

3.2.1 Pamba

Pamba River is the third largest river in Kerala and is popularly called as 'Dakshina Ganga'. It has a length of about 176 km and a catchment area of about 2235 km^2 (Fig. 3.2). The river originates from Pulachimala in the Western Ghats at an altitude of about 1650 m above MSL and flows through highly varied geologic and geomorphic provinces of the state like Ranni, Ayroor, Pathanamthitta, Kuttanad, etc. and then finally ends up in the Vembanad backwater. The river drains through Pathanamthitta (major portion) and Alappuzha (minor portion) district and enters into the Vembanad wetland near Kainakary. The river displays dendritic to sub-dendritic drainage pattern. Pamba basin is surrounded by Western Ghats on the east, Manimala River basin in the north and Achankovil River in the south.

3.2.2 Manimala

Manimala River is one of the perennial rivers of Kerala with a length of about 90 km and a catchment area of about 847 km^2 (Fig. 3.2). It originates from the Thattamalai Hills at an elevation of 1156 m above MSL and drains through the highland, midland and the lowland physiographic provinces of Kerala. The river spreads over Idukki, Kottayam and Pathanamthitta districts and empties into the Vembanad wetland, after merging with the Pamba at Valanjavattom near Thiruvalla. Manimala River displays a dendritic drainage pattern. The extensively developed sandy plains and point bars, used for holding annual religious congregations are vanishing at rapid rate due to indiscriminate sand mining.

3.2.3 Achankovil

Achankovil River originates from the hills of Achankovil in Pathanamthitta district and flows through Mavelikkara, Thiruvalla and Karthikapally taluk and it join with river Pamba at Veeyapuram, in Alappuzha district near the Vembanad wetland (http://kerala-rivers.blogspot.in/). The total length of the river is 128 km and a catchment area of about 1484 km^2 (Fig. 3.2). Its average annual stream flow is 2600 mm^3. Achankovil River shares its northern boundary with Manimala river basin.

3.2.4 Meenachil

Meenachil River flows through the heart of Kottayam district of Kerala and have a length of 78 km and a catchment area of about 1272 km^2 (Fig. 3.2) and flows through Poonjar, Teekoy, Erattupetta, Pala, Ettumanoor and Kottayam before emptying itself into the Vembanad wetland at Kumarakom, the famous tourist place of Kerala. The Meenachil River is formed by several streams originating from the Western Ghats. The general elevation ranges from 77 m to 1156 m in the high lands and less than 2 m in the lowlands and 8 to 68 m in the midlands. The river has a total annual yield of 2,349 mm^3 and an annual utilizable yield of 1,110 mm^3. The river has 38 tributaries including major and minor ones. The river has 47 sub watersheds and 114 micro watersheds.

3.2.5 Muvattupuzha

Muvattupuzha River has a length of 121 km, catchment area of about 1554 km^2 (Fig. 3.2) and an average annual stream flow of 3560 mm^3. The word “Muvattupuzha” is composed of three words 'Moonu' meaning three, 'Aaru' meaning small river and 'Puzha' which also means river. As the word indicates, Muvattupuzha River is also composed of three rivers namely Kothamangalam River, Kaliyar River and the Thodupuzha River, all of which together forms the Muvattupuzha River draining into Vembanad wetland near Vaikkom region. The industrial activities mainly by the Hindustan Newsprint Limited situated near the banks of Muvattupuzha River and the effluent from the industry affect the water quality of the river.

3.2.6 Periyar

Periyar River is the longest river in Kerala state having a length of about 244 km and a catchment area of about 5398 km^2 (Fig. 3.3). It originates from Sivagiri Hills of Western Ghats. The average annual stream flow of Periyar was 4867 mm^3. The river flows along almost virgin forests in places such as Kokaripara, Neriamangalam, Edamalayar and Malayattoor. At Aluva, the river bifurcates into two, Marthandavarma and Mangalapuzha branches. The Mangalapuzha branch joins Chalakudy River and empties into the Arabian Sea at Munambam while the Marthandavarma branch flows southwards, through the Udyogmandal area and joins the Cochin backwater system at Varapuzha [Periyar Valley Irrigation Project (PVIP), 1972]. Periyar River plays a major role in the economy of Kerala. Major portion of Kerala's electrical power get through the hydroelectric projects in Periyar River. Kochi city depend up on Periyar River for the drinking water source. Around 25 % of Kerala's industries are situated along the banks of Periyar River.

3.2.7 Chalakudy

Chalakudy River or Chalakudy Puzha is the fourth longest river in Kerala. The river flows through Palakkad, Thrissur and Ernakulam districts. It is formed by the confluence of the Parambikulam, Kuriarkutty, Sholayar, Karappara and Anakkayam streams. Of these, the Parambikulam and Sholayar originate from the Coimbatore district in Tamil Nadu and remaining streams from hills of Palakkad district. The Parambikulam wildlife sanctuary is drained by the streams of Chalakudy River. The river originate at an altitude of >1250 m above msl. The river has a length of 130 km and it drains an area of 1404 km^2 in Kerala and 300 km^2 in Tamil Nadu. It joins the Periyar River at Elenthikara (near Puthanvelikkara, adjacent to Manjali, North Paravur in Ernakulam district). Though Chalakudy River in strict geological sense is a tributary of the Periyar River, for all practical purposes it is treated as a separate river by Government and other agencies. According to the annual report of National Bureau of Fish Genetic Resources Lucknow, the Chalakudy River is the richest river in fish diversity perhaps in India. In addition to evergreen and semi-evergreen species, the riparian forests of the region have been shown to be distinguished by the occurrence of typical riparian species of plants. Of the 319 species of flowering plants identified from the region, 24 are endemic species of the Western Ghats and 10 are rare and endangered. Furthermore, the Chalakudy River is recognised for its rich diversity, as it contains 85 species of fresh water fishes out of the 152 species known from Kerala. Of these, 35 are endemic species of the Western Ghats and nine are considered to be endangered. The famous waterfalls, Athirappilly Falls and Vazhachal Falls are located on this river. The Thumboormoozhy Dam is constructed across this river for irrigation purposes. Besides, the Parambikulam Dam has been built on the Parambikulam River, one of its five tributaries.

3.2.8 Karuvannur

The Karuvannur River or Karuvannur Puzha has its origins at Pumalai Hills in Chimmony Wildlife sanctuary of Thrissur district. The Karuvannur River is formed by the confluence of two rivers, Manali River and Kurumali River. The Manali tributary of Karuvannur originates from Vaniampara Hills (>365 m) and the other tributaries such as Chimmony and Mupli from Pumalai at an elevation of >1100 m above msl. The Peechi part of Peechi-Vazhani wildlife sanctuary is drained by Manali tributary and Chimmony wildlife sanctuary is drained by Chimmony tributary. The river flows west and splits in two, one falling in Enamakkal Lake in Thrissur district and the other one into Periyar River. The total length of the river is 40 km, drains an area of 1054 km^2 and gives drinking water to many Panchayats in Thrissur district.

3.2.9 Keecheri

The Keecheri River or Keecheri Puzha is one of the small rivers in the state and is practically dry during summer. It is a west-flowing river which has its origins at Machad Hills in Thrissur district at an elevation of >365 m above msl. The river is 51 km in length and empties to Arabian Sea at Chettuva Lake. It is linked with backwaters at Enamaakkal. Choondal Thodu is the only important tributary of this river. It has a drainage area 401 km and the river basin is located in the Thrissur district. The Vazhani part of Peechi-Vazhani wildlife sanctuary is drained by the Keecheri River.

3.2.10 Puzhakkal

Puzhakkal is a westward flowing river in Thrissur district of Kerala. It originates from Killannoor Hills at an elevation of >150 m above msl and empties into Thrissur-Kol wetlands. The total length of the river is 29 km and a total drainage area of 234 km^2. Parathodu, Nadathodu, Poomalathodu and Kattachirathodu are the maintributaries of this river.

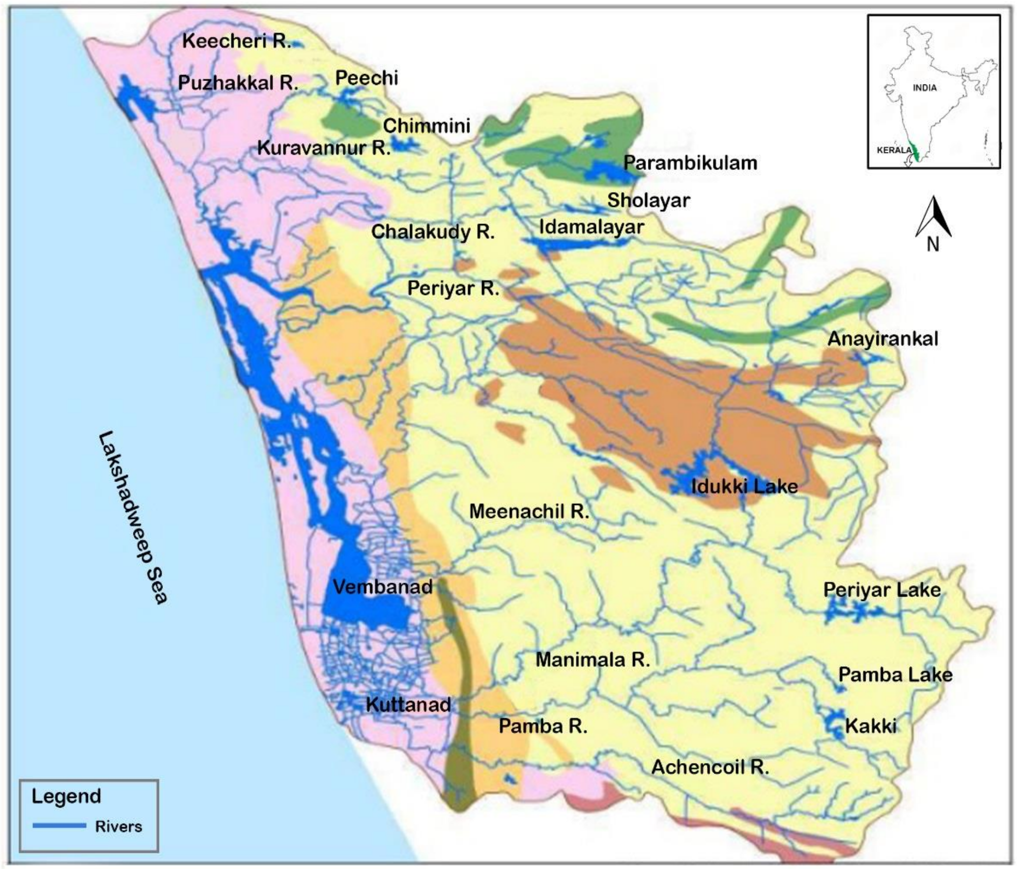

Fig. 3.1 Riverine map of Vembanad wetland system

(Source: Kerala Soil Map by National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur, India)

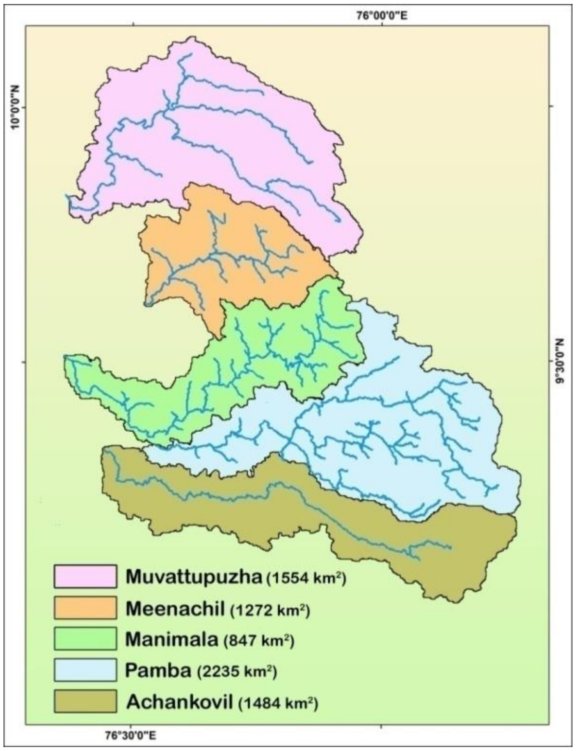

Fig. 3.2 Catchment area of rivers draining into Vembanad wetland system

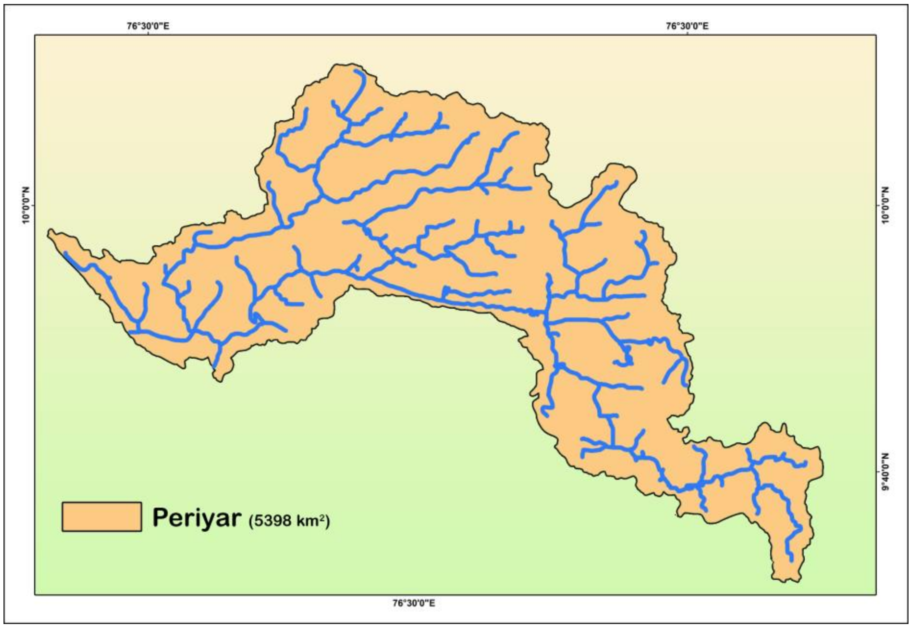

Fig. 3.3 Catchment area of Periyar River draining into Vembanad wetland system

3.3 Major reservoirs and dams in Kerala

There are 81 dams in Kerala, in which 59 dams are owned by the Kerala State Electricity Board and which form around 45 reservoirs, 20 dams are owned by the Kerala State Irrigation Department which form 20 reservoirs and the Kerala Water Authority vests the control of 2 dams with 2 reservoirs. Three dams have no drainage area across the river (i.e. Munnar Headworks dam, Lower Periyar dam and Maniyar dam). Besides this, 10 large barriers are also present in the state. Of the 81 dams, 37 reservoirs are used for hydroelectric power, 27 reservoirs are used for irrigation and 9 reservoirs are used for both hydroelectric power and irrigation. Around 74 % of the total live water storage of Kerala is accommodated in the 7 major reservoirs, each having a live storage capacity of more than 0.20 BCM (Table 3.1).

Table 3.1 Reservoirs having a live storage capacity of more than 0.20 BCM

Sl. No.	Name of reservoir	Live storage capacity (MCM)
1.	**Idukki**	1460
2.	**Idamalayar**	1018
3.	**Kallada**	488
4.	**Kakki**	447
5.	**Parambikulam (for use of TN)**	380
6.	**Mullaperiyar (for use of TN)**	271
7.	**Malampuzha**	227

3.3.1 Periyar River basin (PRB)

The Periyar (244 km) is the longest river and PRB is the second largest river basin of Kerala, with a catchment area of 5398 km^2 out of which nearly 98 % lies in the Kerala state and drains parts of Idukki and Ernakulam districts of the state. The state wise distribution of the drainage area is given in Table 3.2. The Periyar River system is mainly regulated by 17 dams and reservoirs and 2 barrages, which are constructed for the purpose of hydroelectric power generation as well as irrigation. Around 80 % of the hydroelectric projects of the state are located in the Periyar River basin (Abe & Joseph, 2015).

Table 3.2 State wise area distribution of Periyar sub-basin

Name of State	Drainage area (km^2)	Percentage of total drainage area
Tamil Nadu	114	2
Kerala	5284	98
Total	5398	100

Periyar River has a drainage area of 4,033 km^2 up to CWC gauging station at Neeleshwaram. Idukki, Idamalyar and Mullaperiyar are the three reservoirs with substantial live storage capacity in Periyar sub-basin. The Periyar River has a catchment area of about 637 km^2 at Mullaperiyar dam. The free catchment between Mullaperiyar and Idukki dam is about 605 km^2. Catchment area obstructed by Idamalayar dam is about 472 km^2. Periyar sub-basin comprised of about 50 % of the total live storage of the state (i.e. about 2.92 BCM). The total storage of Idukki reservoir is about 1997 MCM at FRL of 732.43 m. It has a total storage of about 537 MCM at MDDL (Minimum Drawdown Level) of 694.94 m. The live storage between FRL and MDDL is about 1460 MCM. The Idamalayar dam is located on the Idamalayar River, a tributary of the Periyar River. Its live storage is about 1018 MCM.

3.3.2 Pamba River basin

In Pamba River, two hydrological observation stations are maintained by CWC i.e. at Kalloppara on river Manimala and Malakkara on river Pamba. The Pamba River bifurcates at Pandanad, with one branch taking a western course. The Manimala joins the Pamba in its Neeretupuram branch. After that the river flows north and falls into Vembanad wetland through many branches, with the Pallathuruthy Aar and the Nedumudy Aar being the important ones. There are 8 dams and one barrage in Pamba sub-basin. The total live storage capacity is 487 MCM, which is 10.5 % of the average annual runoff of 4.64 BCM (4640 MCM). Out of the total live storage capacity, only Kakki (447 MCM live storage) has a significant storage and it is the major reservoir project in Pamba basin. Kakki reservoir is built across the river Kakki, a tributary of Pamba River. It has a gross storage of about 450 MCM at FRL of 981.46 m and storage of 7.6 MCM at MDDL of 908.3 m. In

Pamba sub-basin, the Kakki storage is about 92 % of the total live storage. Next to Kakki storage is the Pamba storage (live storage only 31 MCM). The total live storage of all other reservoirs and barrages is only 9 MCM.

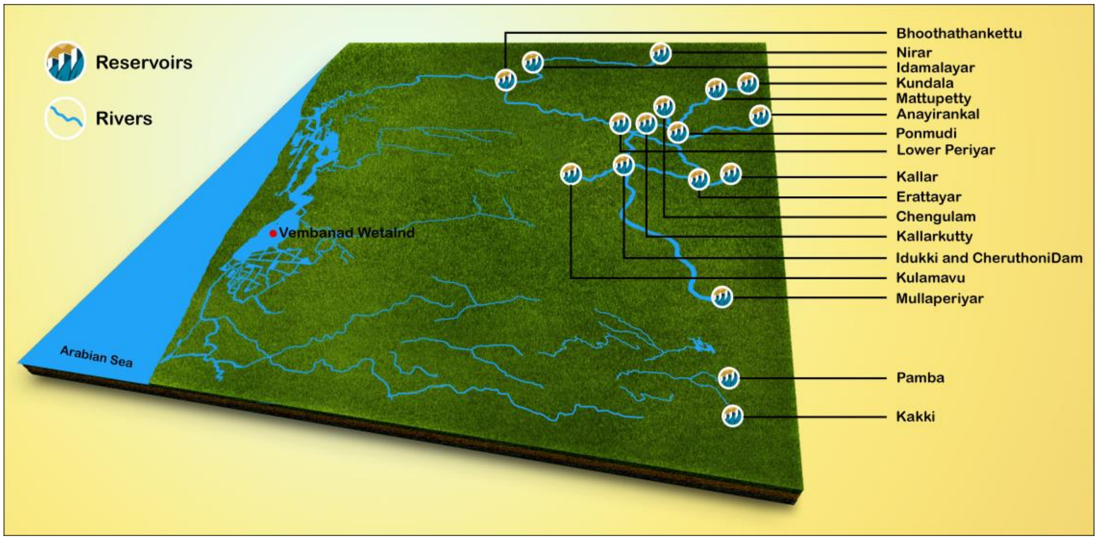

Fig. 3.4 Rivers and reservoirs influencing the Vembanad wetland system

3.4 Rainfall data

Kerala economy solely depends on monsoon rainfall for its water needs and the rainfall in the state is mainly controlled by the south-west and north-east monsoons. But recently a wide spread change can be seen in rain spell due to the climate change and the change in monsoon wind pattern over the region. Kerala has an average annual precipitation of about 3000 mm. However, according to Indian meteorological Department data (IMD), the state witnessed 2346.6 mm rainfall as against 1649.5 mm (42 % above the normal) during 2018 flood. The rainfall departure in Idukki was the highest viz. 92 %. The district wise rainfall occurred during 1st June 2018 to 22nd August 2018 is shown in Fig. 3.5.

3.4.1 Rainfall pattern in Kerala during flood, 2018

According to CWC, the rainfall obtained during 15-17th, August 2018 flood period was entirely significant, with more than 800 mm rainfall obtained at Peermade rain gauge station followed by more than 700 mm at Idukki. This resulted in severe flooding in 13 districts of the state, but only one district (Kasaragod) was out of this tragic flood. Kerala experienced above than normal rainfall during June, July and August. June faced 15 % more, July 18 % more and 1st to 19th of August, it was 164 % more (758.6 mm against the normal of 287.6 mm) (Table 3.3).

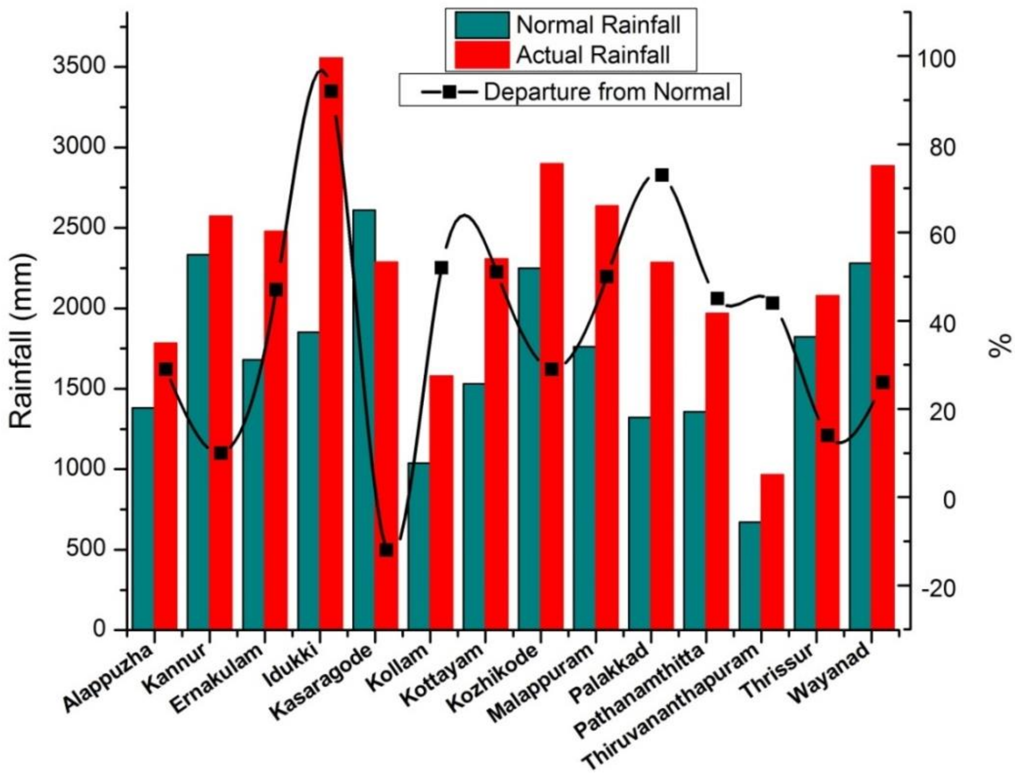

Fig. 3.5 District wise rainfall obtained during 1st June 2018 to 22nd August 2018
(Source: Central Water Commission report, Govt. of. India - September, 2018)

Table 3.3 Month wise normal rainfall, actual rainfall and percentage departure from normal

Period	Normal Rainfall (mm)	Actual Rainfall (mm)	Departure from normal (%)
June, 2018	649.8	749.6	15
July, 2018	726.1	857.4	18
1-19, August, 2018	287.6	758.6	164
Total	1649.5	2346.6	42

3.4.2 Rainfall obtained during 15-17th, August 2018 flood period

During 15-17th August 2018, the intense rainfall and storm was spread over the entire state with maximum rainfall at Peermade, a place between Periyar and Pamba sub-basins. Due to the severe storm, the gates of 35 dams were opened to release the flood runoff. All 5 overflow gates of the Idukki dam were opened, for the first time in 26 years. Heavy rains in hilly districts especially Wayanad and Idukki causes heavy landslides, causalities and crop loss and left the hilly districts isolated. The Cochin International Airport, India's fourth busiest in terms of international traffic, and the busiest in the state suspended all operations on August 15th until August 29th following flooding of its runway. The severity of the flood has been compared with the flood of 16-18th July 1924 centred at Devikulam in Kerala is shown in Table 3.4. According to the data, the 2-day and 3-day rainfall obtained in Pamba, Periyar and Bharathapuzha sub-basins, during 15-17th August 2018 was almost comparable to the Devikulam flood of 16-18th July 1924. For the entire Kerala, during 15-17th August 2018, the rainfall obtained was 414 mm while the same during 16-18th July 1924 was 443 mm.

Table 3.4 Comparison of rainfall obtained in different sub-basins and rest of the Kerala during 15-17th, August 2018 flood with Devikulam flood of 16-18th, July 1924

Sl. No	Name	Area (km^2)	15 Aug 2018	15-16, Aug 2018	15-17, Aug 2018	16 Aug 2018
			1-day (mm)	2-day (mm)	3-day (mm)	1-day (mm)
1	Rest of the Kerala	26968	132	279	364	155
2	Kallada	1139	129	208	289	83
3	Pamba	1620	176	397	538	217
4	Periyar	4035	198	452	588	248
5	Bharathapuzha	5784	114	297	373	182
6	Chaliyar	1992	128	256	331	141
7	Valapattanam	1019	180	263	336	83

3.4.3 Rainfall obtained in Periyar River basin during flood period, 2018

The rainfall obtained during extreme rainfall event of 15-17th August 2018 in Mullaperiyar, Idukki and Idamalayar catchments and remaining part of the sub-basin along with estimated runoff during the same period are given in Table 3.5.

Table 3.5 Rainfall and runoff in Periyar sub-basin up to CWC G&D site

Catchment	Area (km^2)	Rainfall depth 15 Aug 2018 (1-day) (mm)	Rainfall depth 15-16, Aug 2018 (2-day) (mm)	Rainfall depth 15-17, Aug 2018 (3-day) (mm)	Runoff 15Aug 2018 (1-day) (MCM)	Runoff 15-16, Aug 2018 (2-day) (MCM)	Runoff 15-17, Aug 2018 (3-day) (MCM)
Free Periyar	2362	203	459	589	374	845	1084
Between Idukki and Mullaperiyar	605	240	523	682	123	269	351
Mullaperiyar	637	196	415	536	106	225	290
Idamalayar	472	179	394	496	72	158	199
Total	4076	190	454	584	675	1498	1925

According to the CWC report, the maximum discharge at Neeleshwaram G&D site was about 8800 m^3s^{-1} on 16th August 2018. The cumulative runoff for 15-17th August 2018, computed from the Neeleshwaram G&D records was about 1.93 BCM, while the estimated runoff from IMD rainfall was about 1.925 BCM for a runoff coefficient of 0.78 for free catchment and 0.85 for catchments tapped by dams.

During the extreme rainfall event of 15-17th August 2018, the total release during three days from Idukki reservoir was about 345 MCM (spill) and 30 MCM (power house going to Muvattupuzha River) against the inflow volume of 435 MCM. Hence, about 60 MCM of flood runoff was absorbed by Idukki reservoir during 15-17th August. On

15th August 2018, the average release from Idukki reservoir was about 1100 m^3s^{-1} with peak release of 1500 m^3s^{-1} against the average inflow of 1640 m^3s^{-1}. Idukki reservoir received an average 533 m^3s^{-1} discharge from Mullaperiyar on 15th August 2018 with a peak discharge of 760 m^3s^{-1}. On 16th August 2018, the average release from Idukki reservoir was about 1400 m^3s^{-1} with peak release of 1500 m^3s^{-1} against the average inflow of about 2000 m^3s^{-1}. Idukki reservoir received an average 650 m^3s^{-1} discharge from Mullaperiyar on 16th August 2018 with a peak discharge of 760 m^3s^{-1}. On 17th August 2018, the average release from Idukki reservoir was about 1460 m^3s^{-1} with peak release of 1500 m^3s^{-1} against the average inflow of about 1440 m^3s^{-1}. Idukki reservoir received an average 390 m^3s^{-1} discharge from Mullaperiyar on 17th August 2018 with a peak discharge of 590 m^3s^{-1}.

3.4.4 Rainfall obtained in Pamba River basin during flood period, 2018

Generally, the Pamba basin experiences good rainfall, moderate temperature and humid atmosphere. The south-west and north-east monsoon have great influence over the climatic condition of the basin. Even though the coastal regions of the basin experience hot with high humidity, the hilly region is generally cold. The average annual rainfall in Pamba basin varies between 2276 mm to 4275 mm. The rainfall obtained in Kakki dam, Pamba dam and remaining part of the sub-basin along with estimated runoff during 15-17th August 2018 is given in Table 3.6.

Table 3.6 Rainfall and runoff in Pamba River basin up to CWC G&D site

Catchment	Area (km^2)	Rainfall depth 15 Aug 2018 (1-day) (mm)	Rainfall depth 15-16, Aug 2018 (2-day) (mm)	Rainfall depth 15-17, Aug 2018 (3-day) (mm)	Runoff 15 Aug 2018 (1-day) (MCM)	Runoff 15-16, Aug 2018 (2-day) (MCM)	Runoff 15-17, Aug 2018 (3-day) (MCM)
Manimala G&D to confluence	700	175	388	526	92	204	276
Manimala G&D site to confluence	93	175	388	526	12	27	37
Pamba dam	75	207	449	586	12	25	33

Kakki dam	177	196	394	522	26	52	69
Catchment up to Malakkara G&D site	1369	181	409	551	185	420	566
Catchment between Malakkara G&D site and Manimala confluence	63	110	197	280	5	9	13
Total	2477	179	397	537	297	663	894

According to this, the estimated areal rainfall of Pamba sub-basin was about 179 mm, 397 mm and 537 mm respectively for 1-day, 2-day and 3-day rainfall of 15-17th August 2018. For Manimala River up to CWC G&D site, the runoff volume of 1-day, 2-day and 3-day have been estimated as 92 MCM, 204 MCM, and 276 MCM respectively assuming a runoff coefficient of 0.75 corresponding to three day observed runoff of 277 MCM at Kallooppara G&D site. The same runoff coefficient has also been adopted for Pamba sub-basin with estimated 1-day, 2-day and 3-day runoff of 223 MCM, 497 MCM and 668 MCM upto Malakkara G&D site. From the flood hydrograph of Malakkara G&D site total runoff in 3 days is about 533 MCM. The difference in volume may be attributed to retention of overtopped water over river banks in nearby areas.

3.4.5 Combined runoff of Pamba, Manimala, Meenachil and Achankovil Rivers during flood

The estimated runoff for a runoff coefficient of 0.75 from Pamba, Manimala, Achankovil and Meenachil River systems up to Vembanad wetland during 15-17th August 2018 is given in Table 3.7.

Table 3.7 Rainfall and runoff in Pamba, Manimala, Achankovil and Meenachil river systems in Vembanad wetland

Catchment	Area (km²)	Rainfall depth 15 Aug 2018 (1-day) (mm)	Rainfall depth 15-16, Aug 2018 (2-day) (mm)	Rainfall depth 15-17, Aug 2018 (3-day) (mm)	Runoff 15Aug 2018 (1-day) (MCM)	Runoff 15-16, Aug 2018 (2-day) (MCM)	Runoff 15-17, Aug 2018 (3-day) (MCM)
Achankovil	1359	122	231	329	124	235	336
Pamba & Manimala	2656	173	382	517	346	762	1030
Meenachil	820	146	327	437	90	201	268
Total	4835	441	940	1283	560	1198	1634

3.4.6 Hydro-climatic conditions of Kerala during August 2018

According to the study conducted by Mishra *et al*. (2018), the long-term (1901-2018) average annual precipitation in Kerala was approximately 2400 mm with a standard deviation of 400 mm. Therefore the 117 years (1901-2018) of Kerala's observed rainfall record reveals that the two wettest years occurred in 1924 and 1961, with an annual rainfall of around 3600 mm. However in Kerala, the rainfall in 2018 (until August) was lower than the rainfall recorded in 1924 and 1961. They also calculated the return period of extreme rainfall in Kerala during August 2018 using GEV (Generalized Extreme Value) distribution. They find that, the 1-day maximum rainfall (120.2 mm) averaged over the entire state in August 2018 (occurred on 15th August) had a return period of about 75 years. Moreover, the 2-day maximum rainfall (235.5 mm) (occurred on 15-16th August 2018), had a return period of about 200 years. The 3-day maximum rainfall (294.2 mm) (occurred on 15-17th August 2018), was more than a 100-year event considering the record of 117 years. Hence, from this, it is clear that, the 2-day maximum rainfall in Kerala during August 2018 was the most detrimental to the return period of more than 200 years.

The monsoon season of 2018 was anomalously wet between May 1st and August 21st, as the majority of the state received more than 1500-2000 mm rainfall. In 2018, rainfall in most of Kerala was 42 % above normal average, while between May 1st and

August 21st 2018, the southern region recorded more than 200 % rainfall. During 8-17th August 2018, heavy rainfall occurred in much of the state. Majority of the state received more than 500 mm rainfall with an excess of 40-50 % during this period (8-17th August, 2018). The study of daily rainfall from 3-20th August shows that there was significant rainfall during 8-9 August 2018, which continued in Kerala until 18th August. Rainfall occurred on August 15th and 16th was anomalously higher, as most part of Kerala received more than 200 mm rainfall each day. Before heavy rain that caused enormous flooding and loss of life in Kerala, the persistent rainfall before 15-16th August could have produced saturated conditions.

In India, severe precipitation events have increased in frequency and intensity over the last few decades (Roxy *et al*., 2017; Guhathakurta *et al*., 2011; Goswami *et al*., 2006). According to Fowler *et al*. (2010), frequent and extreme precipitation events cause flooding, which have become common in India (Mohapatra and Singh, 2003). According to the Fifth Assessment Report of the Intergovernmental Panel for Climate Change (IPCC) 2014, south-west season floods can be understood as an obvious illustration of the effect of global climate change with very heavy rainfall in a short period of time. In India, Mukherjee *et al*. (2018) have recorded a rise in extreme precipitation from anthropogenic warming. In their study, they find that, 1-5 day heavy rainfall at 5-500 year return period is increases by 10-30 % under the anthropogenic warming. Moreover, when compared to north India, heavy rainfall in southern India increases with a much faster (18 %/K) rate in response to warming. However, the attribution of a single extreme event to climate change is difficult, despite the consensus of the increase in extreme precipitation under the warming climate. For instance, According to van Oldenborgh *et al*. (2016), climate change did not cause the flooding and heavy rain event in Chennai, 2015.

3.5 Impact of rainfall, river discharge and reservoir operation during 2018 flood on the Vembanad wetland

The 2018 flood event in Kerala demonstrates that, reservoirs can play a crucial role in the flood situation. The storage of reservoirs during the monsoon season plays a significant role, providing water for irrigation and producing hydroelectric power. Hence, before the monsoon departs, most of the reservoirs optimise their storage. In Kerala there are 57 large dams, out of which 4 dams are operated by Government of Tamil Nadu. The total live storage capacity under these dams is 5.806 BCM. This is equal to 7.4 % of annual average runoff of all 44 rivers in Kerala, which is about 78 BCM (Water Resources of Kerala, 1974). Out of these dams, only 7 reservoirs are having a live storage capacity of more than 0.20 BCM and they constitute 74 % of the total live storage in Kerala. Before the flooding, the storage condition of these major reservoirs (i.e. Idukki, Idamalyar, Kallada, Kakki, Parambikulam, Mullaperiyar and Malampuzha) was anomalously high. All these seven major reservoirs had storage much higher than their long-term (2007-2017) mean. For example, on 8th August, 2018, six (out of seven) reservoirs were at more than 90 % of their full reservoir level (FRL). Parambikulam had reservoir storage 99.5 % of its FRL while in Idukki, Idamalyar, Kakki, Kallada and Malampuzha reservoir storage on 8th August 2018, was 92.5 %, 97.3 %, 90.5 %, and 97.8 % of their FRL. Mullaperiyar was the only major reservoir that had reservoir storage of less than 80 % of its FRL. During May 1st to August 2018, excess rainfall (40-50 %) occurred in Kerala, which led to above average reservoir storage. Reservoirs such as Idukki, Kakki, and Periyar were already almost full, witnessed extreme rainfall of more than 500 years return period. Excess rainfall was received by Idukki, Kakki, and Periyar reservoirs were 279 %, 700 %, and 420 % respectively from their long-term mean between May and August in 2018. Kerala recorded above normal rainfall in the 2018 monsoon season, which significantly contributed to the storage of reservoirs. According to Mishra *et al*. (2018), the Kerala flood, 2018 was caused by multi-day extreme rainfall and partly due to high reservoir storage. There are several other small and medium sized reservoirs in Kerala that could have had elevated storage before the flood. Therefore, most of the major reservoirs were almost full before the heavy rainfall occurred on 15-17th August 2018. Therefore, there was no capacity for reservoirs to handle the additional flow generated in the upstream catchment areas by unprecedented extreme rainfall. Reservoirs had to release a significant amount of water in a short period of time due to heavy rainfall after August 8th. A red alert was flashed on Idukki reservoir on 9th August 2018, which later on opened all the gates to release water to lower the reservoir level (Anon, 2018).

In Pamba River basin, the live storage of Kakki reservoir is about 447 MCM. The reservoir level on 8th July 2018 was 965.05 m i.e. 16.41 m below FRL. In terms of storage volume, the live storage was 226 MCM i.e. 51 % of total live storage capacity. Afterwards, there was continuous rain during 9-27th, July. As the reservoir was only half-full prior to this spell of rains, there were no spills and reservoir level rose to 979.04 m on 28 July 2018 with a live storage of about 403 MCM. The reservoir was now 91 % full. So, the Kakki reservoir absorbed this heavy spell of rain fully. However, as a result, it got very close to FRL in July itself with only 39 MCM extra flood cushion available below FRL. The releases from Kakki reservoir could not be made to deplete water level in Kakki reservoir, as at that time the below MSL areas in Kuttanad region were already experiencing heavy inundation. Moreover, the Thottappally spillway at Vembanad wetland, which receives water from Pamba, Manimala, Achankovil and Meenachil rivers, out of which only Pamba basin is having Kakki dam as a control structure. The other three are uncontrolled rivers. The Thottappally spillway has a discharging capacity of around 630 $m^3 s^{-1}$. Therefore, the water takes time to pass through the spillway and get accumulated in the low-lying areas around Vembanad wetland. So, when the low lying areas in Kuttanad region are already experiencing inundation, the discharge from Kakki reservoir, makes it a complicated situation.

If Kuttanad region was not flooded prior to the second spell of extreme rains, preferably, when this spell of rain once abated, the reservoir level could have been brought down to some extent, to moderate any future extreme flood events that might affects the reservoir in the month of August. Unfortunately, this happened 11 days later. On 9th August 2018, the reservoir level was 981.25 m and it was nearly with and no spills from the dam. Now, any flood event could have been moderated between the space available between FRL (981.46 m) and MWL (982.16 m). Only about 20 MCM dedicated flood space is available between FRL and MWL. As per dam site rainfall record, the rainfall during the second event that occurred during 9-20th August 2018 was 1724 mm with 590 mm rainfall in just two days i.e. 15-16th, August 2018. The maximum inflow in the reservoir was 835 m^3s^{-1} with a corresponding release of 938 m^3s^{-1}. As there was no space left in the reservoir, it could not provide any flood attenuation during this second event and the space between FRL and MWL was quickly exhausted. The total flood peak observed in Pamba sub-basin was 2900 m^3s^{-1}. Even if there was just 500 m^3s^{-1} release from Kakki, the downstream flood peak would still have been about 2400 m^3s^{-1}.

As per the report of Planning Commission (July 2008), the water carrying capacity of the Vembanad wetland system was reduced to an appalling 0.6 BCM from 2.4 BCM as a result of land reclamation. The Pamba reservoir (31 MCM) and Kakki reservoir (447 MCM), in the Pamba sub basin can hardly regulate 10.5 % of the average annual flow in the Pamba River. All other storages in Pamba River are very small ones having no appreciable storage capacity. Also, the other three rivers such as Manimala, Meenachil and Achankovil have no storages on them. As part of the Kuttanad development scheme, Thottappally spillway was constructed in 1954 for mitigating flood situation in Kuttanad, by diverting flood water of Pamba, Manimala, Achankovil and Meenachil directly to the sea. The Thottappally spillway consists of a leading channel 1310 m long 365 m wide with a bridge cum regulator across the spillway channel. The bridge cum regulator is 365 m along with 40 vents, each having 7.6 m clear span. Though the original discharge capacity of the spillway was about 1812 m^3s^{-1}, it is reported that at present the average maximum discharge passing through the spillway is limited to 630 m^3s^{-1}, which is almost one - third of the design capacity of the spillway.

During 15-17th August 2018 rainfall, the runoff generated from Pamba, Manimala, Achankovil and Meenachil Rivers was about 1.63 BCM (1630 MCM) against the 0.6 BCM (600 MCM) carrying capacity of Vembanad wetland. Furthermore, the discharging capacity of Thottappally spillway (630 m^3s^{-1}) was other major constraint for the disposal of runoff. Considering the wetland carrying capacity of about 600 MCM and discharging capacity of 630 m^3s^{-1} of Thottappally spillway and around 1706 m^3s^{-1} present discharging capacity of Thanneermukkom barrage, it can be concluded that out of 1.63 BCM the runoff generated during the 15-17th and subsequent days in August 2018 rainfall, only about 0.605 BCM runoff was possible to drain out of the Vembanad wetland. The remaining runoff volume of about 1 BCM created the rise of the water level in the wetland and adjacent areas. This continuous rising of water may be one of the reasons of overall change in the river hydrodynamics of Pamba, Manimala, Meenachil and Achankovil River systems resulting higher water level for a particular discharge in these rivers. Considering the high rainfall during 15-17th, August 2018, the absence of substantial storage reservoirs in the upstream of the major rivers, reduction of depth and shrinkage of carrying capacity of Vembanad wetland, reduction of the capacity of Thottappally spillway and the structural limitations of Thanneermukkom barrage may have worsened the flooding in Kuttanad region and the water flows to the low-lying areas in the upper reaches of the backwater. This may be the reason for the heavy flooding experienced in the low-lying areas closer to the Vembanad wetland in the Alappuzha, Kottayam, Ernakulam, Thrissur and Pathanamthitta districts. Several places in Chengannur, Kuttanad and Ambalapuzha taluks have been isolated following an alarming rise in the water level. In Kuttanad taluk, Kainakary, Pulinkunnu, Chambakulam, Edathua and Ramankary were badly affected. More than 200 relief camps and 483 gruel centres have been opened in different parts of the district for around 1.25 lakhs people.

3.6 Effect of flood on the Western Ghats ecology with special reference to Vembanad wetland

The Western Ghats is known to be one of the world’s eight hottest biodiversity hot spots and an ecologically sensitive region. It stretch 1600 km from the mouth of Tapti River near the Gujarat and Maharashtra borders to Kanyakumari, Tamil Nadu southernmost tip of India, covering six states; Gujarat, Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu (Fig. 3.6). With its high stature, lush tropical rain forests, the vegetation reached its greatest diversity towards the southern tip of Kerala. As a real water tower of the Indian

Peninsula, the Western Ghats are the source of several east and west-flowing rivers. Also, there are a variety of natural as well as several man-made wetlands in the Western Ghats region, that are valuable from the perspective of aquatic species and migratory waterfowl. Besides serving as corridors, the riparian vegetation along the various east and west-flowing rivers and streams of the Ghats shelters high levels of plant and animal diversity. Hence, the entire Western Ghats region needs to be considered as ecologically sensitive as being 'upper catchment areas' critical for the sustainability of the rivers of the Indian Peninsula and also as a repository of wetlands. However, many reasons have contributed to this fragile habitat being disrupted and this has necessitated the restoration of the Ghats and the sustainable use of its resources.

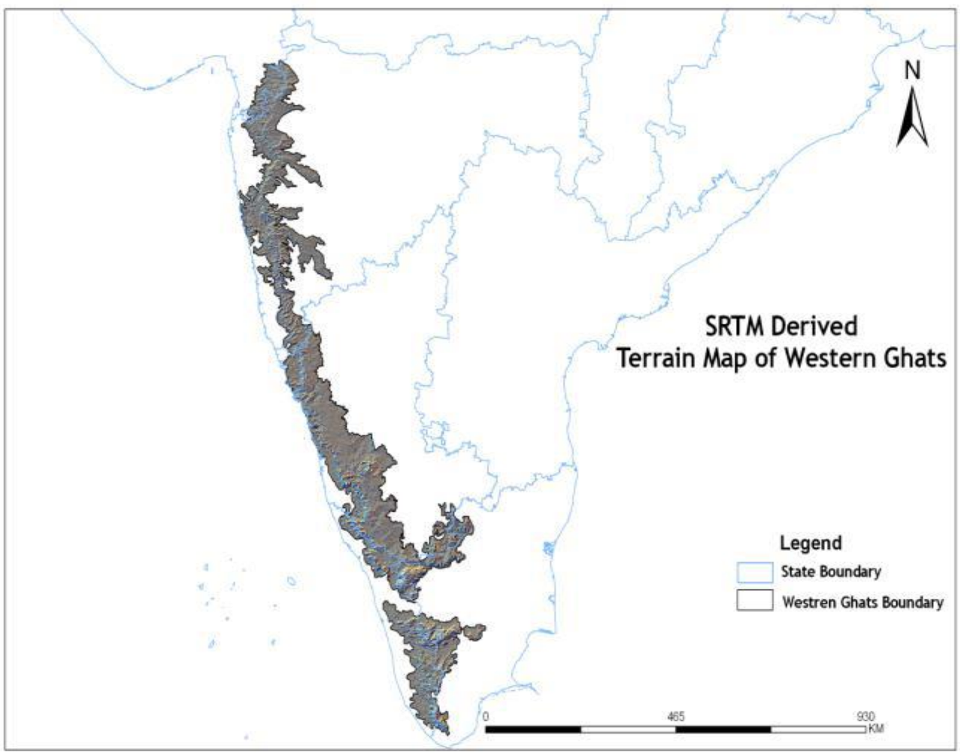

Fig. 3.6 The Western Ghats boundary
(Source: WGEEP report, 2011)

Today, Kerala has over 5,000 quarries, out of which over 2,000 are in the Western Ghats. Out of 81 dams in Kerala, 35 are hydroelectric projects which contributed to the destruction of over 350 km^2 of evergreen forests and altered the riverine ecosystem in many ways. Many dams commissioned before 1971, the reservoir capacity has been significantly reduced due to silting and thus unable to hold water as per their designed capacity. When united Kerala was created in 1957, 36 % Kerala's land area constituted forests, according to 2016 economic survey only 3.9 % is 'dense' forests. In an ecologically fragile state where 75 % of the land has a gradient of above 20 %, the loss of dense forest cover of this magnitude is an invitation to disaster. Massive forest losses in the catchments of rivers and dams have contributed to excess runoff during the extreme rains in August 2018 in Kerala, adding to severity of floods. Deforestation for planting cash crops like tea, coffee, cardamom and pepper results massive soil erosion leads landslides in hilly districts of Kerala. That had happened in many parts of Kerala during the monsoon season. Heavy landslides may change the geography of an entire land. Wherever landslides happened, there were granite quarries on the other side of the hill. Although legal, these quarries were allowed to run despite running the risk of landslides; 10 out of the 11 pockets which witnessed major landslides, and where 91 quarries operated, were classified as 'ecologically sensitive zones' and proposed to be banned from mining and quarrying by the Western Ghats Ecology Expert Panel, also known the Madhav Gadgil Committee in its report in 2011. After the Gadgil report was criticized as biased against development, the government constituted another committee, the high-level working group or the Kasturirangan committee, which recommended a reduced zone of protection. But even by the Kasturirangan committee report, five out of these 11 landslide areas should have been banned from mining and quarrying. As per the report, Kerala has a total 5,924 quarries, an average of six quarries per panchayat, of which 3,332 are in the ecologically sensitive zones identified by Gadgil. In sum, 56 % of the quarries are on fragile spots in the Western Ghats, making them prone to landslides.

Based on the type of environmental impacts involved and the ecological sensitivity of the Western Ghats zone, a graded or layered approach to the regulation and promotion of construction activities situated in the Western Ghats is recommended by the Western Ghats Ecology Expert Panel (WGEEP). As per this, the WGEEP has identified the entire Western Ghats as an Ecologically Sensitive Area (ESA) and allocated three levels of Ecological Sensitivity to separate regions of it termed as Ecologically Sensitive Zone 1 (i.e. Regions of highest sensitivity or ESZ1), Ecologically Sensitive Zone 2 (Regions of high sensitivity or ESZ2) and Ecologically Sensitive Zone 3 (Regions of moderate sensitivity or ESZ3). Based on this ESZ1, ESZ2 and ESZ3 levels were assigned within the Western Ghats frontier to the 30 taluks in Kerala. A total of 25 taluks in 12 districts with 50 % or more of their area is included within the Western Ghats boundary in which, 15 taluks coming under ESZ1, 2 taluks in ESZ2 and 8 taluks in ESZ3 (Table 3.8). Furthermore, a total of 18 taluks in 9 districts with less than 50 % of their area is also included within the Western Ghats boundary in which, 2 taluks coming under ESZ1 and 16 taluks in ESZ2 (Table 3.9). There can be no doubt that the Western Ghats are a rare biological heritage that needs to be preserved and nurtured along the path of environmentally and socially sound development. For this cause, the WGEEP strongly suggested that the entire Western Ghats tract be considered to be an Ecologically Sensitive Area, with large areas brought under Ecologically Sensitive Zone 1 and 2. The Peechi-Vazhani and Athirappilly-Vazhachal in Thrissur district and Periyar are coming under the Ecologically Sensitive Localities (ESL). As per the suggestion of WGEEP, the Chalakudy River (one of the river that draining into Vembanad wetland through Periyar River) should be designated as a region rich in fish diversity to be administrated in Kerala under the 'Conservation of biodiversity rich areas of Udumbanchola taluk' pattern. Pronab Sen committee report (2000) categorized the origins of rivers and wetlands as an Ecologically Sensitive Areas of having intrinsic ecological service values. The Ecologically Sensitive Zones and Protected areas in Kerala as per WGEEP are shown in the Figure 3.7.

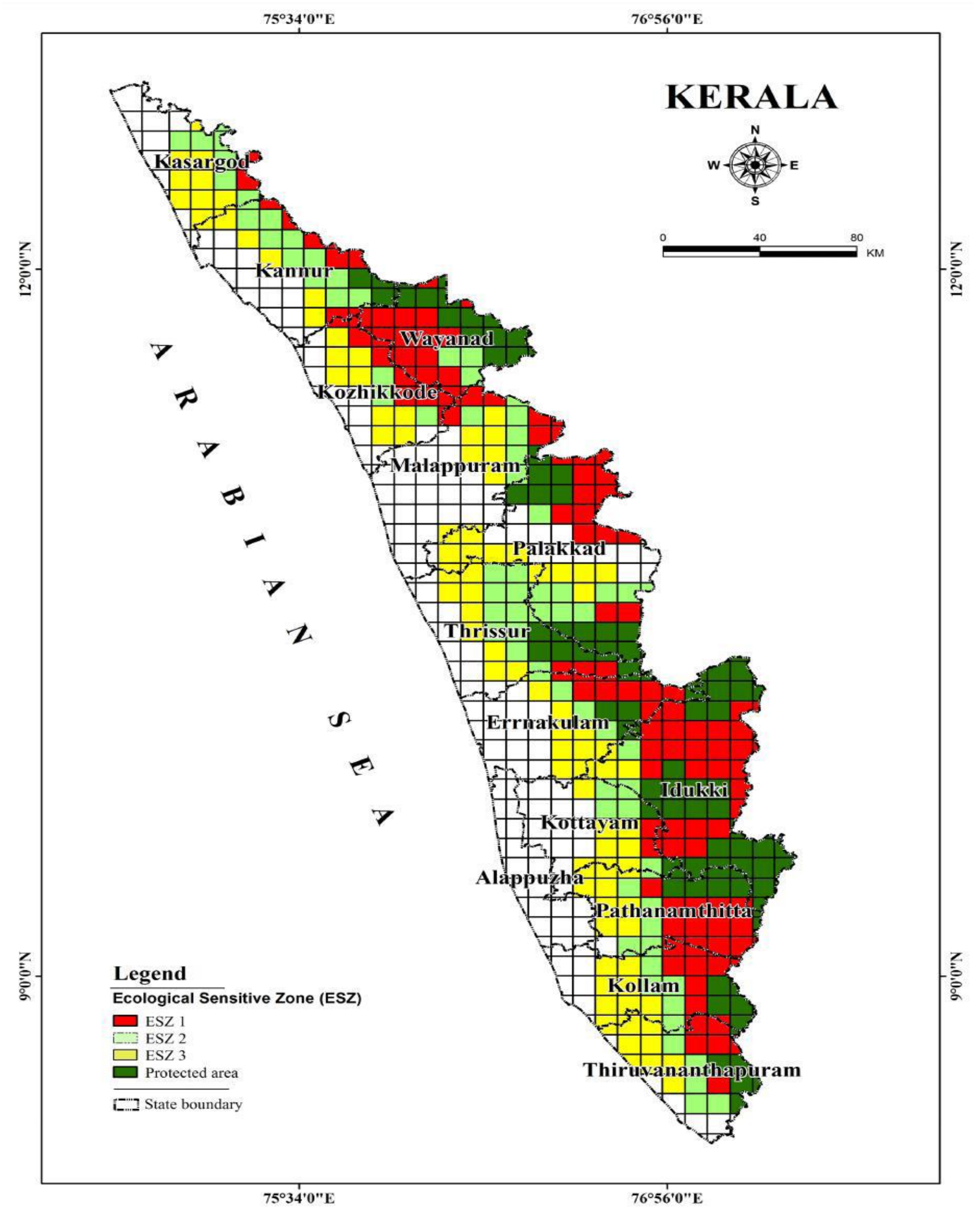

Fig. 3.7 Ecologically Sensitive Zones and Protected Areas of Kerala
(Source: KSBB report, 2011 (Modified after WGEEP report, 2011)

Table 3.8 Various taluks in 12 districts of Kerala with 50 % or more of their area is included within the ESZ1, ESZ2 and ESZ3 of Western Ghats

Sl. No.	District	Taluks assigned to ESZ1	Taluks assigned to ESZ2	Taluks assigned to ESZ3
1	Kasaragod	-	-	Hosdurg
2	Kannur	Tellicherry	-	-
3	Wayanad	Vythiri, Mananthavady, Sultan Bathery	-	-
4	Kozhikode	-	-	Mahe
5	Malappuram	-	-	Malappuram
6	Palakkad	Mannarkkad, Chittur	-	Alathur
7	Thrissur	Irinjalakuda	Thrissur	Wadakkanchery
8	Idukki	Todupulai, Udumbanchola, Devikulam, Pirmed	-	-
9	Kottayam	-	Kanjirapally	Pala (Lalam)
10	Kollam	Punalur	-	Kottarakkara
11	Pathanamthitta	Ranni	-	Mallappally
12	Thiruvananthapuram	Nedumangad	-	-

(Source: WGEEP report, 2011)

Table 3.9 Various taluks in 9 districts of Kerala with less than 50 % of area is included within the ESZ1 and ESZ2 of Western Ghats

Sl. No.	District	Taluks assigned to ESZ1	Taluks assigned to ESZ2
1	Kasaragod	-	Kasaragod
2	Kannur	-	Talipparamba
3	Kozhikode	Kozhikode	Koyilandy, Kozhikode
4	Malappuram	-	Perinthalmanna, Tirur
5	Palakkad	Palakkad	Palakkad, Ottappalam
6	Ernakulam	-	Perumbavoor, Aluva, Kothamangalam, Muvattupuzha
7	Kottayam	-	Changanassery
8	Kollam	-	Kollam
9	Thiruvananthapuram	-	Thiruvananthapuram, Chirayinkil

(Source: WGEEP report, 2011)

Geographically, the Western Ghats is the catchment for river systems that drain almost 40 % of the land area in India. Among the rivers in peninsular India which originated from the Western Ghats, Godavari, Krishna, Kaveri, Kali Nadi and Periyar having inter-state importance. The shorter perennial monsoon fed west-flowing rivers like Sharavati, Netravathi, Periyar, and the Bharathapuzha travel through steeper and more undulating topography before emptying into the Arabian Sea. Except for a few coastal streams, one-third of the basin area of most of the river basins is located within the Western Ghats. Also, the marine and backwater fisheries are maintained by the rich nutrients and sediments brought down by these flowing rivers. Among the west-flowing rivers in Western Ghats Periyar, Chalakudy, Keecheri, Puzhakkal, Karuvannur, Muvattupuzha, Meenachil, Manimala, Pamba and Achankovil rivers drain into Vembanad-Kol wetland before emptying into the Arabian Sea. Most of these rivers are either dammed or diverted, some of them for power generation in the upper reaches and irrigation in the lower reaches at many places. For example, the west-flowing shorter rivers such as Periyar and Pamba have been dammed at several places. By violating all natural laws, west-flowing rivers have been virtually transformed into east-flowing rivers. The construction of the dam will entirely modify the ecology of the river system. Hence, dams are without dispute the most direct modifiers of river flows. They can significantly modify the magnitude (amount) of water flowing downstream, the timing, frequency and duration of high and low flows and change the natural rates at which rivers rise and fall during runoff events. Extreme daily flow fluctuation between peak and off peak times below dams is commonplace in west-flowing dammed rivers. In addition to cutting off flood plains and influencing aquatic ecology and riparian systems, drinking water schemes, major and minor irrigation programmes running in downstream regions have been affected. Similarly, following power generation, diversion of flows into another river basin causes issues of regular floods in the recipient basin and drought in the diverted basins. Furthermore, many of the rivers in Western Ghats are facing the repercussions of indiscriminate sand mining and it is also one of the serious problems faced by the major rivers associated with the Vembanad wetland system. The immediate consequences are the reduction of water tables and the degradation of water quality. Besides, one of the most important ecological issues of considerable concern is that degradation and pollution of soil and water in the upper reaches of the Western Ghats gets carried downstream contributing to the degradation of midlands and coastal areas. In the Western Ghats, the need to curb the usage of chemical pesticides and fungicides used in plantations is of greater significance than elsewhere, as the use of these ‘toxins’ in the higher hills gets carried downstream polluting the entire wetland system. Hence, the serious ecological alterations and modifications in most of the west-flowing rivers which arises due to the various problems in Western Ghats also impacts the ecology of Vembanad wetland system, as some these rivers empties into Vembanad wetland before reaches to Arabian Sea. The encroachment of river basins of the Western Ghats for various developmental activities (i.e. for hydropower or water projects) has raised many concerns. Therefore, the Vembanad wetland encompassing the ten river system, river basins, riparian zones and associated dams fall directly or indirectly under the ESZ1, ESZ2 and ESZ3 mostly in the districts of Ernakulam, Kottayam, Idukki, Pathanamthitta and Thrissur. Therefore, as suggested in the WGEEP report (2011), there is a need for decentralized river basin planning for west-flowing rivers and maintaining environmental flow in these rivers. Other major threats associated with riverine ecosystems of the Western Ghats which include deforestation, development of road infrastructure andplantations, unplanned tourism and biological invasions. Hence, a policy shift is thus desperately justified in reducing the environmentally devastating activities takes place in the Western Ghats.

Salient findings...

- *The lack of significant storage reservoirs in the upstream of the major rivers, reduction of depth and shrinkage in carrying capacity of Vembanad wetland, the structural limitations of Thottappally spillway and the Thanneermukkom barrage that plays a major role in worsening the 2018 flooding in Kuttanad region.*
- *Also, the overall degradation, pollution from various sources and waste accumulation has led to the loss and reclamation in large areas of the rivers and wetland habitat significantly modifying the carrying capacity, causing serious flood condition in the area.*
- *Vembanad wetland is a notable part of the larger Western Ghats and its ecological conditions. The floods in 2018 and the subsequent period have affected the river flow, storage capacity of dams and reservoirs in the Ecologically Sensitive Zones (ESZ1, ESZ2 and ESZ3) of the wetland. So, a decentralized river basin planning for west-flowing rivers and maintaining environmental flow in these rivers is necessary.*
- *New scientific and development oriented initiatives should be proposed and implemented in the Western Ghats region considering the ESZ zones and its conservation strategies. The recent report of the IUCN (2020) has also highlighted the urgent need for implementation of the Gadgil and Kasthurirangan recommendations of the WGEEP (2011) report in total. At present due to various anthropogenic interventions and looming climate change issues, the Vembanad wetland area under the Western Ghats region has degraded miserably, also the 2018 floods and subsequent periods have worsened the situations in the area.*

4. IMPACT OF FLOOD AND POST FLOOD ON WATER QUALITY AND PRODUCTIVITY OF VEMBANAD WETLAND

4.1 Introduction

Water quality is defined in terms of the chemical, physical and biological contents of water. With the seasons and geographic regions, the water quality of rivers and lakes varies, even though there is no pollution present. Temperature, rainfall, pH, salinity, dissolved oxygen (DO), biochemical oxygen demand (BOD), alkalinity and acidity and heavy metal contaminants are the major physical and chemical parameters affecting the aquatic environment. These parameters are the limiting factors for the survival of aquatic organisms (flora and fauna). Poor water quality may be induced by low water flow, municipal wastewater and industrial discharges (Chitmanat and Traichaiyaporn, 2010).

Estuaries are highly dynamic because they are regulated by freshwater from rivers and streams mixes with salt water from the marine environment (Silva *et al*., 2011). They are an integral part of the hydrological cycle and shows temporal and spatial changes. The temporal changes ranged from instant hourly variations to long lasting seasonal variations. These temporal changes are mainly due to changes in meteorology, marine influences such as tides and saline water influx and riverine influences, such as freshwater flow and sedimentation. Estuaries are spatially heterogeneous due to gradients in distribution of hydrographic parameters. The gradient distribution of hydrographic parameters in the estuary depends upon the morphology, circulation and mixing, sources of dissolved and suspended constituents and anthropogenic pressure (Bergamino and Richoux, 2015). The hydrographic conditions in an ecosystem are also determined by the factors such as regional precipitation and the temperature resulting in surface cooling and heating. These spatial, temporal and local changes determine the physical and chemical nature of an aquatic ecosystem. The influence of the hydrographic parameters over the living community shows the abiotic and biotic relationship in an environment. The spatio-temporal variation in the hydrographic parameters in turn affects the community structure of an ecosystem. The physical parameters like currents and the tidal flow and the meteorological parameters like seasonal rainfall and evaporation are mainly determining the hydrographic conditions in an aquatic ecosystem. Changes in these parameters also effect the distribution of other physical parameters like depth, salinity, temperature and transparency. Another important factor that determines the dynamic nature of an estuary is the chemical parameters. In an aquatic ecosystem, the land runoff, sewage, industrial effluents and sedimentation are the major sources of chemical parameters like pH, alkalinity and BOD. The distribution of chemical parameters is also affected by the physical parameters in the ecosystem. This shows that the dynamic nature of an aquatic ecosystem is the net effect of its physical and chemical entities.

Estuaries are vulnerable habitats that are experiencing declining water quality and eutrophication. Anthropogenic activities associated with urbanization, coastal development, aquaculture and industrial expansion seriously affected the quality of natural habitats in these sensitive waters. Water may be polluted by several factors including decayed animal and vegetable matter and living microorganisms such as algae and bacteria, industrial and commercial solvents, heavy metals, herbicides and pesticides. These factors may constitute water a bad taste, colour, odour and cause hardness, corrosiveness, staining or frothing. The quality of water not only retards the availability of potable water, but also decreases biodiversity and fisheries potential. Eutrophication is another problem facing the estuarine system of Kerala. The trend in eutrophication is evidenced by the progressive concentration of nutrients like phosphate and nitrate. The aquatic water bodies satisfy our domestic, industrial, transport and sporting needs. Alterations in the water quality parameters seriously affect the dynamic and delicate balance of these pristine aquatic ecosystems. In the environmental studies, water quality assessment attained an important position because the physico-chemical characteristics of the aquatic water bodies have gained worldwide acceptance. The water quality and biodiversity of the estuarine system are degrading day by day mainly due to increase in human settlements near the shore, industrialization and urbanization.

Estuaries receive inputs of pollutants, as they are often situated in the vicinities of highly populated and industrialized areas. Toxic metals are usually present in industrial, municipal and urban runoff, which can be harmful to humans and biotic life. Increased urbanization and industrialization are to be blamed for an increased level of trace metals, especially heavy metals, in our waterways (Seema Singh *et al.*, 2011). Heavy metals are high priority pollutants because of their relatively high toxic and persistent nature in the environment. Metal ions can be incorporated into food chains and concentrated in aquatic organisms to a level that affects their physiological state. In the present study, water and sediment were analysed for heavy metals viz. copper (Cu), zinc (Zn), nickel (Ni), cadmium (Cd), lead (Pb) and iron (Fe).

Estuaries provide habitat for species that are valued commercially, ethnically and recreationally. An increasing world population reaching 7.1 billion people, of which 50 - 60 % are living in the coastal regions and this increased population creates continuous pressure on coastal zones. Many estuaries are subjected to over exploitation and destruction since industrial revolution. Human activities directly modify the river ecosystems by drawing water from water bodies for irrigation, industry and population, dredging, filling and pollution of rivers and lakes from point and diffusion sources and so on. Nutrients that include many chemicals used as fertilizers in agriculture as well as waste from livestock and humans are dumped into the estuaries by land runoff. All these activities also alter the hydrographic parameters such as salinity intrusion, tidal forcing and current speed, sedimentation, freshwater out flow and residence time of an aquatic ecosystem.

Estuaries provide multiple functions, significant to social, economic and environmental values. Over the years the availability of domestic and industrial wastes, urban discharges and agricultural effluents increase the nutrient concentration by many times to the levels that occur naturally causing several environmental modifications in estuarine and coastal waters. Many estuaries are subjected to overexploitation and destruction since industrial revolution. Sustaining good water quality condition is important not only for ecosystem health, but also for providing service and health to people.

Over the years, the ecobiological status of the Vembanad wetland has under gone grave modifications mainly due to excessive anthropogenic interventions; particularly pollution from various sources includes tourism development, reduction and shrinkage of the water body, habitat change, depletion, extinction of bio resources affecting the livelihood condition. Several of the changes have been taken place on the hydrology and environmental quality in the estuary. There has been lot of alterations in the upland areas of Vembanad, on account of the various projects as well as the increased use of water for a wide array of activities. There are also *in-situ* changes in the Vembanad area on account of various interventions. The implementation of various developmental projects has led to the loss of productive estuaries along the Kerala coast mainly affecting its life sustainability. Such demographic impacts have altered the ecology and biotic production of several coastal estuarine systems on the southwest coast of India (Bijoy Nandan, 2008). The basic feature of an estuary is the instability that is acting as the main driving force for healthy estuarine dynamics. The estuarine dynamics depend upon the physical and chemical characteristics that bring spatial and temporal changes in hydrographic conditions. In the present study, an assessment has been attempted to evaluate the effects of Kerala floods 2018 on the water quality parameters of Vembanad wetland system.

4.2 Results

4.2.1 Physical characteristics

The physical characteristics of surface and bottom water like depth, temperature, transparency and salinity were determined in the study area and its spatial and temporal variations are explained.

4.2.1.1 Depth

The average depth in the study area during flood was 3.29 ± 1.78 m. The lowest depth recorded was 0.7 m at St.7 and highest depth of 8 m recorded at St.5 (Fig. 4.1). During post flood, the depth ranged between 1 to 8 m (av. 3.26 ± 1.66 m). St.1 recorded with the highest depth and lowest depth observed in St.7. During the study period, most of the stations showed a shallow nature, particularly the stations south of TMB. The average depth decreased during post flood period compared to flood period.

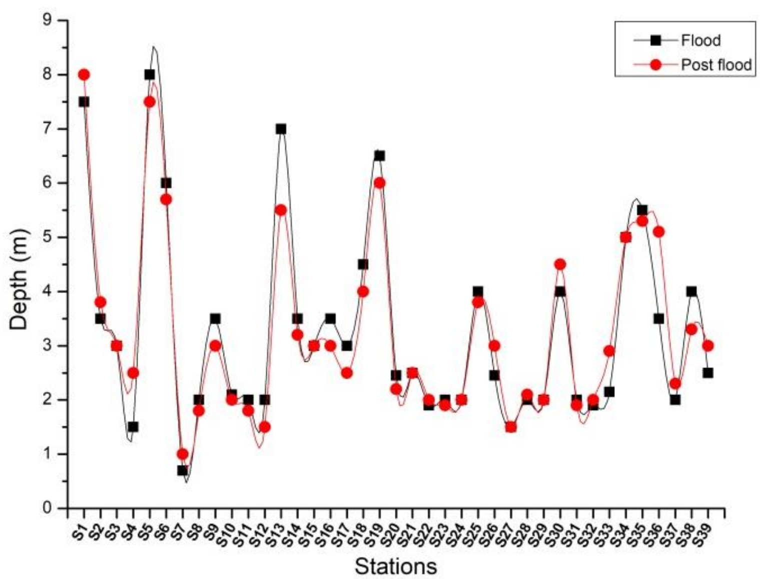

Fig. 4.1 Spatial variation of water depth (m) in Vembanad wetland during flood & post flood, 2018

4.2.1.2 Transparency

During flood, the maximum transparency of 1 m was observed in St.26, St.28, St.29 and St.30 whereas the minimum value of 0.3 m was observed in St.31 and St.38. Station 15 was also recorded with a lowest value of 0.4 m (Fig. 4.2). The transparency values showed a uniform distribution in most of the stations. The average transparency of the water column was 0.65 ± 0.19 m during flood period. The transparency values during post flood were ranged between 0.2 to 1 m (av. 0.56 ± 0.16 m). The maximum value recorded at St.29 and minimum value at St.34. Comparatively lower value (0.4 m) was recorded in St 2 and 8. The average transparency was found to be decreased during post flood period.

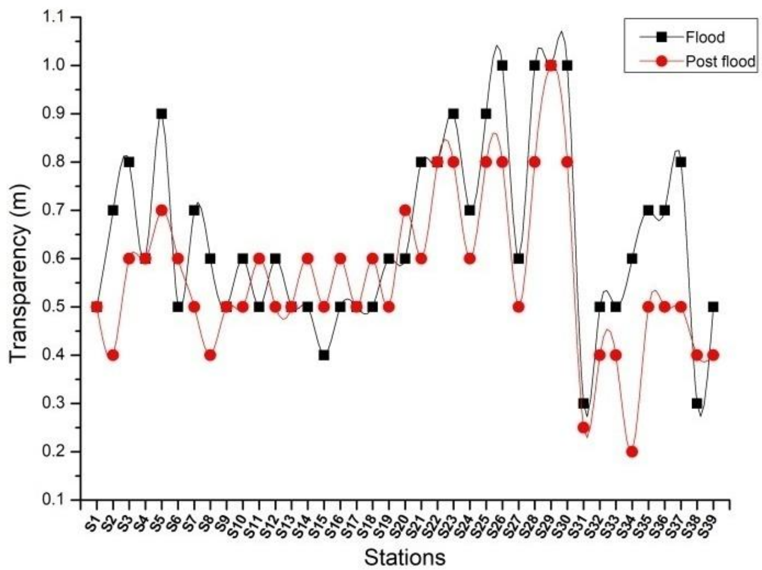

Fig. 4.2 Spatial variation of water transparency (m) in Vembanad wetland during flood & post flood, 2018

4.2.1.3 Temperature

During flood, the surface water temperature ranged between 28 to 32 °C (av. 30.03 ± 0.71 °C). The lowest temperature of 28 °C was observed at St.39 and highest value of 32 °C was recorded at St.38. Stations 10, 11, 12, 13 and 15 were also recorded with comparatively lower temperature (29 °C) (Fig. 4.3). In bottom water, the values ranged between 28 to 30 °C (av. 29.46 ± 0.72 °C). In most of the stations, temperature showed a uniform distribution. Comparing the average surface and bottom water temperature, surface water showed the higher value.

However, during post flood, the surface water temperature ranged between 29 to 31 °C (av. 30.13 ± 0.57 °C). The highest value was recorded at stations 4, 7, 11, 13, 15, 23, 27, 28 and 32 whereas the lowest value recorded at St.1 and St.16. In bottom water, the values ranged between 28 to 31 °C (av. 29.85 ± 0.63 °C). The highest value recorded at St.5, St.15, St.25 and St.32 whereas the lowest value recorded at St.17. The average temperature was maximum during post flood period compared to the flood period. Surface water showed comparatively higher temperature than bottom water.

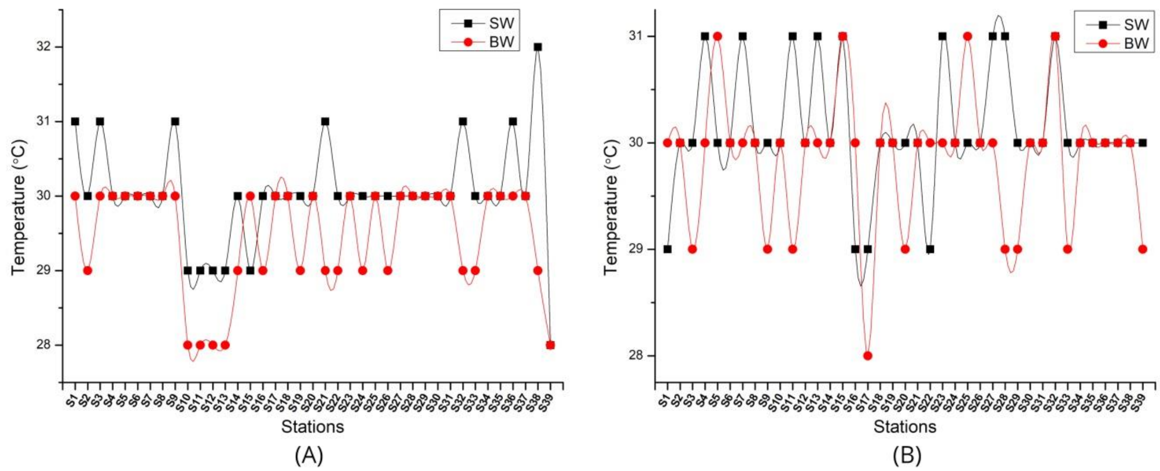

Fig. 4.3 Spatial variation of surface and bottom water temperature (°C) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.1.4 Salinity

During flood, the salinity of surface water ranged between 0 to 31 ppt (av. 1.28 ± 5.42 ppt) and bottom water values ranged between 0 to 35 ppt (av. 1.62 ± 6.32 ppt). Station 39 recorded with the maximum value for both surface and bottom water (Fig. 4.4). Whereas, stations 1 to 30 and stations 33 to 38 were recorded with zero. During flood period most of the stations exhibited a purely limnetic condition. The average salinity value of bottom water was high as compared to the surface water.

During post flood, the salinity values ranged between 0 to 30 ppt (av. 5.64 ± 9.94 ppt) in surface water and the highest value was observed at St.39. In bottom water, the values ranged between 0 to 31 ppt (av. 6.18 ± 10.83 ppt). Like surface water, St.39 showed the highest value. Stations 3 to 30 were recorded with zero during post flood period. Compared to the flood period, the salinity showed a slightly increasing trend during post flood. The bottom water showed higher salinity compared to surface water.

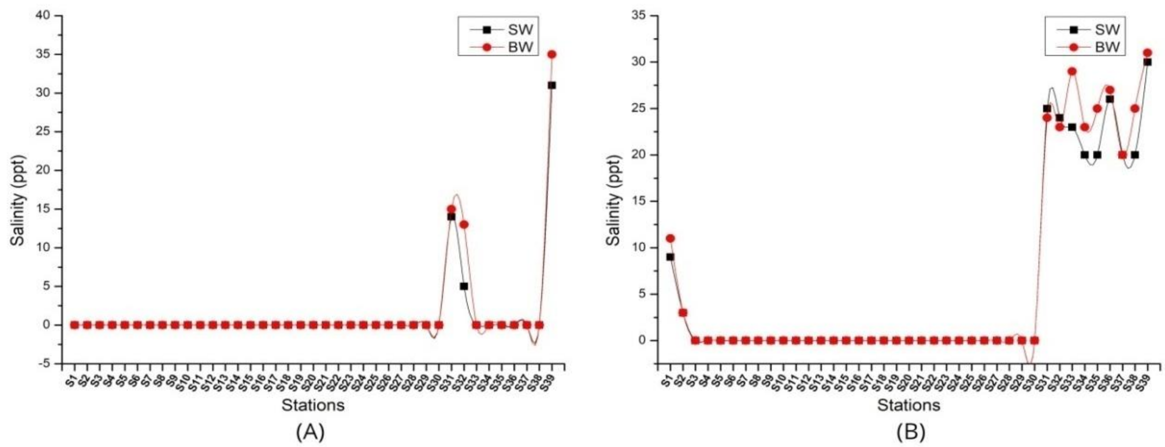

Fig. 4.4 Spatial variation of surface and bottom water salinity (ppt) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.2 Chemical characteristics

The chemical characteristics of surface and bottom water in the study area were determined. pH, alkalinity, dissolved oxygen, biological oxygen demand, hydrogen sulphide and inorganic nutrients were determined.

4.2.2.1 pH

During flood, the average pH of surface water was found to be 5.96 ± 0.79 and it ranged between 4.8 to 8.67. The maximum value was observed at St.34 and minimum value observed at St.12. In bottom water, the values varied from 4.35 to 8.05 (av. 5.99 ± 0.79). Like surface water, St.12 showed the lowest value and St.32 showed the highest value. pH values showed wide variation in most of the stations, particularly stations south of TMB (Fig. 4.5). During flood, the average pH of bottom water was high when compared to the surface water.

During post flood, the surface water pH varied from a lower value of 4.92 observed at station 13 and a higher value of 7.68 observed at station 31 with an average value of 6.17 ± 0.84. In bottom water, the values ranged between 6.02 to 7.63 with an average value of 6.69 ± 0.52. Station 32 recorded with the highest value and St.22 recorded with the lowest value. The pH value of most of the stations increased during post flood period compared to that of flood period. Bottom water recorded with the highest pH compared to surface water.

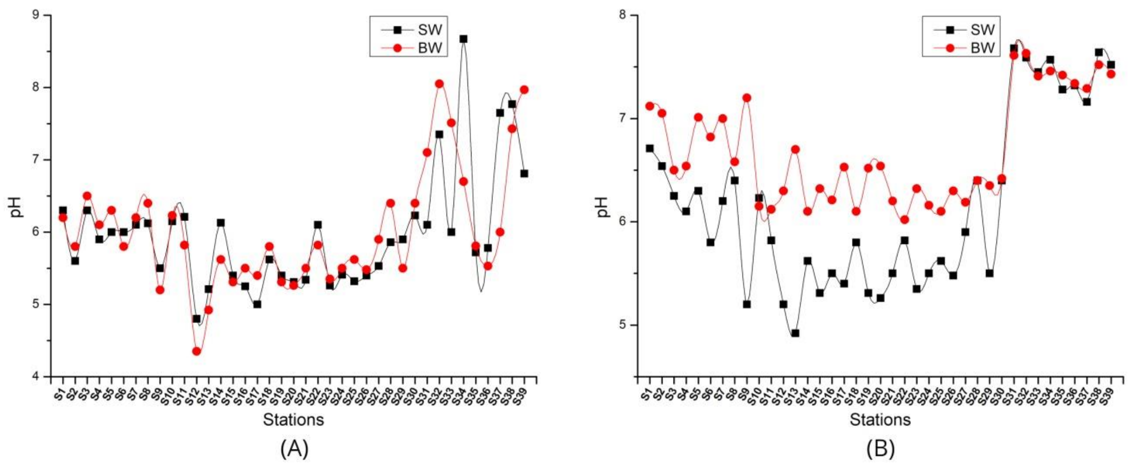

Fig. 4.5 Spatial variation of surface and bottom water pH in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.2.2 Alkalinity

During flood, the alkalinity of surface water ranged between 15 to 55 mg L^{-1} (av. 22.44 ± 6.97 mg L^{-1}). The maximum value was recorded at St.39 and minimum value at St.3, St.4, St.21 and St.37 (Fig. 4.6). The bottom water alkalinity values ranged between 15 to 100 mg L^{-1} (av. 23.85 ± 13.59 mg L^{-1}). Like surface water St.39 recorded with the highest value, whereas the lowest value observed at St.1, St.20, St.21, St.34, St.36 and St.37. Alkalinity values showed a uniform distribution in most of the stations. During flood, bottom water showed comparatively higher value than the surface water.

During post flood, the surface water alkalinity varied from a lower value of 20 mg L^{-1} observed at stations 16, 25 and 28 and a higher value of 95 mg L^{-1} observed at St.1 with an average value of 31.15 ± 13.69 mg L^{-1}. In bottom water, the alkalinity values ranged between 20 to 75 mg L^{-1} (av. 29.49 ± 9.72 mg L^{-1}). The maximum value was recorded at St.1 and minimum value observed at St.6, 10, 17 and 21. Alkalinity values were higher during post flood period compared to that of flood period. Surface water showed higher alkalinity compared to bottom water during post flood.

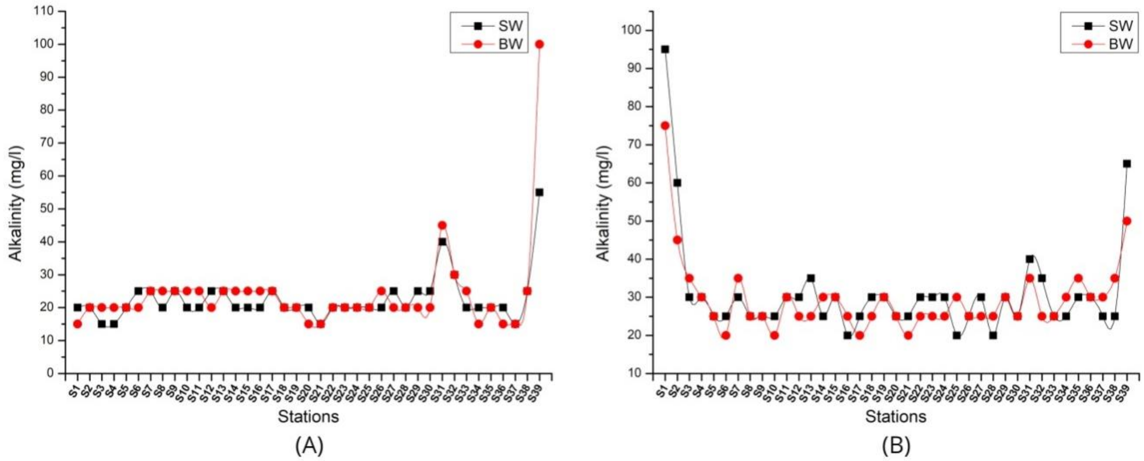

Fig. 4.6 Spatial variation of surface and bottom water alkalinity (mg L^{-1}) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.2.3 Dissolved oxygen

During flood, the DO values in surface water ranged between 4.7 to 10.2 mg L^{-1} (av. 7.26 ± 1.22 mg L^{-1}). The lowest value recorded at St.16 and St.39 whereas the highest value observed at St.8. In bottom water, the DO varied from a lower value of 3.15 mg L^{-1} observed at station 8 and a higher value of 10.23 mg L^{-1} recorded at station 2 with an average value of 7.33 ± 1.38 mg L^{-1} (Fig. 4.7). The DO showed higher values in most of the stations during flood period. Bottom water showed comparatively higher DO value than the surface water.

During post flood, the surface water DO varied from a lower value of 3.1 mg L^{-1} recorded at St.31 and a higher value of 10.6 mg L^{-1} observed at St.37 with an average value of 6.56 ± 1.80 mg L^{-1}. The bottom water DO values ranged between 3.07 to 10.47 mg L^{-1} (av. 7.11 ± 1.52 mg L^{-1}). Similar to the surface water the maximum value observed at St.37 and minimum value observed at St.31. The average DO concentration observed during post flood was lower as compared to the flood period. The bottom water showed maximum value during post flood.

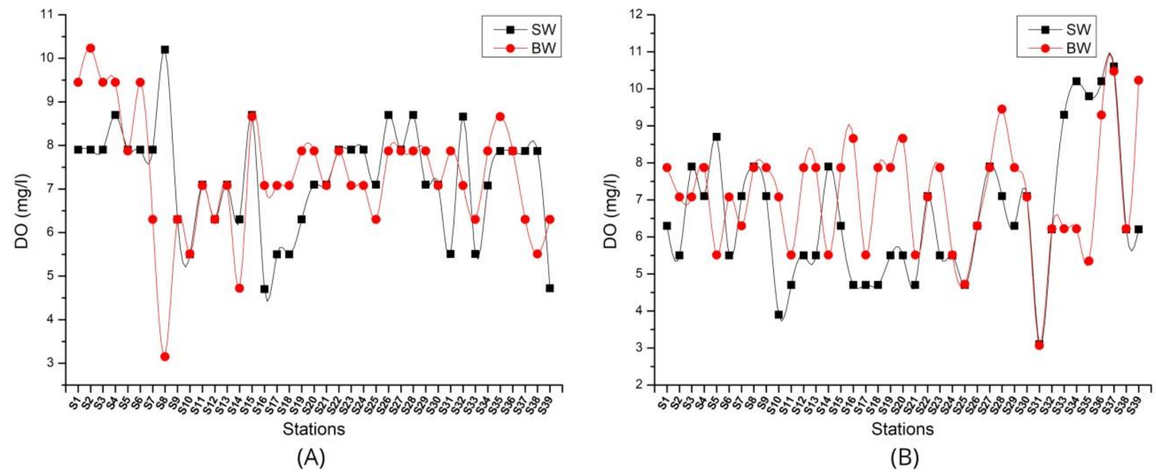

Fig. 4.7 Spatial variation of surface and bottom water DO (mg L^{-1}) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.2.4 Biological oxygen demand (BOD)

During flood, the BOD in surface water varied from a lower value of 0.79 mg L^{-1} (St.17) to a higher value of 6.3 mg L^{-1} (St.8 and St.15) with an average value of 3.71 ± 1.42 mg L^{-1}. In bottom water, the values ranged between 0.79 to 6.3 mg L^{-1} (av. 3.69 ± 1.33 mg L^{-1}). Station 15 showed the maximum value whereas St.8 and St.14 showed the minimum value (Fig. 4.8). During flood, most of the stations were recorded with comparatively higher BOD values. The surface water showed comparatively higher BOD value than the bottom water.

During post flood, the surface water BOD values ranged between 0.79 to 5.51 mg L^{-1} (av. 2.79 ± 1.02 mg L^{-1}). The highest value was observed at St.14 and lowest value at St.10. In bottom water, the BOD varied from a minimum value of 1.5 mg L^{-1} (St.33) to a maximum value of 5.51 mg L^{-1} (St.28) with an average value of 3.12 ± 1.01 mg L^{-1}. BOD showed maximum value during flood period compared to the post flood period. Bottom water showed higher BOD value during post flood.

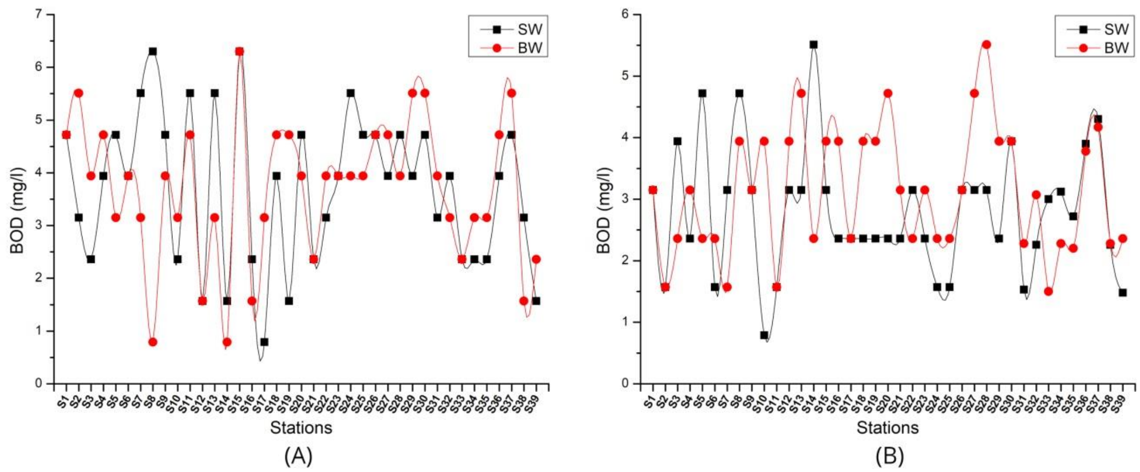

Fig. 4.8 Spatial variation of surface and bottom water BOD (mg L^{-1}) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.2.5 Hydrogen sulphide (H_2S)

During flood, the average hydrogen sulphide concentration in surface water was found to be 1.05 ± 1.49 µmol L^{-1} and it ranged between 0.05 to 7.93 µmol L^{-1}. The maximum value was observed at St.12 and minimum value at St.2, St.3, St.9, St.22 and St.39 (Fig. 4.9). In bottom water, the values ranged between 0.05 to 3.71 µmol L^{-1} (av. 0.78 ± 0.91 µmol L^{-1}) while St. 37 recorded the highest value. Like surface water St.12 was also showed comparatively higher concentration. During flood period, surface water showed higher value.

During post flood, the surface water H_2S varied from a lower value of 0.05 µmol L^{-1} observed at St.28 and a higher value of 9.62 µmol L^{-1} at St.13 (av. 2.88 ± 2.60 µmol L^{-1}). In bottom water, the values ranged between 0.05 to 8.49 µmol L^{-1} (av. 2.39 ± 1.70 µmol L^{-1}). Station 9 recorded with the maximum value and the minimum value observed at St.15. During the study period, the southernmost stations (stations south of TMB) recorded the higher H_2S concentration. The average H_2S concentration was higher during post flood compared to the flood. Like flood period, surface water showed higher H_2S concentration than bottom water.

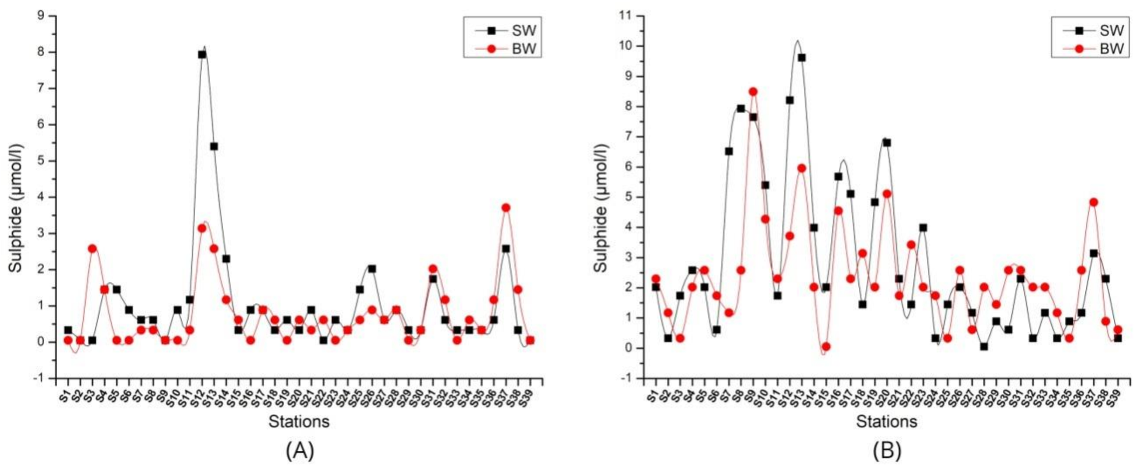

Fig. 4.9 Spatial variation of surface and bottom water hydrogen sulphide (µmol L^{-1}) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.3 Inorganic Nutrients

4.2.3.1 Phosphate-Phosphorus

During flood, the phosphate-phosphorus concentration in surface water ranged between 3.28 to 27.55 µmol L^{-1} (av. 10.44 ± 6.36 µmol L^{-1}). Station 39 showed the highest value and St.6 showed the lowest value (Fig. 4.10). The average bottom water concentration was found to be 5.58 ± 3.17 µmol L^{-1} and it ranged between 3.28 to 15.35 µmol L^{-1}. The maximum value was observed at St.37 and minimum value at St.3, St.27 and St.29. Surface water showed higher phosphate concentration than bottom water.

During post flood, the surface water PO_4-P concentration varied from a lower value of 0.89 µmol L^{-1} recorded at St.37 and a higher value of 23.06 µmol L^{-1} observed at St.1 with an average value of 7.41 ± 4.94 µmol L^{-1}. In bottom water, the values ranged between 2.96 to 20.94 µmol L^{-1} (av. 7.67 ± 4.22 µmol L^{-1}). The highest value was observed at St.31 and lowest value at St.37. Like surface water St.1 showed comparatively higher value (14.07 µmol L^{-1}). The average PO_4-P displayed higher concentration during flood than post flood period. The bottom water showed higher concentration than surface water.

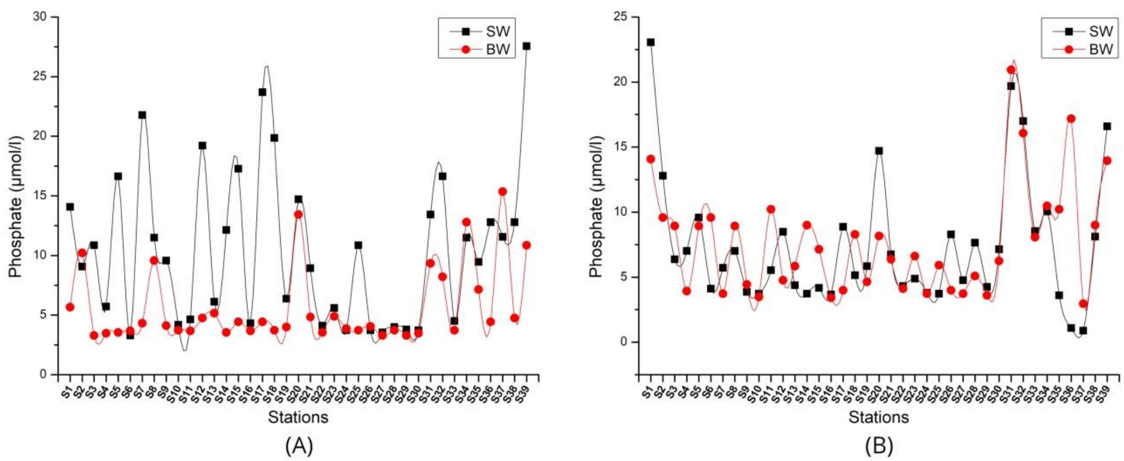

Fig. 4.10 Spatial variation of surface and bottom water phosphate (µmol L^{-1}) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.3.2 Silicate-Silicon

During flood, the SiO_4-Si concentration in surface water ranged between 20.75 to 158.13 µmol L^{-1} (av. 59.83 ± 34.96 µmol L^{-1}). Highest value was recorded at St.15 and lowest value at St.31. In bottom water, the values ranged between 13.27 to 124.04 µmol L^{-1} (av. 59.15 ± 29.55 µmol L^{-1}). Station 15 showed the maximum value whereas the minimum value observed at St.2 (Fig. 4.11). Most of the stations were recorded with higher SiO_4-Si values during flood period. The surface water showed slightly higher silicate concentration than bottom water.

During post flood, the average SiO_4-Si in surface water was found to be 28.76 ± 15.32 µmol L^{-1} and it ranged between 0.72 to 63.45 µmol L^{-1}. The highest value observed at St.17 and lowest value at St.37. In bottom water, the SiO_4-Si varied from a lower value of 2.98 µmol L^{-1} (St.37) to a higher value of 35.05 µmol L^{-1} (St.19) with an average value of 22.12 ± 7.82 µmol L^{-1}. In the present study, SiO_4-Si showed maximum concentration during flood compared to the post flood. The surface water showed higher silicate concentration than bottom water.

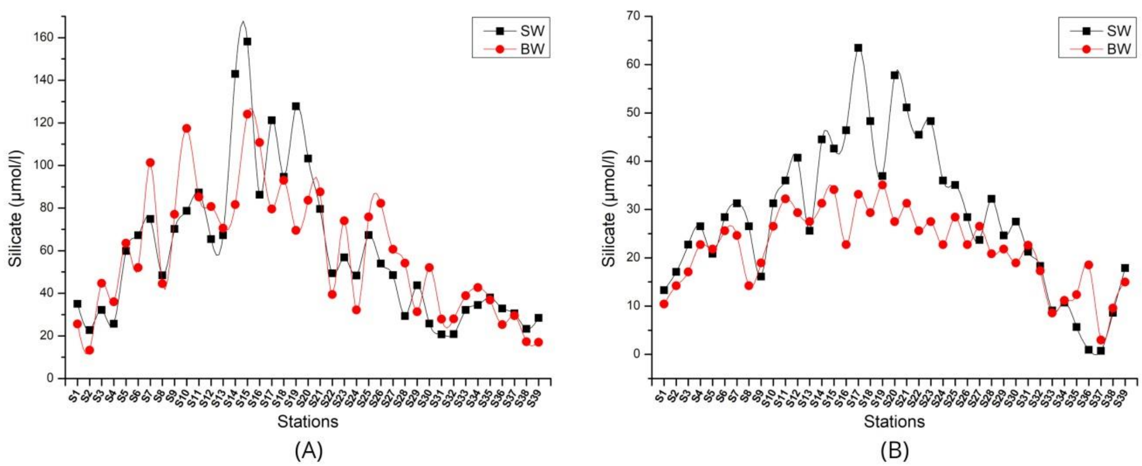

Fig. 4.11 Spatial variation of surface and bottom water silicate (µmol L^{-1}) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.3.3 Ammonia-Nitrogen

During flood, the concentration of NH_4-N in surface water ranged between 0.03 to 18.11 µmol L^{-1} and the estimated average concentration was found to be 3.12 ± 3.82 µmol L^{-1}. The maximum concentration was observed at St.37 and minimum concentration at St.30 (Fig. 4.12). The bottom water NH_4-N varied from a lower value of 0.25 µmol L^{-1} (St.6) to a higher value of 12.7 µmol L^{-1} (St.37) with an average value of 3.40 ± 3.39 µmol L^{-1}. The average bottom water ammonia concentration was higher compared to the surface water.

During post flood, the average NH_4-N concentration in surface water was found to be 8.80 ± 6.80 µmol L^{-1} and it ranged between 0.83 to 33.86 µmol L^{-1}. Station 37 recorded the highest value and St.25 showed the lowest value. The stations south of TMB were also recorded with higher values during post flood period, among this St.10 - Nehru trophy finishing point (22.13 µmol L^{-1}) and St.12 - Punnamada (20.68 µmol L^{-1}) showed the higher concentration. In bottom water, the values ranged between 1.9 to 28.91 µmol L^{-1} (av. 9.44 ± 5.88 µmol L^{-1}). Like surface water, the maximum value was recorded at St.37 whereas the minimum value at St.17. The NH_4-N showed an increasing trend from flood to post flood period. Bottom water showed higher concentration compared to surface water.

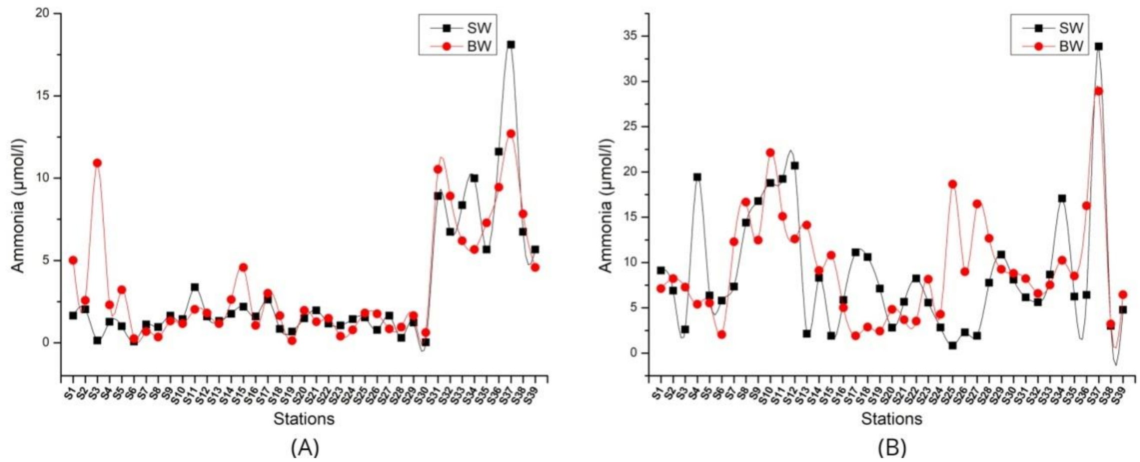

Fig. 4.12 Spatial variation of surface and bottom water ammonia (µmol L^{-1}) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.3.4 Nitrite-Nitrogen

During flood period, the NO_2-N concentration in surface varied from a lower value of 0.65 µmol L^{-1} (St.16) to a higher value of 1.58 µmol L^{-1} (St.31) with an average value of 0.92 ± 0.24 µmol L^{-1} (Fig. 4.13). The average concentration of NO_2-N in bottom water was found to be 0.78 ± 0.11 µmol L^{-1} and it varied from a lower value of 0.65 µmol L^{-1} (St.2, St.5, St.18 and St.30) to a higher value of 1.06 µmol L^{-1} (St.33). The surface water showed higher nitrite concentration than bottom water.

During post flood, the nitrite concentration in surface water ranged between 0.15 to 3.36 µmol L^{-1} (av. 1.18 ± 0.85 µmol L^{-1}). The maximum value was observed at St.1 and minimum at St.38. The concentration of NO_2-N in bottom water ranged between 0.11 to 2.9 µmol L^{-1} and the estimated average concentration was found to be 0.84 ± 0.57 µmol L^{-1}. Station 2 showed the highest value whereas St.38 showed the lowest value. The average surface water nitrite concentration was higher compared to the bottom water.

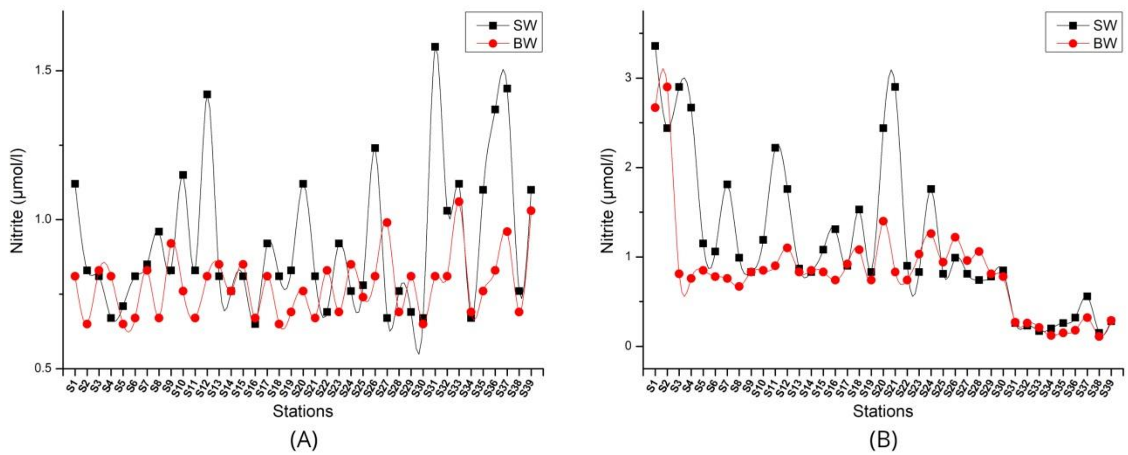

Fig. 4.13 Spatial variation of surface and bottom water nitrite (µmol L^{-1}) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.3.5 Nitrate-Nitrogen

During flood, the average NO_3-N concentration in surface water was found to be 2.91 ± 2.18 µmol L^{-1} and it ranged between 1.29 to 9.22 µmol L^{-1}. The maximum value observed at St.37 and minimum at St.6 and St.29. (Fig. 4.14). In bottom water, the values ranged between 1.29 to 14.98 µmol L^{-1} (av. 2.53 ± 2.47 µmol L^{-1}). The highest value recorded at St.39 and lowest at St.18 and St.30. The surface water showed higher concentration than bottom water.

During post flood period, the nitrate concentration in surface water varied from a lower value of 1.33 µmol L^{-1} (St.5 and St.17) to a higher value of 33.14 µmol L^{-1} (St.39) with an average value of 3.93 ± 5.46 µmol L^{-1}. Like flood period, St.1 displayed comparatively higher value (9.22 µmol L^{-1}). The bottom water values ranged between 1.29 to 21.18 µmol L^{-1} (av. 3.67 ± 3.86 µmol L^{-1}). Station 39 showed the highest value and lowest value observed at St.6 and St.14. The NO_3-N showed maximum concentration during post flood as compared to the flood. Like in flood period, the NO_3-N showed higher concentration in surface water than bottom water.

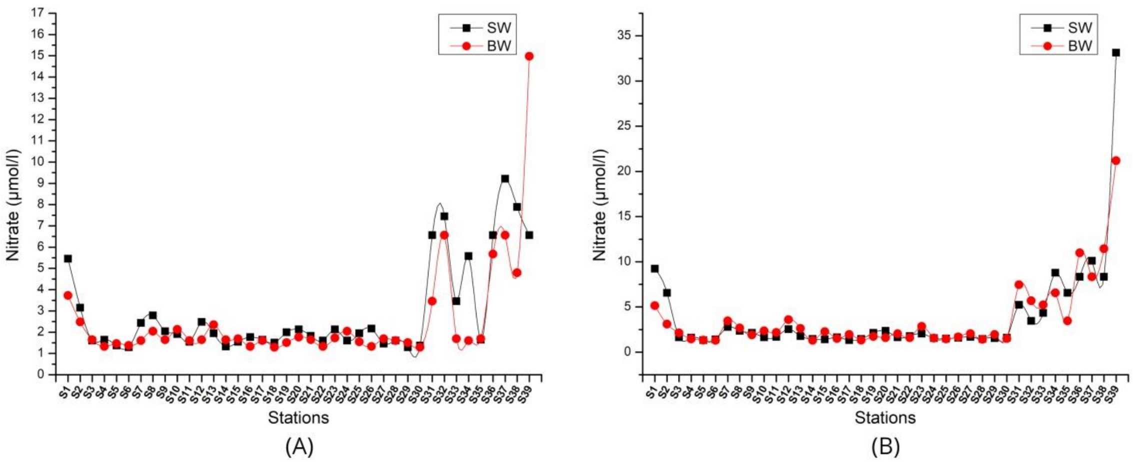

Fig. 4.14 Spatial variation of surface and bottom water nitrate (µmol L^{-1}) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.4 Primary productivity

During flood, the surface water gross primary productivity (GPP) ranged between 0.74 to 3.69 g C m^{-3} day^{-1} (av. 1.70 ± 0.81 g C m^{-3} day^{-1}). Station 8 showed the highest value of 3.69 g C m^{-3} day^{-1} whereas the lowest value of 0.74 g C m^{-3} day^{-1} was recorded at St.5, St.6, St.13, St.14, St.18, St.20, St.21, St.29, St.31, St.33 and St.37 (Fig. 4.15). In bottom water, the GPP values ranged between 0.74 to 4.43 g C m^{-3} day^{-1} (av. 1.61 ± 0.88 g C m^{-3} day^{-1}). The highest value was observed at St.2 whereas the lowest value of 0.74 g C m^{-3} day^{-1} recorded in most of the stations. The net primary productivity (NPP) in surface water varied from 0.74 to 2.21 g C m^{-3} day^{-1} (av. 1.10 ± 0.47 g C m^{-3} day^{-1}). Stations 10, 14 and 16 were recorded the highest value and most of the stations were recorded the lowest value of 0.74 g C m^{-3} day^{-1} (Fig. 4.16). The bottom water NPP values ranged between 0.74 to 5.17 g C m^{-3} day^{-1} (av. 1.08 ± 0.77 g C m^{-3} day^{-1}) and the maximum value was observed at St.8.

During post flood, the surface water GPP values ranged between 1.48 to 5.54 g C m^{-3} day^{-1} (av. 4.10 ± 1.00 g C m^{-3} day^{-1}). Station 35 was recorded the highest value and St.38 recorded the lowest value. In bottom water, the GPP values varied from 0.74 to 5.9 g C m^{-3} day^{-1} (av. 3.24 ± 1.26 g C m^{-3} day^{-1}). The maximum value was observed at St.39 whereas the minimum at St.17, St.21 and St.22. The NPP values in surface water varied from 0.74 to 5.17 g C m^{-3} day^{-1} (av. 2.02 ± 1.25 g C m^{-3} day^{-1}) and the highest value was observed at St.33. The average NPP in bottom water was found to be (av. 1.56 ± 1.01 g C m^{-3} day^{-1}) and it ranged between 0.07 to 4.5 g C m^{-3} day^{-1}. The highest value was observed at St.39 and the lowest at St.32. During the study period, GPP showed the highest value compared to NPP and the maximum productivity observed during post flood period. In the present study, surface water recorded with the maximum GPP and NPP compared to bottom water.

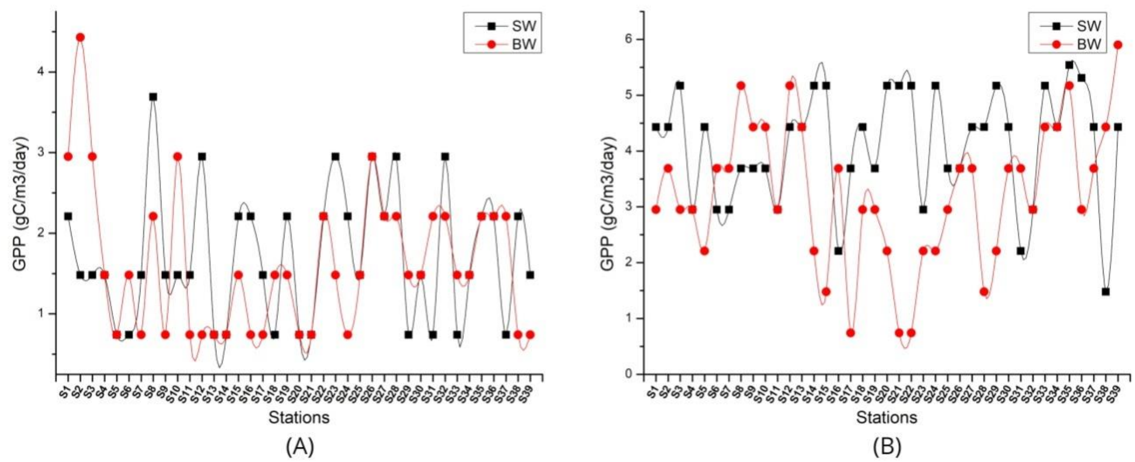

Fig. 4.15 Spatial variation of surface and bottom water GPP (g C m^{-3} day^{-1}) in Vembanad wetland during flood (A) & post flood (B), 2018

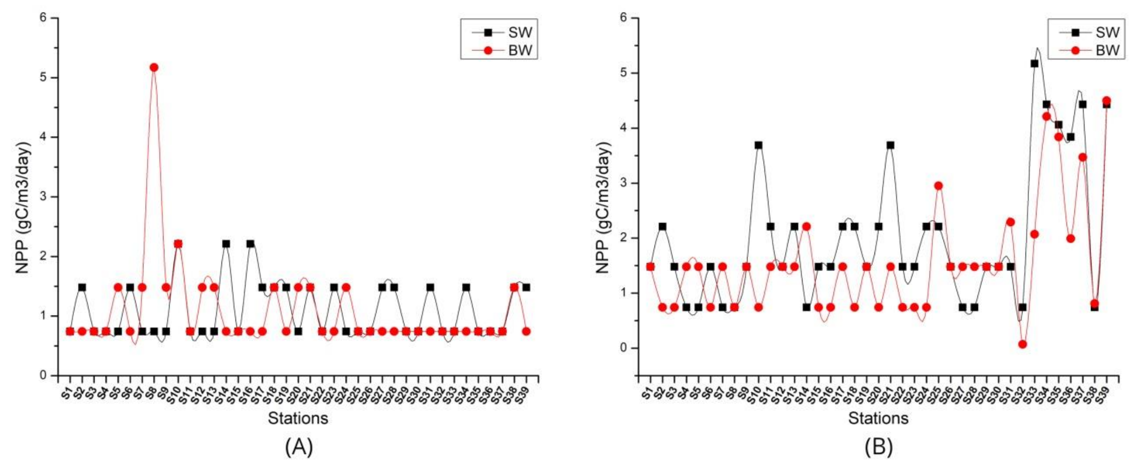

Fig. 4.16 Spatial variation of surface and bottom water NPP (g C m^{-3} day^{-1}) in Vembanad wetland during flood (A) & post flood (B), 2018

4.2.5 Distribution of heavy metals in water

The distribution of **copper** in water samples during flood ranged from BDL to 4.375 µg L^{-1} (Fig. 4.17). The highest value of copper was noted in station 20 and the lowest value was noted in all the stations except 6, 25, 26 and 30. During post flood, the Cu concentration ranged from 0.25 to 8.06 µg L^{-1} (Fig. 4.18). The highest value was found in station 39 and the lowest value in station 15. In the study Cu showed a positive correlation with water bound Fe (r = 0.173) [p<0.05], transparency (r = 304), BOD (r = 0.224), silicate (r = 280) and sediment bound Ni (r = 0.393) [p<0.01].

In the present study, the **nickel** and **cadmium** concentrations in all the stations were BDL during flood (Fig. 4.17). In the case of post flood, the concentration of Ni ranged from BDL to 9.06 µg L^{-1} (Fig. 4.18). The highest concentration was found in station 19. The Ni was found to be positively correlated with transparency (r = 0.173), silicate (r = 0.176) [p<0.05] and sediment bound Cu (r = 0.393) [p<0.01]. In case of Cd, the concentration ranged from BDL to 9.38 µg L^{-1}. The highest concentration was observed in station 32. Cd showed a positive correlation with salinity (r = 0.406), pH (r = 0.335), GPP (r = 0.294), NPP (r = 0.435), ammonia (r = 0.423), nitrate (r = 0.222), water bound Cd (r = 0.562), Zn (0.315), Fe (r = 0.225), sediment bound metals like Pb (r = 528) and Zn (r = 595) [p<0.01].

The concentration of **lead** during flood ranged from BDL to 9.38 µg L^{-1}. The maximum concentration was found in station 2 and 24 (Fig. 4.17). During post flood, the lead concentration ranged from BDL to 46.26 µg L^{-1} (Fig. 4.18). The maximum concentration was noted in station 19. In the study, the Pb was found positively correlated with DO (r = 0.197), salinity (r = 0.166), pH (r = 0.187), water bound Fe (r = 0.204) [p<0.05], NPP (r = 0.217), ammonia (r = 245), water bound metals like Cd (r = 0.576), Zn (r = 0.407) and Fe (r = 0.204) [p<0.01].

The concentration of **zinc** was maximum (145.63 µg L^{-1}) in station 26 and minimum (1.25 µg L^{-1}) in station 28 during flood (Fig. 4.17). During post flood, the Zn concentration ranged from 4.16 to 166.25 µg L^{-1} (Fig. 4.18). The high concentration was in station 39 and low in station 15. Zn showed a positive correlation with sediment bound DO (r = 0.185), nitrate (r = 0.166), Zn (r = 0.179) [p<0.05], salinity (r = 0.244), pH (r = 0.334), NPP (r = 0.296), ammonia (r = 0.417), water bound metals like Cd (r = 0.521) and Fe (r = 0.235), sediment bound metals like Cd (r = 0.595) and lead (r = 0.542) [p<0.01].

In the study during flood, maximum **iron** concentration of 918.75 µg L^{-1} was found in station 2 and a minimum concentration of 4.75 µg L^{-1} in station 28 (Fig. 4.17). During post flood, the concentration of Fe ranged from 103.44 to 2202.5 µg L^{-1} (Fig. 4.18). The high concentration was noted in station 34 and low concentration in station 2. In the study, Fe showed a positive correlation with transparency (r = 0.229) and water bound Fe (r = 0.268) [p<0.01].

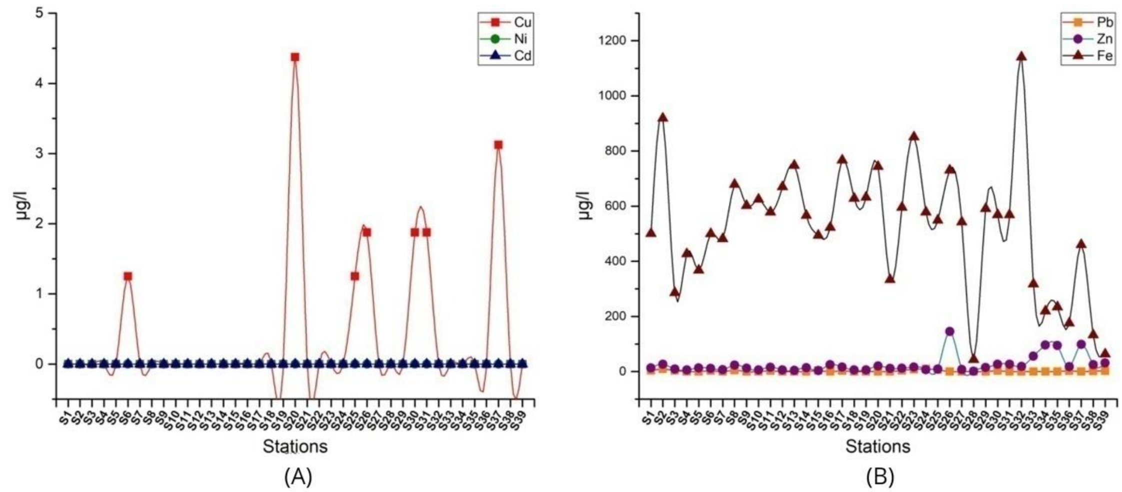

Fig. 4.17 Spatial variation of heavy metals in water samples (µg L^{-1}) in Vembanad wetland during flood, 2018

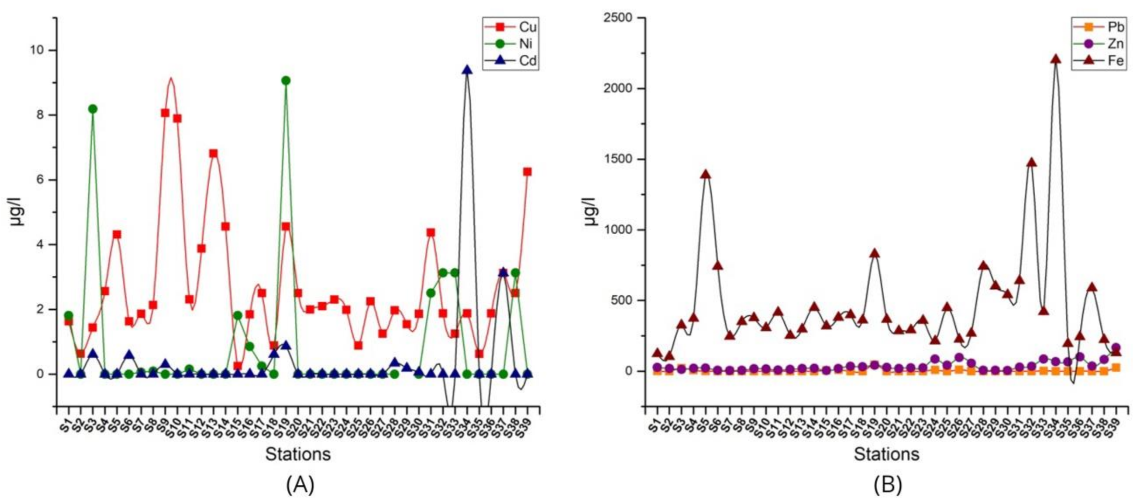

Fig. 4.18 Spatial variation of heavy metals in water samples (µg L^{-1}) in Vembanad wetland during post flood, 2018

4.2.6 Data analysis

4.2.6.1 Principal Component Analysis (PCA)

A multivariate correlation analysis (PCA) was carried out to determine the distribution and influence of various physico-chemical parameters in Vembanad wetland (Fig. 4.19). Principal component analysis (PCA) extracted two principal components (PCs) from the variance present in the data. The PCA was carried out with factors having eigenvectors higher than one. Factor loadings (correlations between the variables and the extracted factors) for the two retain Eigen values are given in Table 4.1. The first PC accounted for 21.8 % variability with an Eigen value of 6.1 and second PC accounted for 10.6 % variability with Eigen value of 2.98, whereas the remaining PCs each explained <10 % of the variation. The variables with highest loadings on PC1 were transparency, BOD and silicate. The second PC had higher loadings for alkalinity, nitrite, sulphide, water bound Cu, Ni and Pb.

Table 4.1 Results of PCA analysis of physico-chemical parameters in Vembanad wetland during flood and post flood period, 2018

	PC1	PC2	PC3	PC4	PC5
Eigen values	6.1	2.98	2.22	2.21	1.56
% Variation	21.8	10.6	7.9	7.9	5.6
Cum % Variation	21.8	32.4	40.3	48.2	53.8
Variable					
Depth	-0.037	-0.070	0.106	-0.069	-0.254
Temperature	0.002	-0.120	-0.091	-0.350	0.074
Transparency	0.240	-0.047	-0.159	-0.104	0.065
Salinity	-0.333	-0.062	0.234	-0.009	0.001
pH	-0.299	-0.079	0.140	-0.163	0.139
Alkalinity	-0.247	0.267	0.101	0.073	0.018
DO	0.024	-0.210	-0.096	-0.497	0.044
BOD	0.126	-0.185	-0.149	-0.410	-0.009

Sulphide	-0.091	0.133	-0.463	0.161	-0.018
Ammonia	-0.262	0.005	-0.308	0.019	0.178
Nitrate	-0.315	-0.039	0.205	-0.079	0.147
Nitrite	0.092	0.302	-0.193	0.094	0.165
Phosphate	-0.112	0.095	0.277	0.025	0.056
Silicate	0.321	0.069	0.143	0.161	-0.024
GPP	-0.217	0.075	-0.338	-0.058	-0.131
NPP	-0.205	-0.046	-0.046	0.264	-0.124
Cu (Water)	-0.202	0.110	-0.393	0.061	-0.188
Ni (Water)	-0.146	0.136	0.080	-0.074	-0.453
Cd (Water)	-0.160	-0.291	-0.125	0.055	-0.277
Pb (Water)	0.006	0.160	0.133	-0.207	-0.478
Zn (Water)	-0.229	-0.099	0.063	0.050	-0.062
Fe (Water)	0.095	-0.249	-0.035	0.086	-0.416
Cu (Sediment)	0.238	-0.212	-0.072	0.201	-0.054
Ni (Sediment)	0.127	-0.090	0.098	0.318	-0.074
Cd (Sediment)	-0.198	-0.332	-0.044	0.139	0.081
Pb (Sediment)	-0.007	-0.352	-0.120	0.134	0.093
Zn (Sediment)	-0.079	-0.396	0.084	0.177	0.129
Fe (Sediment)	0.083	-0.173	0.007	0.010	-0.156

(**PCA code-** DO-Dissolved oxygen; BOD-Biological oxygen demand; GPP-Gross primary productivity; NPP-Net primary productivity; Cu-Copper; Ni-Nickel; Cd-Cadmium; Pb-Lead; Zn-Zinc; Fe-Iron)

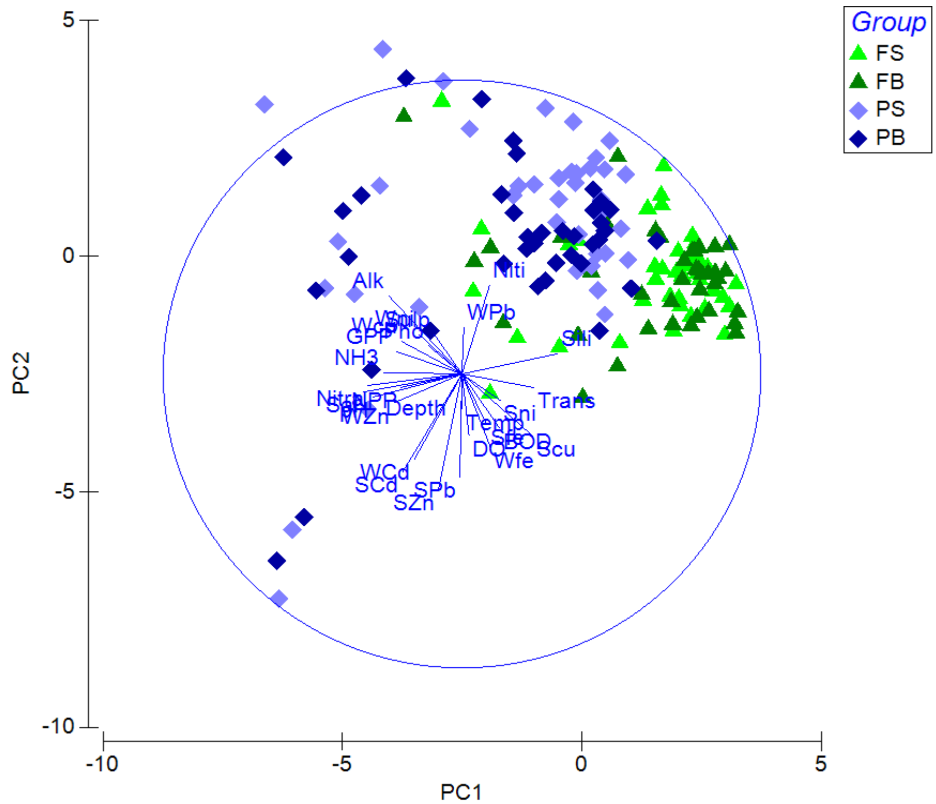

Fig. 4.19 PCA ordination of physico-chemical parameters in Vembanad wetland during flood and post flood period, 2018

4.2.6.2 Multiple regression analysis

Multiple regression analysis was carried out to determine the edaphic variables (independent variables) like rainfall and river discharge influencing the physico-chemical parameters in the study area during flood and post flood period.

4.2.6.2.1 Rainfall

Multiple regression analysis revealed that rainfall had significant influences on the factors like alkalinity and ammonia during the flood ($p<0.05$) (Table 4.2). But in case of post flood, it influenced transparency ($p<0.05$), temperature, salinity, NPP and water bound Pb and Fe ($p<0.01$).

Table 4.2 Multiple regression analysis of rainfall influencing the physico-chemical parameters in the Vembanad wetland during flood & post flood, 2018 (R^2 = 0.660)

Variables	Flood			Post flood		
	β	t	p value	β	t	p value
Temperature	-.095	-.784	.437	-2.532	-3.335	.002**
Transparency	.230	1.633	.109	13.784	2.636	.011*
Salinity	-.101	-.679	.500	-.506	-2.959	.005**
DO	.014	.046	.963	-.956	-1.619	.112
BOD	-.331	-1.922	.060	1.271	1.479	.146
Alkalinity	-.339	-2.258	.028*	-.091	-.874	.387
pH	.049	.155	.878	2.198	1.494	.142
GPP	.144	.705	.484	1.064	2.124	.039
NPP	.049	.325	.747	-1.794	-2.715	.009**
Ammonia	-.518	-3.473	.001*	.069	.582	.563
Phosphate	.049	.231	.819	.310	1.582	.121
Nitrite	.065	.434	.666	.485	.466	.644
Sulphide	-.172	-1.130	.264	.027	.076	.940
Nitrate	-.113	-.756	.453	-.496	-1.959	.056
Silicate	.130	.455	.651	-.082	-.968	.338
Cu in water	.110	.680	.500	-.471	-1.086	.283
Pb in water	-.026	-.162	.872	-2.085	3.011	.004**
Zn in water	.064	.476	.636	1.911	-1.576	.122
Fe in water	-.186	-.841	.404	.448	-3.184	.003**
Cu in sediment	.438	2.784	.008*	-.052	-1.679	.100
Ni in sediment	.147	.807	.423	-.008	.827	.412

Cd in sediment	-.205	-1.034	.306	-.047	-.588	.559
Pb in sediment	-.399	-1.671	.101	.021	.158	.875
Zn in sediment	.634	2.792	.007*	-.246	-.657	.515
Fe in sediment	.137	.724	.472	.003	.170	.866
Zooplankton	-.326	-2.045	.046*	-.003	-.427	.671
Phytoplankton	-.038	-.214	.832	8.526	2.063	.045*
Benthos	-.565	-2.330	.024*	-1.73	.104	.917

∗=statistically significant at 0.05 level of significance

∗∗=statistically significant at 0.01 level of significance

4.2.6.2.2 River discharge

Multiple regression analysis revealed that river discharge showed significant influences on the factors like alkalinity, nitrite, nitrate and water bound Zn and Fe during flood ($p<0.01$) (Table 4.3). But in the case of post flood, it influenced the sulphide ($p<0.01$).

Table 4.3 Multiple regression analysis of river discharge influencing the physico-chemical parameters in the Vembanad wetland during flood & post flood, 2018 (R^2 = 0.660)

Variables	Flood			Post flood		
	β	t	p value	β	t	p value
Temperature	99.11	.488	.63	145.49	.310	.758
Transparency	-276.49	-.330	.74	2425.365	.750	.457
Salinity	30.83	.586	.56	2.014	.019	.985
DO	-91.70	-.653	.52	257.506	.706	.484
BOD	-56.48	-.481	.63	-100.139	-.188	.851
Alkalinity	-55.80	-1.95	.05*	84.190	1.304	.199
pH	162.86	.613	.54	-532.734	-.585	.561
GPP	-.173	.000	.99	-283.742	-.916	.365
NPP	-281.79	-1.11	.27	-327.871	-.802	.427

Ammonia	-30.77	-.54	.59	-15.178	-.208	.836
Phosphate	4.05	.163	.87	-38.575	-.319	.751
Nitrite	-1565.42	-2.16	.04*	-820.136	-1.274	.209
Sulphide	-71.74	-.58	.57	-614.166	-2.781	.008**
Nitrate	422.12	3.95	.00**	-148.258	-.947	.349
Silicate	-3.61	-.74	.46	93.195	1.786	.081
Cu in water	-219.23	-1.28	.21	134.030	.499	.620
Pb in water	-4.73	-.09	.92	39.279	.427	.672
Zn in water	-20.04	-2.88	.006**	-15.982	-.779	.440
Fe in water	2.62	4.07	.00**	-1.719	-1.069	.291
Cu in sediment	-7.00	-2.16	.04*	-20.776	-1.207	.234
Ni in sediment	-26.23	-2.96	.005**	-3.542	-.223	.825
Cd in sediment	915.55	1.66	.102	-116.922	-.452	.654
Pb in sediment	9.68	3.65	.001**	-9.802	-.919	.363
Zn in sediment	1.44	1.65	.105	.295	.124	.902
Fe in sediment	-.018	-1.69	.098	-.078	-2.532	.015*
Zooplankton	.007	.44	.660	-.043	-1.707	.095
Phytoplankton	-8.14	-1.48	.146	-12.242	-.728	.470
Benthos	-.160	-.99	.328	-.266	-.461	.647

*=statistically significant at 0.05 level of significance

**=statistically significant at 0.01 level of significance

4.3 Discussion

Estuaries show strong spatial and temporal variation in their physical, chemical and biological characteristics. They are highly dynamic environments and this dynamism leads to a large variability in estuarine characteristics. In estuaries, during monsoon season, the amount of precipitation and land runoff naturally carry about the dynamic variation from a marine environment to a brackish water characteristic (Qasim and Sen Gupta, 1981). In an estuary the tidal mixing and estuarine circulation are vital factors controlling its hydrographic condition which in turn influence the nutrient dynamics and overall productivity of the system.

According to Suprit *et al*. (2012), the west coast of India experiences the heaviest rainfall in the Indian subcontinent due to the orography of the region. Also, due to the geographical peculiarities, the major share of the heavy summer-monsoon rainfall reaches the Arabian Sea through the rivers (Suprit *et al*., 2012). Rainfall intensity effects in the nutrient transport in surface runoff. During periods of heavy rainfall, increased runoff brings more nutrients into the estuary, as it carries terrestrial washouts along with the surface runoff. Seasonal alteration of river discharge induced by the monsoon, play an important role in the spatial and temporal variations in nutrients and other biotic components in estuarine waters. The increased freshwater discharges into the estuary during the rainy season and decreased discharges during the dry season presumably lead to increase in delivery of terrestrial materials into the estuarine region during MN and low terrestrial input during dry season.

The assessment of physico-chemical characteristics of water serves as a visible tool for investigation of water quality status and almost all observations bring out the seasonality in the environmental behaviour of Vembanad wetland system controlled by the monsoon induced fresh water flow. Vembanad-Kol wetlands receive freshwater inflows from nine drainage basins of which 60 % occurs during the Southwest monsoon (June to August), 30 % during Northeast monsoon (September to December) and the remaining in the summer months (WISA, 2013). Rivers such as Pamba, Manimala, Achankovil and Meenachil drain into the southern zone of Vembanad wetland and receive 57.9 % of the total river discharge, whereas Muvattupuzha River carries 42.1 % in the northern sector. In Cochin estuary, Revichandran *et al*. (2012) noted that, the annual total river discharge was 22×10^3 Mm^3/year from the seven rivers and from the total discharge value, around 60-70 % of received during MN season and the annual total discharges from river Periyar (6795 Mm^3) and Achankovil (1250 Mm^3) brought the maximum and minimum rate respectively.

According to MSSRF (2007), the monsoon propels flow towards the sea during the entire tidal cycle, except near to the barmouth, and then with the decrease in river discharge, flow reversal occurs resulting in reduced river discharge during PRM season in the estuary. The flow pattern in the estuary depends mainly on the tidal conditions. During MN season both tidal and river discharges play a great role in maintaining the flow pattern. According to Joseph (1989), the hydrographic characteristics of Vembanad backwater vary annually, particularly during July and August, the estuary behaves as a salt-wedge type. But, during PM months, it shows significant stratification and in PRM a well-mixed type estuarine condition evolves. Knowledge on tidal dynamics is important for analyzing many oceanographic processes in any location, especially in the coastal and estuarine sites, because tide is an important factor controlling the mixing, circulation and other processes in the sites (Srinivas *et al*., 2003). All the estuaries have specific tidal features that affect the mixing, circulation and hydrodynamic reaction of the system. In estuaries, tidal force is affected by factors such as friction, river runoff, nature of bathymetry and also the shape of the channel (Vinita *et al.*, 2015).

In the present study, the average **depth** of Vembanad wetland ranged from 3.29 ± 1.78 m during flood and 3.26 ± 1.66 m during post flood period. Extreme river discharge during the flood period might be contributed to massive sedimentation in the backwater and resulted in lowering the depth during the post flood period. Six major rivers i.e. Pamba, Manimala, Achankovil, Meenachil, (in the south), Periyar and Muvattupuzha (in the north) draining into Vembanad wetland with an average discharge of 29.568×10^3 Mm^3 (Asha *et al*., 2016). Besides this, four other rivers; Chalakudy, Keecheri, Puzhakkal and Karuvannur also drains into the northern part of the wetland. The total annual sediment yield from all rivers draining into the wetland system is estimated to be 32 million tonnes/year (Remani *et al.*, 2010). Chitrapuzha, a small stream also drains into the central part of the Vembanad wetland, which also contributed the sedimentation. The carrying capacity of backwater gets affected due to sedimentation from the river inflow gradually altering the bathymetry. The rapid shrinkage of flood carrying capacity of Vembanad wetland occurred by 78 % (i.e. from 2.4 km^3 to a mere 0.6 km^3) due to the reduction in the lake area and depth (Asha *et al*., 2016; MSSRF, 2007). According to their observation, the rapid decrease in area was mainly due to unrestricted encroachments and reclamation of lake area and raising lakebed due to silting. Until, 1980s paddy cultivation was responsible for the reclamation but the intensive tourism activities was accountable for the reclamation of wetland area now. In 1912, the area of backwater was 315 km^2 and shrunk to 180 km^2 (43 % of original) in 1983 (Gopalan *et al*., 1983). According to Asharaf (1998), of the 130 km^2 surveyed in 1998, nearly 14 % (18 km^2) has been observed to be reclaimed by both natural and artificial processes. The bathymetry of the water body indicates that depth variations occur between 1.5 m and 6.0 m in most parts except the dredged channels, which are 10-13 m deep. According to Gopalan *et al*. (1983), the 36,329 ha of open water area of Vembanad backwater existed before agriculture practice in Kuttanad, reduced to 12,700 ha (34.8 %). It further declined to 13,224 ha in 1992 and 12,504 ha in 2000 and its rate of decline has increased over the years. The annual rate of decline during the first phase (1834-1983) was 0.23 %, in the second phase (1983-1992), which increased to 4.93 % and to 0.68 % during the third phase (1992-2000). Remote Sensing and GIS analysis of Vembanad estuary revealed that from 1944 to 2009, the estuarine area has declined to 12.96 % (15.11 km^2) (Dipson, 2012). The depth of the estuary is decreasing 1 % per year and its rate increased after the construction of Thanneermukkom barrage particularly the cofferdam situated in the middle of the estuary. According to Kerala Land Use Board (2005), the net area under water bodies of the Vembanad wetland and its associate river systems and channels has declined by 11.4 %. According to Bianchi (1992), the drastic reduction in depth alters the species assemblage inhabiting in it, as it often plays a crucial role in shaping species assemblage in tropical waters. Depth of Vembanad backwater reveals a declining trend from early 1900's onwards (Gopalan *et al*., 1983). Shallowness may reduce the drainage capacity of the estuary. Hence, shrinkage of carrying capacity of Vembanad wetland system plays a major role in worsening the flooding in the Kuttanad region and the backwater flows to the low-lying areas in the upper reaches of the wetland. This may be the reason for the heavy flooding experienced in the low-lying areas closer to the Vembanad wetland in the Alappuzha, Kottayam, Ernakulam, Thrissur and Pathanamthitta districts. The depth of the Vembanad backwater ranged between 1.45 to 9 m during previous study (Asha *et al*., 2016) whereas it ranged between 0.7 to 8 m during the flood period of the present study. Station 5 (Thanneermukkom south) was deeper compared to other stations in the southern part of the wetland system during the present study. Indiscriminate mining of lime shells and river sands are more in the southern zone, which causes severe damage to the lake system. From the river catchment of Vembanad wetland an average of 11.73 million ty^{-1} of sand and gravel were removed from the channel and 0.414 million ty^{-1} of sand removed from the river flood plains (Padmalal *et al*., 2008). Station 1 (Aroor) showed higher depth compared to other stations in the northern zone of the backwater, which could be attributed to periodic dredging, carried out at the mouth to maintain the port. This was similar to the previous studies conducted in the Vembanad wetland system (Asha *et al*., 2016; Cleetus *et al*., 2016). During flood period, northernmost station (stations in Cochin estuarine zone) such as station 32 (Bolgatty) was recorded with lower depth. River discharge mainly from Periyar, Muvattupuzha and Chalakudy might be contributed to heavy sedimentation in the northernmost stations of Vembanad wetland system. Most of the stations showed a shallow nature during the study period particularly during post flood. The siltation caused by heavy river discharge during flood and the tidal influx might have led to the decrease in the depth of the backwater during post flood. According to previous study reports, the geospatial analysis of Cochin estuary showed that the estuarine system is being inflicted with major geomorphic changes at several segments and also its reduction in area. Reduced depth of

Cochin estuary was observed by many authors (Thasneem *et al*., 2018). From 1967 to 2011 onwards, the shrinking rate of the system was estimated as 0.288 km^2/year. According to Dinesh Kumar *et al*. (2014), the quantitative comparison of inner island segments of the estuary shows significant changes in island widths and area through time.

Table 4.4 Reduction in depth range in different locations of Vembanad wetland system over the years

Location	Depth range (m)				
	Source: (Gopalan *et al*., 1983)		Asha *et al*., 2016	KSPCB report, 2019	Present study
	Year 1920	Year 1980			
South of Thanneermukkom	8 - 9	3 - 3.5	1.6 - 4.5	0-9 - 7	0.7 - 8
Between TMB north to Varanad	8 - 9	3 - 4	2.5 - 7	1.5 - 6	1.5 - 3
Between Varanad to Perumbalam	7 - 9	4 - 5	1.5 - 4.3	1.5 - 4	3 - 3.5
Aroor region	7- 8	7- 8	6.0 - 8.5	6 - 8	7.5 - 8

In estuaries, the **transparency** is mainly influenced by spatial, temporal and climatic variations together with tidal flow (Meera and Bijoy Nandan, 2010). In addition, various physical factors such as wind, turbidity and biological factors such as plankton blooms are also influencing the transparency. In the present study, the average transparency in Vembanad wetland system decreased during post flood compared to that of flood period. The increased river discharge accompanied with the extreme rainfall during the flood carry higher amount of suspended sediment in Vembanad backwater and this could be the reason for lower transparency in most of the stations. Lower transparency observed during post flood period could be attributed to the post flood sedimentation and increased turbidity. According to Qasim *et al*. (1968), monsoon associated heavy river runoff brings suspended sediments which reduces the transparency of the water column having implications on the phytoplankton composition and physiology. Apart from this, the extensive runoff from the land followed by the intense monsoonal rainfall during flood may result in the turbid water leads to lower transparency in the study area. Lower transparency values due to land runoff and increased turbidity during the active monsoon months was reported by Meera and Bijoy Nandan, 2010. The reduction in the values during the monsoon period was due to the decrease in solar radiation and the increase in river runoff (Bijoy Nandan *et al*., 2014; Jayachandran *et al*., 2012; Patil and Anil, 2011; Gouda and Panigrahy, 1993). According to Renjith *et al*. (2013), heavy rainfall and intense cloud cover prevailing in the monsoon season reduces solar insolation and the high input of suspended sediments makes the estuary more turbid. The annual variation of transparency is directly related to rainfall and river discharge. The maximum transparency in several estuaries was recorded during the pre-monsoon period (Gopinathan and Qasim, 1971; Qasim *et al*., 1968). Transparency values were similar in most of the stations during the present study. Higher similarities among aquatic habitats during floods than during non-flood periods were found in several floodplains (Thomaz *et al*., 2007). In its simplest form, this homogeneity was first defined as the presence of a high physical, chemical or biological similarity between the main river and the backwaters of its floodplain (e.g., Bozelli, 1992, in the Trombetas River floodplain; Hamilton and Lewis, 1990, in the Orinoco River floodplain; and Furch & Junk, 1985, in the Amazonian floodplain). Studies shows that the homogenization effect of floods operates at different spatial extents. For example, at the scale of whole water body, different sampling sites at the same lagoon tend to be more similar during periods of high water. At a broader spatial extent, different lagoons of a same floodplain and the lagoons of a floodplain and their main river (e.g., Orinoco, Parana, Amazon) tend to be more similar during high water periods. The transparency values showed a decreasing trend during the present study compared to previous studies in Vembanad wetland. As per the study report of KSPCB (2019), the maximum transparency value obtained during the monsoon period was 4 m (Pathiramanal) whereas in the present study the maximum value recorded was 1 m. Similarly, Asha *et al*. (2016) also reported maximum transparency value in Pathiramanal (1.3 ± 0.22 m). Further, during the present study Pathiramanal showed lower transparency (0.5 m during flood and 0.6 m during post flood) compared to pre flood period. Most of the stations showed minimum transparency when compared with the previous study results. The waste discharge from nearby houses, runoff from the land containing sewage and other industrial discharges may be reached the backwater during heavy flood and this might be another reason for lower transparency.

Temperature is a limiting factor in the aquatic environment. Water temperature is considered to be one of the most significant environmental variables. It affects aquatic organism's development, metabolic activities, feeding, reproduction, distribution and migratory behaviour. It controls solubility of gasses and salts in water. Gas solubility decreases with increased temperature. Increased tourism activities and decomposition of faecal matters may increase faecal contamination in the lake water which in turn increases the water temperature. Temperature is affected by time of the day; high temperatures may be recorded in daytime and become low at night. Temperature may cause thermal stratification occurs in the oceans. As per the previous study conducted in Vembanad wetland, the maximum temperature of surface water recorded during monsoon period was 33 °C. It decreased to 31 °C during the flood period of the present study. The extreme rainfall during flood period may be the reason for lower temperature in the present study. The temperature values for the entire period of study reflect climatic variations to a certain extent and also due to different timing of collection (Pillai *et al*., 1975). Sankaranarayanan and Qasim (1969) reported that an important factor that reduces the water temperature in the estuary could be the influx of fresh water and influx of cold water from the sea in to the estuarine environment. During the present study period temperature values were similar in most of the stations. The water temperature showed clear variations between surface and bottom in most of the stations. It was higher in the surface water as compared to the bottom water except for some stations. During flood period the surface water showed lower temperature of 29 °C and that of bottom water showed 28 °C. This is mainly due to the heavy monsoonal rainfall during flood period and also the increased freshwater inflow from major rivers such as Pamba, Manimala, Achankovil and Meenachil may bring down the temperature. In the present study, the average temperature was slightly higher in post flood period compared to that of flood period. Temperature values in most of the stations showed a uniform distribution throughout the study period. When comparing the southern and northern zone of Vembanad wetland system, the reduction of temperature values in the southern zone was mainly due to the increased river discharge.

Salinity is a dynamic indicator of the nature of the exchange system. It describes the distribution of organisms in aquatic environments. The salinity of the water within the estuary tells us how much fresh water has mixed with sea water. As salinity increases, oxygen solubility decreases slightly, but oxygen solubility decreases more as temperature goes up regardless of salinity. Salinity is an important ecological parameter in its own right; and it is important in some chemical processes. The gradual increase in salinity from the head (usually a freshwater source such as a river) towards the mouth of the system is a typical estuarine character (Dauvin and Desroy, 2005; Stickney, 1984; Manikoth and Salih, 1974). The evaporation sometimes causes the salinity at the head of an estuary to exceed seawater (Manna *et al*., 2012). The salinity of the estuary is influenced by the wind pattern and the currents. Among the hydrographic parameters, salinity exhibit extreme variations from almost fresh water condition during monsoon season to relatively high salinity conditions during the pre-monsoon period. Salinity regime of the Vembanad wetland system is governed by the inflow from Arabian Sea through Cochin barmouth. In the present study, during flood period, all the stations in southern zone (i.e. stations south of TMB) and most of the stations in northern zone (stations north of TMB) of Vembanad wetland recorded with zero. In the southern stations, the high fresh water influx from Pamba, Manimala, Meenachil and Achankovil rivers were the main factor for the zero salinity condition. In addition to this, agricultural runoff from the nearby paddy fields and the unprecedented southwest monsoon during flood period also bring enormous amounts of freshwater into these southern stations, creating a pure limnetic (< ±0.5 ppt) condition. The intense rainfall along with increased river discharge from Periyar and Muvattupuzha during flood period was the main reason for low salinity in stations north of TMB. Devassy and Gopinathan (1970), observed similar decreasing trend in salinity and fresh water condition during the monsoon months. With the onset of monsoon rainfall, the hydrographic condition of estuary undergoes considerable transformation with condition of fresh water dominating the area (Wyatt and Qasim, 1973). When compared with the previous studies, station 1 (Aroor) showed a drastic decline in salinity (zero) due to the heavy flood. During the monsoon season of pre flood period, the salinity values in Aroor varied from a lower value of 3 ppt to a higher value of 27 ppt. The extent of incursion of saline water depends on the strength of the tidal influx and the fresh water efflux which differ with seasons. Salinity value increases from monsoon to pre monsoon season and freshwater conditions prevailed during monsoon season whereas saline condition in post monsoon and pre monsoon season (Shivaprasad *et al*., 2012; Binzy Jacob *et al*., 2013; Martin *et al*., 2012; Madhu *et al*., 2007). During flood, the maximum value recorded at station 39 (Cochin Barmouth, 35 ppt) mainly due to the sea water influence whereas stations 33-38 recorded with zero. Extreme rainfall (i.e. 40 - 50 cm in a few hours) occurs in the Cochin estuarine area during the peak southwest monsoon and as a consequence, salinity reaches near zero values over most parts of the Cochin estuary within a short time (Jyothibabu *et al.* 2006). Similar to flood period, station 39 showed the highest value (31 ppt) during post flood period. Menon *et al*. (2000) stated that the major hydrological variable in the Cochin backwater is salinity, and noted a salinity of 30 ppt at the entrance of the estuary to 0.2 ppt at the point of entry of the rivers and found that salinity gradient in the Cochin estuary supports numerous species of flora and fauna based on their ability to tolerate oligohaline, mesohaline or marine conditions. Compared to flood period, most of the northernmost stations (St.1 and 2, St.31-39) showed an increase in salinity during post flood whereas stations 3-30 recorded zero salinity. The study shows that changes in salinity were due to the variations in rainfall and the river discharge (Binzy *et al*., 2013; Menon *et al*., 2000). The study conducted by Cleetus *et al*.

(2016) in Vembanad backwater showed a remarkable seasonal fluctuation with high values in non monsoon season (dry season) i.e. av. 7.89 ± 1.15 ppt and low during monsoon season (wet season) i.e. av. 1.37 ± 2.1 ppt. Associated to this, the maximum peak in salinity was observed during post flood (post monsoon i.e. November 2018) period with a remarkable seasonal variation (av. 5.64 ± 9.94 ppt during post flood; and av. 1.28 ± 5.42 ppt during flood). Qasim (2004) has given the details of salinity pattern of most of the estuaries in India and noted that in most of the estuaries annual variation in salinity was large from the mouth to upstream. Based on the Venice system for the classification of marine waters, a salinity classification, the observed zones in Vembanad wetland system during the study period were limnetic (< ±0.5 ppt), Oligohaline (±5 - ±0.5 ppt), Mesohaline (±18 - ±5 ppt), Polyhaline (±30 - ±18 ppt) and Mixoeuhaline (> ±30 ppt but < adjacent euhaline sea). During the present study, bottom water showed higher salinity values. The salinity always increases towards the bottom indicating a two layered flow.

pH or hydrogen ion concentration measures the acid-base dissociation in the water and these pH variation mainly affected by the changes in the salinity and temperature. pH is one of the vital environmental parameter decides the survival, metabolism, physiology and growth of aquatic organisms. For maximum development and production of shrimp and carp, recommended an optimum pH range of 6.8-8.7. pH is mainly affected by acidity of the bottom sediment and biological activities. High pH may result from high rate of photosynthesis by dense phytoplankton blooms. According to Abowei (2010), pH greater than 7 but lower than 8.5 is optimal for biological productivity, but pH at <4 is harmful to aquatic life. Total alkalinity and acidity, runoff from surrounding rocks and water discharges can affect pH. According to the study of Gupta (2009), pH was positively correlated with electrical conductance and total alkalinity. pH is most important parameter in determining the corrosive nature of water. Lower the pH value higher is the corrosive nature of water. In the present study, during flood period, the pH values of Vembanad wetland showed acidic nature. Most of the stations were recorded with lower pH values when compared with the previous studies conducted in Vembanad wetland. This may be due to the heavy spill of monsoon during the flood period. In most of the estuaries the lowest pH was recorded in monsoon season and the maximum in pre monsoon season. Bijoy Nandan *et al*. (2012) also observed similar situations in the Kodugallur-Azhikode estuary. Several other authors are also reported similar variations of pH in different estuaries (Madhu *et al*., 2010). Since the salinity is lower during monsoon season pH is also reduced (Muduli *et al*., 2012). Natural rain water is slightly acidic in nature because it contains dissolved gases like CO_2, and this acidic water reduces the pH in monsoon season (Wurts and Durborow, 1992). Also annual monsoonal flood water flushed into the backwater during MN season and the acidic organic sediments beneath reflects the slight acidic nature of pH during MN (Cleetus *et al*., 2016; MSSRF, 2007). During the present study, lowest values observed in southern stations such as station 12 (Punnamada) and station 13 (Pallathuruthy). The soil of Kuttanad area is highly acidic (Thampatti and Jose, 2000) and this will impart low pH in the southern stations. The 'kari' soils in Kuttanad region are acidic in nature (due to rich organic carbon) especially in the dry months. The runoff from agricultural fields with the heavy spill of southwest monsoon during flood may also attribute to the acidic pH in southern stations. In addition to this, higher freshwater discharges from rivers like Pamba, Manimala, Achankovil and Meenachil which drain into the Vembanad wetland on the southern region. These rivers and streams transport large quantities of humic material in colloidal suspension which are frequently slightly acidic. Pidgeon and Cains (1987) observed that organic acids resulting from decaying vegetation might be responsible for the low pH in most aquatic ecosystems. During post flood period, slight increase in pH values observed in some stations of Vembanad wetland compared to that of flood period. The decreased river discharge increases the salinity and other dissolved inorganic ions which in turn increases the pH in post monsoon and pre monsoon season. The northernmost stations showed an alkaline nature during post flood period indicating the sea water influence through Cochin barmouth. High pH in the marine zone was on account of the intrusion of sea water and low values in riverine zone that could be due to the influence of freshwater and effluents introduced through various sources (Nair *et al.*, 1987). During post flood, station 1 (Aroor) was also showed higher pH values due to the sea water influence, but it was lower as compared to previous studies. Dilution of seawater by freshwater influx, removal of CO_2 by photosynthesis through bicarbonate degradation, reduction of salinity and temperature and decomposition of organic matter can be related with the fluctuations in pH values (Paramasivam and Kannan, 2005; Rajasegar, 2003; Upadhyay, 1988). During the present study, bottom water showed comparatively higher values. Increase in pH from surface to bottom water is related to freshwater discharge over the high saline bottom water.

The **alkalinity** of water body is its capacity to neutralize acids to a designated pH (Edokpayi, 2005; APHA, 1980). In other words, alkalinity is a measurement of the buffering capacity of water. Total alkalinity of water is due to presence of mineral salt present in it. It is primarily caused by the carbonate (CO_3^{2-}), bicarbonate (HCO^{3-}) and hydroxide (OH^-) ions and it is taken as an indication of the concentration of these constituents. The measured values also may include contributions from borates, phosphates, silicates or other bases which may be derived from industrial wastes, dissolved rocks, salts, soils or bottom sediments. Alkalinity acts as a stabilizer for pH. The $CaCO_3$ level, organic matter, temperature and partial pressure of CO_2 are the major factors contributing to alkalinity of the water body. High alkalinity results in physiological stress on aquatic organisms and may lead to loss of biodiversity. In the present study, during flood period, alkalinity in both surface and bottom water in most of the stations of Vembanad wetland were generally low as compared to earlier studies. Stations north of TMB such as station 1 (Aroor) and station 2 (Perumbalam) (which are closest to Arabian Sea) showed lower alkalinity compared to previous study results. The extreme rainfall during the flood period might be the reason for lower alkalinity. Alkalinity showed negative correlation to rainfall (Reynolds, 2006; Murugavel and Pandian, 2000). Qasim and Gopinathan (1969) observed a marked variation in alkalinity value during the MN months. During the present study, stations south of TMB were also recorded with lower alkalinity. In these stations fresh water discharge from Pamba, Manimala, Achankovil and Meenachil uphold a reduced condition of alkalinity. According to Jennerjahn *et al*. (2006), tropical river basins play a major role in chemical weathering and transfer of dissolved silicate and alkalinity to rivers and oceans due to their geological and climatic settings. The weathering rates are influenced by climatic factors such as temperature and precipitation (Bouwman *et al*., 2013). Freshwater mixing reduces the salinity and prevents the tidal inflow by heavy river discharge that in turn reduces the alkalinity in the estuary. The drastic variation of alkalinity values in northernmost stations was mainly due to the continuous rainfall along with the increased river discharge from Periyar and Muvattupuzha during the flood period. The desired total alkalinity level for most aquaculture species lies between 50-150 mg L^{-1} $CaCO_3$, but no less than 20 mg L^{-1}. Alkalinity between 30 and 500 mg L^{-1} is generally acceptable to fish and shrimp production (Abowei and George, 2009; McNeely *et al*., 1979). According to Boyd (1982), alkalinity ranged between 20 and 50 mg L^{-1} that will permit plankton production for fish culture. Furthermore, according to the studies conducted by Meera and Bijoy Nandan (2010), the alkalinity values greater than 100 mg L^{-1} was classified as highly productive and those with less than 50 mg L^{-1} as oligotrophic. In the present study, some stations in Vembanad wetland recorded 15 mg L^{-1} and generally the alkalinity values were ranged between 15-25 mg L^{-1} during flood period. Hence, it shows that the condition of study stations in Vembanad wetland during flood period were not very favourable for fish production. The uptake or release of carbon dioxide by organisms can change the proportion of carbonate and bicarbonate ions in water which may also reduce the alkalinity. During flood period, the alkalinity values were similar in most of the stations. During post flood period, there is an increase in alkalinity values compared to that of flood period. River discharge diminishes with receding rainfall parallel the tidal influences gains its momentum towards the upper reach of the estuary. Marine water is alkaline in nature so, the marine water intrusion increases the alkalinity in the estuary.

Dissolved oxygen (DO) is one of the most important parameter. Its correlation with water body gives direct and indirect information e.g. bacterial activity, photosynthesis, availability of nutrients, stratification etc. (Premlata Vikal, 2009). The value of dissolved oxygen is remarkable in determining the water quality criteria of an aquatic system. The DO values typically remain lower in the system where the rates of respiration and organic decomposition are high, than those of the system, where the rate of photosynthesis is high (Mishra and Tripathi, 2007). Dissolved oxygen affects the solubility and availability of nutrients. Its low levels can result in damages to oxidation state of substances from the oxidized to the reduced form thereby increasing the levels of toxic metabolites. Further, dissolved carbon dioxide in an aquatic environment increases with decreased dissolved oxygen. The diversity of organism is directly dependent upon the DO concentrations. In the present study, during flood period, dissolved oxygen showed higher concentrations in most of the study stations in Vembanad wetland. According to the study conducted in Vembanad backwater by Asha *et al*. (2016), DO values varied from 4.88 to 8.94 mg L^{-1} in surface water whereas it varied from 5.69 to 9.76 mg L^{-1} in bottom water. In the present study, the DO values varied from 4.7 to 10.2 mg L^{-1} in surface water and 3.15 to 10.23 mg L^{-1} in bottom water. The increased dissolved oxygen during this period could be due to the heavy rainfall and extremefreshwater discharge which decreases the salinity and temperature in the estuary. According to Das *et al*. (1997), these observed higher monsoonal values of DO may be due to cumulative effect of wind and tidal action from the Arabian Sea coupled with rainfall and resultant freshwater mixing. During previous studies the average DO was slightly higher in Vembanad backwater when comparing with other water bodies. Similar trend was observed in the present study. Increased precipitation and extreme river discharge during flood was the main reason for higher DO during this period. Stations south and north of TMB do not show much variation in DO values. The highest value was recorded at southern station such as station 8 (Sports Authority). As oxygen solubility is higher for fresh water, runoff from the rivers such as Pamba, Manimala, Achankovil and Meenachil contributed higher DO mostly in the southernmost stations. Extreme river discharge mainly from Periyar and Muvattupuzha during flood period influences the DO values in most of the northernmost stations. During flood period, oxygen showed an increasing trend from barmouth to the upper reach of the estuary. Influence of sea water may be the reason for lower DO observed in station 39. But station 1 (Aroor) and station 2 (Perumbalam) (which was closest to Arabian Sea) showed higher DO values compared to previous studies. The heavy fresh water runoff from Periyar and Muvattupuzha during flood might be contributed higher DO values in these northernmost stations. During flood period, bottom water showed higher DO values. This is mainly due to the lower salinity in most of the stations during flood. During post flood period, the DO showed a slightly decreasing trend compared to that of flood period. Diminishing river discharge with monsoonal rainfall and decomposition of organic matter might be the reason for reduction in DO during post flood.

Biological oxygen demand (BOD) is a measure of organic material contamination in water or in other words, BOD is defined as the amount of oxygen required by bacteria in stabilizing the decomposable organic matter. BOD indicates the quality of water (Miranda and Krishnakumar *et al*., 2015; Mishra *et al*., 2008) and gives an idea about the extent of pollution. BOD is also used to measure waste impact on natural water, and to evaluate their purification capacities. According to BIS (ISI) standards, the permissible level of BOD in the inland surface water is 20 mg L^{-1} whereas the standard permit of BOD is 5 mg L^{-1} as per ICMR (Meera and Bijoy Nandan, 2010) and WHO (1984). In the present study, during flood, the BOD levels in some stations in Vembanad wetland exceed 5 mg L^{-1} but was below the permissible level of BIS standards. Southern stations such as station 8 (Sports Authority) and station 15 (Meenappally Vattakayal) were showed higher values. Comparing the southern and northern stations of TMB, southern stations recorded with comparatively higher values. The high level of BOD indicates significant levels of organic pollution in southern region. The biodegradation of organic materials exerts oxygen tension in the water and increases the biochemical oxygen demand (Gupta *et al*., 2009). Further, the waste carried by the flood water from the polluted and flow restricted Alappuzha canal directly entering the southern region of Vembanad backwater and these events might enhances the BOD level in southern stations. The average BOD level during post flood i.e. post monsoon (av. 2.79 ± 1.02 mg L^{-1}) was lower than that of flood period i.e. monsoon (av. 3.71 ± 1.42 mg L^{-1}). Similar trend was observed in the study conducted by Bijoy Nandan *et al*. (2012) in the Kodungallur-Azhikode estuary (KAE). In their study, maximum value observed during monsoon (3.1 mg L^{-1}) as compared to the post monsoon (2.2 mg L^{-1}). According to Radojevic and Bashkin (2006), the BOD level below 2 mg L^{-1} shows the pristine river condition and above this level up to 10 mg L^{-1} shows moderately polluted. In the present study, the average BOD level in Vembanad wetland was above this limit shows that the backwater was moderately polluted. Northernmost station such as station 37 (FACT) also showed maximum value during the entire period. The large amount of industrial discharge with untreated waste could be the reason for higher BOD level in this station. In the present study, similar to southern stations most of the northern stations were recorded with higher BOD values. Organic pollution in the Cochin estuarine zone is attributed to the high BOD values in northernmost stations. In addition to this, effluents primarily from shellfish industries and sewage from human settlements along the banks of backwater has also enhanced the BOD level. During the study period, most of the stations were recorded with higher values. High BOD indicates an increase in the organic content and bacterial activity of the estuary (Rai and Tripathi 2009; Dhage*et al*., 2006). In addition to this, extreme river discharge during flood containing highly suspended sediments might be influenced the BOD level. Water requires more oxygen to oxidise these particles. So this could be one reason for the increased BOD level during flood period.

Hydrogen sulphide is a very toxic compound that can cause acute mortalities in aquatic animals at relatively low concentrations by affecting the nervous systems (Augspurger *et al*., 2003). In the present study during flood period station 12 (Punnamada) showed the maximum concentration. Large amount of organic matter load during flood and its decomposition by bacteria may results in the utilization of dissolved oxygen and production of hydrogen sulphide. During post flood, station 13 (Pallathuruthy) showed the highest value in surface water whereas station 9 (Nehru trophy ward 17) showed highest value in bottom water. During the present study, southern stations (stations south of TMB) showed higher sulphide concentration compared to northern stations (stations north of TMB). The spatial variation of H_2S showed an increasing trend towards the freshwater region compared to the lower arm of the estuary. The decomposition of organic matter especially dead remains of plants and animals carried by the major rivers during flood might be the reason for high values in southern stations. In addition to this, extensive runoff from land containing sewage and other household wastes may also result in high values. Similar to previous studies Punnamada showed higher sulphide concentration, which may be due to the various pollution problems in this region. Higher level of dissolved hydrogen sulphide is the characteristic feature of the water quality in retting zone. According to the Environmental Protection Agency, maximum acceptable level of H_2S for fish and aquatic life is 0.062 μmol L^{-1}. In the present study, the sulphide concentration exceeds this level. Similarly, station 37 (FACT) showed maximum values in both surface and bottom water during the study period. The untreated effluents mainly from FACT (Fertilizers and Chemicals Travancore Ltd.) may be contributing higher sulphide concentration in this station. Northernmost stations such as station 31 (Marine Science Jetty), station 32 (Bolgatty) station 36 (Eloor) and station 38 (Kadamakudy) were also recorded with comparatively higher values. Increased organic load in estuary during flood mostly by Periyar plays a major role in contributing higher sulphide concentration in most of the stations in northern zone.

As a limiting nutrient in the brackish water ecosystem, inorganic **phosphate** plays a vital role in the productivity of the estuary. It is a major nutrient involved in the biogeochemical processes in estuaries. As per BIS (Bureau of Indian Standard) the permissible limit of phosphate is 0.1 mg L^{-1}. Phosphorus occurs as calcium phosphate and present in rocks and soils. Plants and other microbes take up phosphorus in the form of orthophosphate (PO_4-P) when they die, mineralization due to decaying makes phosphorus available for reuse. The major supply of phosphorus in natural water comes from weathering of rocks, leaching of soil from the catchment area by rain, cattle dung and agricultural activity in adjacent areas (Jhingran, 1982). Phosphorus undergoes sedimentary cycle with no significant role in the gaseous phase so it tends to accumulate in wetland systems (Renjith, 2006). During flood, spatial distribution of phosphate-phosphorus observed in the Vembanad wetland shows highest value in station 17 (Kainakary). In the present study, most of the stations were recorded with higher values compared to the previous study conducted in Vembanad wetland. Allochthonus sources brought in sediment and other organic matter during heavy rain into the ecosystem that could have led to the increase in phosphate concentration during flood period. Asha *et al*. (2016) observed higher phosphate concentration during monsoon season in Vembanad estuarine system and similar situation was occurred during the present study as well. The heavy flood with intense monsoonal rainfall might be contributed higher PO_4-P values. This possibly means that the estuary's phosphorus contribution relies primarily on external sources such as land drainage and fresh water runoff. The increased application of fertilizers, use of detergents and domestic sewage greatly contribute to the heavy loading of phosphorous in the water [Water Resources Commission (WRC), 2003]. Hence, it is interesting to note that, in the southern zone of Vembanad wetland during flood period, the phosphate value was higher (3.28 to 23.7 µmol L^{-1}) which could be mainly due to the fresh water discharge from the paddy fields. The phosphate levels in this region have to be considered in the light of large scale fertilizer application in the surrounding paddy fields practiced every year. During flood, station 20 (C Block) also showed higher value in bottom water. This higher level of phosphate at the bottom can be attributed to two reasons, (1) due to the large quantity of silt brought down by the rivers and (2) due to the churning up of bottom sediment due to the increased flow of fresh water towards the estuary. Northernmost stations were also recorded with higher values. During flood, station 39 (Cochin Barmouth) showed maximum value in surface water and station 37 (FACT) showed maximum value in bottom water. Increased levels of phosphate recorded at these stations could be due to the influence of sea water, land runoff, industrial effluent as well as sewage discharge into the estuarine area. During flood, surface water (av. 10.44 ± 6.36 µmol L^{-1}) showed higher value compared to the bottom water (av. 5.58 ± 3.17 µmol L^{-1}). Qasim (2004), pointed out that during MN the increased rainfall and land runoff is associated with increased phosphorus runoff gets settled to the bottom, from where it is released to the surface. The phosphate-phosphorus values decreased in most of the stations during post flood period with the decreasing river discharge. Northern station such as station 1 (Aroor) recorded with maximum value during post flood. Saline incursion, discharge from sea food industries, urban and municipal discharge from Kochi metro city could be the reason for higher phosphate values in this station. Station 31 (Marine Science Jetty) also showed comparatively higher values in both surface and bottom water. According to Jyothibabu *et al*. (2006), Cochin estuary receives large amount of nutrients from rivers, apart from this, increased supply of nutrients are mainly received from various domestic and industrial activities.

Dissolved **silica** is a key nutrient in natural water as structural constituent of diatoms and many fresh water sponges. Availability of silica to the aquatic ecosystem is largely from weathering of soils and sediment (Habib and Yousuf, 2016). During flood, higher values observed in most of the stations in Vembanad wetland system. Southern station such as station 15 (Meenappally Vattakayal) showed maximum value in surface (158.13 µmol L^{-1}) and bottom water (124.04 µmol L^{-1}). Similar trend was observed in the study conducted by Cleetus *et al*. (2016) in Vembanad backwater. In their study, higher silicate concentration was observed in the southern zone of Vembanad backwater during the monsoon period. The increased river fall, land drainage and agricultural runoff in the MN season may become a major contributor of silicate-silicon (Cleetus *et al*., 2016; Renjith, 2006; Anirudhan and Nambisan, 1990; Sankaranarayanan and Qasim, 1969). Spatial distribution of SiO_4-Si in the present study revealed its higher concentration in the southern stations, which are highly influenced by the riverine and agricultural runoff. Increased discharges from Pamba, Manimala, Achankovil and Meenachil Rivers during flood and terrestrial runoff from the padashekarams contributed higher values. The municipal discharges from the Alappuzha town may also be enhancing the silicate input in southern region. In addition to this, heavy influx of freshwater derived from land drainage carrying silicate leached out from rocks and also from bottom sediments exchanging with overlying water due to the turbulent nature of water. During flood, silicate showed an increasing trend from the barmouth to the upper reach of the estuary. This could be due to the freshwater runoff that contains more silicate. The northernmost stations such as station 35 (Methanam) and station 34 (Cheranelloor) were also showed higher values during flood period. The freshwater discharge from Periyar and Muvattupuzha and terrestrial runoff might play a major role in higher silicate concentration in these stations. Station 39 (Cochin Barmouth) showed comparatively lower value during flood. This could be due to the reduced river water discharge towards the mouth of the estuary (Anirudhan and Nambisan (1990). The present study showed a decreasing trend in silicate concentration from flood to post flood period. During flood, the average silicate concentration recorded was 59.83 ± 34.96 µmol L^{-1} and during post flood it was decreased to 28.76 ± 15.32 µmol L^{-1}. The maximum value observed at station 17 (Kainakary) in surface water (63.45 µmol L^{-1}) and station 19 (Kuppapuram) showed highest value in bottom water (35.05 µmol L^{-1}). Northernmost station (station 1 - Aroor) showed lower values in both surface and bottom water. This might be due to the influence of sea water. Lower silicate values are associated with high salinity of water and vice versa. According to Shivaprasad *et al*. (2012), the negative correlation of silicate to salinity shows that the source of silicate concentration in estuary is of riverine origin. Hence, diminished river discharge might be the reason for lower silicate values observed in most of the stations during post flood period. In Vembanad wetland system, during flood and post flood period, the vertical distribution of silicate showed higher concentration in surface water compared to bottom water. The heavy rainfall and the increased surface runoff during the monsoon period contributed to the higher values of silicate in the surface water. The same observation was made by Shivaprasad *et al*. (2013); Patil and Anil (2011); Jyothibabu *et al*. (2006).

Ammonia (NH_4-N) is a primary decomposing product from organic matter. Nitrification is a two-step process: oxidation of ammonia to nitrite (NO_2-N) and of the latter to nitrate (NO_3-N) under oxic conditions. Under anoxic conditions, nitrite and nitrate can be further transformed to nitrogen gas (N_2) by denitrification. In estuaries, nitrogen compounds exert a significant oxygen demand through microbially mediated nitrogen conversion (Grabemann *et al*., 1990). Organic nitrogen is hydrolyzed to ammonia and the excess ammonia enters the estuaries via the tributary of rivers and also as wastewater discharges. Ammonia is present in terrestrial and aquatic environments. Plants and animals excrete ammonia; it is produced by the decomposition of organisms and by the activity of microorganisms (Prosser and Embley, 2002). During flood, station 37 (FACT) showed the maximum value (18.11 µmol L^{-1}). Industrial waste discharge plays a major role in higher ammonia concentration in station 37. Station 3 (Varanad) was also recorded with higher concentration in bottom water (10.91 µmol L^{-1}). This might be due to the effluent from the distillery located on the estuarine bank. Occurrence of ammonia indicates the presence of sewage in the water body. Southern station such as station 11 (Pangankuzhipadam) was also showed higher value. The NPK fertilzers and Factamphos (20N:20P) using in the padashekarams (Q, S, T, R and C blocks) get leached out during monsoonal rain to these southern stations may also contribute high ammonia concentration. During flood, most of the stations were recorded comparatively lower values (av. 3.40 ± 3.39 µmol L^{-1}). The heavy freshwater discharge containing higher amount of dissolved oxygen with pure limnetic (zero salinity) condition could be one reason for lower ammonia concentration during flood period. According to Miranda *et al*. (2008), salinity and the concentration of ammonia are directly related. During post flood, the ammonia values showed an increasing trend (av. 9.44 ± 5.88 µmol L^{-1}). Southern and northern stations showed higher values compared to flood period. Similar to flood period, northernmost station such as station 37 (FACT) recorded with the highest value (33.86 µmol L^{-1}). Compared to other northern stations, St.34 (Cheranelloor) and St.36 (Eloor) recorded with higher concentration. The effluents discharged from chemical industries located near to these stations and municipal and sewage discharge might be contributed to the higher ammonia level. Northern stations such as station 1 (Aroor) and station 2 (Perumbalam) were also showed higher values during post flood period, indicates its direct relation with salinity as stated by Miranda *et al*. (2008) who studied the relationship between salinity and ammonia. In the southern zone, station 10 (Nehru trophy finishing point) and station 12 (Punnamada) were recorded with higher ammonia concentration. The presences of higher levels of ammonia indicate increased sewage input and agricultural runoff into the surface water (Anirudhan *et al*., 1987; Lakshmanan *et al*., 1987). Apart from this, the sewage and municipal solid waste discharge from flow restricted Alappuzha canal and houseboats directly enters the Punnamada region might also be enhances the ammonia-nitrogen in the southern zone of Vembanad wetland. Most of the southern stations showed higher values indicating sewage load through Pamba, Manimala, Achankovil and Meenachil rivers might be contributed a major share of ammonia in the water body. In the present study, bottom water recorded with comparatively higher ammonia concentration. This could be due to the sediment flux and low oxygen level in bottom water than surface water (Tay, 2011). During the study period, compared to southern zone, stations in northern zone showed higher NH_4-N values. According to Joseph and Ouseph (2010), the ammonia content in Cochin estuary was contributed by the Periyar River and its associated tributaries including Chitrapuzha, which flow through the industrial zones. Hence, the heavy river discharge mainly from Periyar during flood might influence the ammonia concentration in most of the northernmost stations.

Nitrite (NO_2-N) is the most unstable form of dissolved inorganic nitrogen species in water (Sreedharan Manikoth and Salih, 1974) followed by ammonia and nitrate in the process of nitrification. The reactivity of nitrite is very high, leading to a lower concentration of nitrite in the aquatic system compared to ammonia and nitrate. To support algal growth inorganic nitrogen above 0.03 mg L^{-1} is required, and high level of nitrite in water may not be suitable for growth of aquatic organisms. In the present study, among inorganic nitrogen, nitrite-nitrogen showed lowest values and it did not show any noticeable pattern in its distribution. During flood, the maximum value observed in northern station such as station 31 (Marine Science Jetty) in surface water (1.58 µmol L^{-1}) whereas station 33 (Chittoor) showed highest value in bottom water (1.06 µmol L^{-1}). The higher level of nitrite in these stations might be the result of oxidation of ammonia due to rich organic matter in sediments. In southern zone, station 12 (Punnamada) showed the maximum value (1.42 µmol L^{-1}). This might be due to some nitrogenous compounds being added to the estuary from external source around the station. Besides this, increased river discharge with heavy organic load during flood may also contribute higher level of nitrite. Apart from this, the Punnamada region of Vembanad wetland is highly affected by various pollution problems significantly from the houseboat tourism activities. Hence, all these things might be influence the nitrite concentration and results maximum value in this station. Possible cause of lower value observed in St.2, St.5, St.16, St.18 and St.30 reveals the highly unstable nature of nitrite, as it remains as a transient species by the oxidation of ammonia or by the reduction of nitrate and are often released into water as an extracellular product of planktonic organisms (Santschi, 1990; Chandran and Ramamurthy, 1984). Increased uptake of nitrite by the planktonic communities could also attribute to the low level of nitrite. Comparatively lower nitrite values in southern zone (South of TMB) were presumably, it got washed to the northern zone (North of TMB) during increased river discharge. During post flood, northern stations such as station 1 (Aroor) and station 2 (Perumbalam) showed maximum concentration. Station 1 recorded with 3.36 µmol L^{-1} (SW) and station 2 recorded with 2.9 µmol L^{-1} (BW) respectively. The effluent from seafood industries along with municipal waste discharge from Kochi metro city and salt water incursion from the Arabian Sea might play a significant role in increasing nitrite concentration in these northernmost stations, especially in Aroor (station 1) which is the hub of sea food processing industries. According to Lakshmanan *et al*. (1987), the possible input sources of nitrite include sewage discharge and waste from the fisheries industries. Station 37 (FACT) was also showed maximum value in both surface and bottom water. Effluent from nearby industries might be contributed to higher nitrite concentration and is often associated with the unsatisfactory microbial quality of water. In Vembanad wetland, nitrite-nitrogen showed an increasing trend from flood (av. 0.92 ± 0.24 µmol L^{-1}) to post flood (av. 1.18 ± 0.85 µmol L^{-1}) period. The lower freshwater input, increase in salinity and pH may be contributed to the elevated level of nitrite concentration during post flood period.

Nitrates (NO_3-N) are the most abundant and oxidized forms of nitrogen and the end product of the aerobic decomposition of organic nitrogenous matter. Natural waters in their unpolluted state contain only minute quantities of nitrates (Manikannan *et al*., 2011). The main sources of nitrate in water are human and animal waste, industrial effluent, use of fertilizers and chemicals, silage through drainage system (Golterman, 1975). The cycling of nitrogen is more influenced by external input due to the open characteristic of the nitrogen cycle (Quiros, 2003). In the present study during flood period, station 37 (FACT) showed the maximum value (9.22 µmol L^{-1}) in surface water and station 39 (Cochin Barmouth) showed the maximum value (14.98 µmol L^{-1}) in bottom water. Effluents from nearby chemical industries might be contributed to the higher nitrate level in station 37. In addition to this, heavy rainfall and river discharge during flood period may also enhance nitrate concentration. According to Vijayakumar *et al*. (2000), in an estuarine zone increased nitrate concentration during MN season was due to freshwater influx. Similarly Parab *et al*. (2013) noted that increased land runoff during the MN brought nitrate into the Mandovi estuary and observed an addition and dilution of nitrate in the MN season which was responsible for its elevated levels. In the observation of Siddiqui and Ramakrishna (2002), nitrates were loosely bound in soil and its concentration likely increases with surface runoff. The maximum concentration observed at station 39 was mainly due to the influence of seawater intrusion from Arabian Sea. During post flood, station 39 showed the maximum values in both surface and bottom water. According to Rajasegar (2003), one of the possible ways of nitrates entry is through oxidation of ammonia form of nitrogen to nitrite formation. In the present study, station 1 (Aroor) showed higher values during both flood (5.45 µmol L^{-1}) and post flood (9.22 µmol L^{-1}) period, indicating a nitrate input from either sea water or effluent and sewage discharges from the residential and urban areas situated close proximity to this station. During the study period, maximum NO_3-N concentration observed during post flood (post monsoon) compared to flood (monsoon) period. During flood, the average concentration was found to be 2.91 ± 2.18 µmol L^{-1} and during post flood, it was 3.93 ± 5.46 µmol L^{-1}. Babu *et al*. (2010) reported that nitrate was higher during the non-monsoon months than the monsoon months. In the present study, northernmost stations showed comparatively higher nitrate concentration than southernmost stations. The riverine inflow from Periyar and Muvattupuzha may contribute to the higher values in northernmost stations. The slightly lower levels of nitrate observed in southern stations might be due to the variation in freshwater input, salinity, pH and also their utilization by phytoplankton. Surface water showed higher nitrate concentration during the study period. Nitrogen rich agricultural land drainage and riverine and terrestrial runoff during flood could be the possible reason for this higher nitrate values in the surface water.

The synthesis of organic matter from inorganic constituents by the photosynthetic activity of organisms is termed primary production. Estuaries are biogeochemical hot spots as they receive large inputs of nutrients and organic carbon from land and oceans to support high rates of metabolism and primary production (Hopkinson *et al*., 2005) and the whole process is influenced by a host of factors including latitude, season, irradiance, temperature, flow, nutrient loading and recycling, grazing, and watershed geomorphology and development (Day *et al*., 1989; Nixon, 1986). Of these, the abiotic factors such as temperature, salinity, turbidity, solar radiation and light penetration, depth, available nutrients and river water flow and biotic factors such as abundance of phytoplankton and top-down regulation by grazers forms important regulating factors for primary production (Cloern *et al*., 2014; Chaudhuri *et al*., 2012; Cortner *et al*., 2000; Kemp *et al*., 1992; Qasim, 1979) and these factors contribute to its seasonal variation in any aquatic ecosystem (Sultan *et al*., 2003). Primary productivity plays an important role in an ecosystem because they are the basic food sources for all the life forms in an ecosystem and also support resident heterotrophic metabolism (Cloern *et al*., 2014). Primary production is often used for the assessment of fishery resources (Cloern *et al*., 2014; Sreekumar and Joseph, 1997; Mishra and Saksena 1992), the biomass of benthic invertebrates (Herman *et al*., 1999) and sustainable yield of cultured fishes (Bacher *et al.*, 1997). There are two aspects of primary production; gross primary productivity (GPP) and net primary productivity (NPP). Gross primary productivity is the rate at which organic compounds are produced in an ecosystem via photosynthesis or chemosynthesis over a specific period of time and area. Net primary productivity is the organic materials that remain after cellular respiration. In tropical areas, primary production continues on a uniform rate throughout the year with slight seasonal variations (Menzel and Ryther, 1961). The primary production was more or less uniform throughout the study.

During the study period, **gross primary productivity (GPP)** was slightly higher in surface water compared to bottom water. During flood, the average GPP value in surface water was 1.70 ± 0.81 g C m^{-3} day^{-1} and in bottom water it was av. 1.61 ± 0.88 g C m^{-3} day^{-1}. According to Qasim (1973), 90 % of the total production is confined to the topmost layer and maximum occurs either at surface or slightly below. The higher GPP values observed in most of the southern stations could be attributed to the increased phytoplankton density and nutrient enrichment in these stations. The major source for nutrient enrichment in the Vembanad wetland was from the paddy fields and aquaculture farms where artificial manuring is being carried out, with issues of urbanization and industrialization, domestic sewage and surface water runoff. Light penetration (solar energy) also plays a key role in primary production. The GPP showed maximum value during post flood (av. 4.10 ± 1.00 g C m^{-3} day^{-1}) compared to flood (av. 1.70 ± 0.81 g C m^{-3} day^{-1}). Nutrient enrichment, salinity, tidal influx, river discharge, low light penetration due to turbidity and species composition of the primary and secondary producers are the factors controlling GPP in the estuary. The nutrient concentrations were found to be high during the flood (monsoon) period. This indicated that high concentration of nutrients brought by flood runoff and ample supply of sunlight helped to increase the phytoplankton production during post flood (post monsoon). Similar findings was observed by Meera and Bijoy Nandan (2010); Renjith *et al.* (2004); Qasim *et al*. (1972). Temperature and seasonal variations in light intensity also exert influences on the distribution of phytoplankton (Vaillancourt *et al*., 2003). Apart from all these, local rainfall events have been shown to significantly stimulate primary productivity directly in estuaries and coastal waters (Willey and Cahoon 1991). The lower GPP values observed in most of the stations during flood (monsoon) period could be due to the presence of dead and decaying weeds, enhancing the organic load in the area, adversely impacting the transparency of the water body, leading to decreased phytoplankton production. The present study is supported by Qasim (1979), who reported lower production during monsoon months, due to high turbidity leading to low light penetration. In addition to this, the observed lower GPP value during flood period reveal that, rainfall beyond an optimum level is not favourable for phytoplankton production in the estuarine environment since heavy rainfall has impact on other environmental factors such as intensity of flood flow, turbidity, light penetration, salinity, even though enormous quantity of nutrients were brought into the estuary by the consequent freshwater discharge from land drainage.

The **Net Primary Productivity (NPP)** values were maximum in surface water during flood and post flood period. During flood, station 8 (Sports Authority) showed maximum value in bottom water (5.17 g C m^{-3} day^{-1}). This could be due to the greater photosynthetic activities in this region. During post flood, station 33 (Chittoor) recorded with the highest value (5.17 g C m^{-3} day^{-1}). Southern stations such as station 10 (Nehru trophy finishing point) and station 21 (C Block 2) were also showed higher value. But most of the stations were recorded with lower NPP values. This might be due to relatively lower phytoplankton production in the area. Similar to GPP, the NPP values showed an increasing trend from flood (av. 1.10 ± 0.47 g C m^{-3} day^{-1}) to post flood (av. 2.02 ± 1.25 g C m^{-3} day^{-1}) period. During the present study, relatively lower NPP values observed in most of the stations compared to GPP. Increased organic load during flood and eutrophication accounts for the greater respiration in these stations which corroborates with the lower NPP values (0.74 g C m^{-3} day^{-1}). Besides this, increased grazing of phytoplankton by microzooplankton could be one of the reasons for a relatively low level of primary production even though the environmental conditions remained conducive for maximum phytoplankton growth. Apart from grazing by herbivorous zooplankton, large amount of unconsumed phytoplankton crop could get sinked to the below euphotic zone produces anaerobic conditions, where it is utilized by benthic animal communities (Qasim, 1969).

During the present study in the Vembanad wetland system, a decrease in overall accumulation of **heavy metals** in water column was observed compared with the previous studies. The average concentration of heavy metals in water followed the trend Fe>Zn>Pb>Cu during flood and Fe>Zn>Pb>Cu>Ni>Cd during post flood. The average values of Cu, Ni, Cd, Pb, Zn and Fe during flood were 0.40 µg L^{-1}, BDL, BDL, 1.88 µg L^{-1}, 24.71 µg L^{-1} and 524.10 µg L^{-1} respectively. In case of post flood, the average values of Cu, Ni, Cd, Pb, Zn and Fe were 2.67 µg L^{-1}, 0.89 µg L^{-1}, 0.41 µg L^{-1}, 3.51 µg L^{-1}, 35.93 µg L^{-1} and 474.7 µg L^{-1}.

The qualitative analysis of the water based on water quality standards of USEPA (2017) (Table 4.5) shows that the average concentration of Fe was higher than its acceptable limit during both the flood and post flood period. The concentration of Cd in stations 34 and 37 were also higher than the acceptable limit. Cadmium is weakly bound with sediment and hence highly bioavailable (Mohan *et al*., 2012). A study conducted by Jayasooryan *et al*. (2021) also showed that Cd is under very high risk to high risk category in industrial area of Cochin estuary. The multiple sources of cadmium during the river's course is also may the reason behind the high Cd concentration. A study conducted by KSPCB (2019) reported higher ranges of Cd, Fe and Mn in the Cochin estuary. The increasing discharges from mining, electroplating works, painting and printing works, automobile battery, and petrochemical industries contain high levels of copper, zinc, cadmium and lead (Dali-Youcef *et al*., 2006; Mohan *et al*., 2007). Also from increasing industrialization and urbanization, heavy metal pollution can cause serious threats in the coastal waters of tropical and subtropical countries (Ratheesh Kumar *et al*., 2010). A study conducted by Anu *et al.* (2014) reported that the Cochin estuary is facing serious challenges because of heavy metal contamination. The northern part was found more contaminated with the toxic metals in the study. It was also found that a study in Vembanad backwater conducted by KSPCB (2019) reported that the wetland is facing threat from heavy metals. But in this study, there is a decrease in toxic metal concentrations due to the heavy flood that demolished the whole wetland systems in the state. When the river discharge increases, flushing of heavy metals occurs which in turn decrease their concentration often in the peak of the flood. Generally, the concentrations of heavy metals in suspension tend to decrease with an increase in river discharge (Schleichert, 1975).

Table 4.5 Heavy metals and their permissible limits prescribed in various agencies

Sl. No.	Heavy metal	WHO (2008)	US EPA (2017)	Flood, 2018		Post flood, 2018	
				Range	Average	Range	Average
1	Copper (μg L^{-1})	2000	3000	BDL-4.375	0.40 ± 0.98	0.25-8.06	2.67 ± 1.90
2	Nickel (μg L^{-1})	-	100	BDL	BDL	BDL-9.06	0.90 ± 2.09
3	Cadmium (μg L^{-1})	3	5	BDL	BDL	BDL-9.38	0.41 ± 1.57
4	Lead (μg L^{-1})	50	100	BDL-9.38	1.88 ± 2.74	BDL-46.26	3.51 ± 9
5	Zinc (μg L^{-1})	-	5000	1.25-145.63	24.71 ± 31.26	4.16-166.25	35.93 ± 34.76
6	Iron (μg L^{-1})	0.3	0.3	4.75-918.75	524.10 ± 230.56	103.44-2202.5	474.70 ± 405.71

Principal Component Analysis (PCA) was carried in order to find out the environmental parameters, which was influencing the study area. The higher loading of silicate in the first component indicated the extreme fresh water discharge from major rivers and terrestrial runoff during the flood period. Besides this, the municipal waste discharge from Alappuzha town may also enhance the silicate input in the Vembanad wetland. The high loading of BOD, sulphide and water bound Cu, Ni and Pb was mainly due to the various pollution problems in the wetland system. The increased organic load during the flood period, industrial and municipal waste discharge from Alappuzha town as well as Kochi metro city and increased tourism activities in the backwater are the major contributing factors. The higher loading of alkalinity and nitrite is mainly due to the influx of marine water into the backwater from Arabian Sea. Negative loading of depth, salinity and pH were observed in the PCA analysis. The negative loading of depth is mainly due to the reduction of depth in most of the stations of Vembanad wetland. Similarly, drastic decrease in salinity was observed in the study period, mainly due to the extreme river discharge. pH also showed reduced condition, indicating the increased fresh water discharge during flood period.

4.4.1 Impact of flood and post flood on water quality and productivity of the Vembanad wetland

In the present study, most of the parameters showed significant variation between pre flood and post flood period. The depth ranged between 0.9-7 m during pre flood and 0.7-8 m during post flood period. Pathiramanal showed lowest depth during pre flood period whereas Punnamada recorded lowest depth during post flood. During the study period, most of the stations south of Thanneermukkom barrage recorded with lower depth. This could possibly be due to the post flood sedimentation. During pre flood period, the maximum transparency value obtained was 4 m (Pathiramanal) whereas in the present study the maximum value recorded was 1 m. Besides this, Pathiramanal showed lower transparency (0.5 m during flood and 0.6 m during post flood) compared to pre flood period. Extreme river discharge and increased land runoff during flood might be attributed to the increased turbidity and lower transparency values during post flood period. The water temperature ranged from 33 ºC in pre flood and 31 ºC in post flood period. The extreme rainfall and associated heavy river discharge during flood period may be the reason for lower temperature in the present study. Salinity showed extreme variation compared to pre flood period. Most of the stations were recorded with zero, especially stations south of Thanneermukkom barrage. This purely limnetic condition in the southernmost stations is mainly due to the fresh water discharge from Pamba, Manimala, Achankovil and Meenachil. Compared to pre flood period, station 1 (Aroor) also showed drastic decline in salinity (3-27 ppt during pre-flood period and 0 ppt during flood) due to increased river discharge. Similarly, wide variations were observed in the pH values compared to pre flood period. pH values in most of the study stations also showed acidic nature mainly due to the heavy rainfall and freshwater discharge. Compared to the permissible limits of standard values prescribed in various agencies (Table 4.6), the pH values showed values below acceptable limit during the present study period (i.e. 4.8 in SW and 4.35 in BW during flood; 4.92 in SW and 6.02 in BW during post flood). Alkalinity also showed lower values and it ranged between 15 to 55 mg L^{-1} and it was lower compared to pre flood period (25 to 100 mg L^{-1}). In the present study, dissolved oxygen showed higher values during flood period (4.7 to 10.2 mg L^{-1}) compared to pre flood period (3.94 to 7.87 mg L^{-1}) which could be due to the intense rainfall and freshwater discharge during flood. During the study period, DO values of some stations showed values below acceptable limit of standard values prescribed by various agencies such as CPCB and ICMR (Table 4.6). During flood period, DO of 3.15 mg L^{-1} was observed in bottom water at station 8. Similarly, lower values were observed during post flood period also (i.e. 3.1 mg L^{-1} in SW and 3.07 mg L^{-1} in BW at St.31). As dissolved oxygen concentration in water fall below 5.0 mg L^{-1} aquatic life is put under stress. The BOD and hydrogen sulphide showed higher values in most of the stations (especially stations south of TMB) compared to pre flood period which indicates significant levels of organic pollution in the estuary. Similarly, phosphate and silicate showed higher values in southernmost stations compared to pre flood period. This might be due to the increased terrestrial runoff during flood. Ammonia and nitrate showed higher concentration in northernmost stations which could possibly bedue to the increased sewage and industrial discharge during flood period. The GPP and NPP values were lower during the flood period compared to post flood period. Intense rainfall and increased organic load were the major factors contributing lower productivity values during flood period. Compared to pre flood period, the heavy metal concentration in Vembanad wetland showed a decreasing trend during the present study. This may be a good indication of flooding wash off, as it helps to wash off pollutants during heavy river discharge.

Table 4.6 Water quality standards and their permissible limits prescribed in various agencies

Parameters	CPCB (2000)	ICMR	WHO (2008)	US EPA (2017)	Flood, 2018		Post flood, 2018	
					Range	Average	Range	Average
Salinity (ppt)	-	-	100	-	0-31	1.28 ± 5.42	0-30	5.64 ± 9.94
pH	6.5-8.5	6.5-8.5	7-8.5	6.3-9.0	4.8-8.67	5.96 ± 0.79	4.92-7.68	6.17 ± 0.84
Alkalinity (mg L^{-1})	-	120	-	-	15-55	22.44 ± 6.97	20-95	31.15 ± 13.69
DO (mg L^{-1})	>4	5	-	-	4.7-10.2	7.26 ± 1.22	3.1-10.6	6.56 ± 1.80
BOD (mg L^{-1})	-	5	-	30	0.79-6.3	3.71 ± 1.42	0.79-5.51	2.79 ± 1.02

Table 4.7 Variation in the water quality status in Vembanad wetland during flood and post flood, 2018

Parameters	Flood (August, 2018)			Post flood (November, 2018)		
	Values/Range	Average	Status/change	Values/Range	Average	Status/change
Water quality						
Depth (m)	0.7-8	3.29 ± 1.78	Decreased	1-8	3.26 ± 1.66	Decreased
Transparency (m)	0.3-1	0.65 ± 0.19	Decreased	0.2-1	0.56 ± 0.16	Decreased
Temperature (°C)	28-32	30.03 ± 0.71	Not significant change	29-31	30.13 ± 0.57	Slightly increased
Salinity (ppt)	0-31	1.28 ± 5.42	Decreased	0-30	5.64 ± 9.94	Increased
pH	4.8-8.67	5.96 ± 0.79	Decreased	4.92-7.68	6.17 ± 0.84	Increased
Alkalinity (mg L^{-1})	15-55	22.44 ± 6.97	Decreased	20-95	31.15 ± 13.69	Increased
DO (mg L^{-1})	4.7-10.2	7.26 ± 1.22	Increased	3.1-10.6	6.56 ± 1.80	Decreased
BOD (mg L^{-1})	0.79-6.3	3.71 ± 1.42	Increased	0.79-5.51	2.79 ± 1.02	Decreased
Hydrogen sulphide (µmol L^{-1})	0.05-7.93	1.05 ± 1.49	Increased	0.05-9.62	2.88 ± 2.60	Increased
Phosphate-phosphorus (µmol L^{-1})	3.28-27.55	10.44 ± 6.36	Increased	0.89-23.06	7.41 ± 4.94	Decreased
Silicate-silicon (µmol L^{-1})	20.75-158.13	59.83 ± 34.96	Increased	0.72-63.45	28.76 ± 15.32	Decreased
Ammonia-nitrogen (µmol L^{-1})	0.03-18.11	3.12 ± 3.82	Increased	0.83-33.86	8.80 ± 6.80	Increased
Nitrite-nitrogen (µmol L^{-1})	0.65-1.58	0.92 ± 0.24	Not significant change	0.15-3.36	1.18 ± 0.85	Increased
Nitrate-nitrogen (µmol L^{-1})	1.29-9.22	2.91 ± 2.18	Increased	1.33-33.14	3.93 ± 5.46	Increased

Primary productivity						
GPP ($g C m^{-3} day^{-1}$)	0.74-3.69	1.70 ± 0.81	Decreased	1.48-5.54	4.10 ± 1.00	Increased
NPP ($g C m^{-3} day^{-1}$)	0.74-2.21	1.10 ± 0.47	Decreased	0.74-5.17	2.02 ± 1.25	Increased
Heavy metal						
Copper ($\mu g L^{-1}$)	BDL-4.375	0.40 ± 0.98	Higher	0.25-8.06	2.67 ± 1.90	Increased
Nickel ($\mu g L^{-1}$)	BDL	BDL	Decreased	BDL-9.06	0.90 ± 2.09	Increased
Cadmium ($\mu g L^{-1}$)	BDL	BDL	Decreased	BDL-9.38	0.41 ± 1.57	Increased
Lead ($\mu g L^{-1}$)	BDL-9.38	1.88 ± 2.74	Higher	BDL-46.26	3.51 ± 9	Increased
Zinc ($\mu g L^{-1}$)	1.25-145.63	24.71 ± 31.26	Higher	4.16-166.25	35.93 ± 34.76	Increased
Iron ($\mu g L^{-1}$)	4.75-918.75	524.10 ± 230.56	Higher	103.44-2202.5	474.70 ± 405.71	Increased

Salient findings…

- *Depth showed drastic decrease in most of the study stations (mainly stations south of TMB).*
- *Heavy river discharge and land runoff during flood period significantly affects the transparency values.*
- *Salinity showed wide variation and southernmost stations exhibited purely limnetic condition.*
- *Intense freshwater discharge and heavy rainfall during flood reduces the pH and alkalinity in most of the study stations in Vembanad wetland.*
- *DO showed higher values indicating enormous freshwater discharge from rivers.*
- *BOD and hydrogen sulphide showed higher values indicating organic pollution in the wetland system.*
- *Inorganic nutrients showed higher concentration compared to pre flood period.*
- *Intense rainfall and organic load during flood significantly affects the productivity of the Vembanad wetland.*
- *Extreme river discharge and heavy rainfall reduces the heavy metal concentration in water in most of the study stations compared to pre flood period. However, cadmium was higher compared to the standards.*
- *The flood impact created on the water quality and primary productivity continued to influencing the wetland even during the post flood period to a large extent. This indicates that, the environmental degradation of the wetland due to various anthropogenic factors is inherently influencing the overall ecological status and wellbeing of the ecosystem inspite of the prevailing flood and post flood condition in 2018.*

5. IMPACT OF FLOOD AND POST FLOOD ON THE SEDIMENT CHARACTERISTICS IN VEMBANAD WETLAND

5.1 Introduction

In an aquatic ecosystem, sediment provides a habitat for many organismsand also acts as sink and source of contaminants. Sediment particles reach rivers, lakes, streams, estuaries and ocean through wind, water and ice. Studies on the role of sediments in a natural water body in element cycles, transportation of nutrients and contaminants and preservation of the water quality are important for the understanding of an aquatic ecosystem. According to Dethier (1990), the primary physical parameters influencing the distribution of organisms in estuaries are sediment composition, salinity and elevation. Any variation in sediment property affects the quality and cause habitat variation, ultimately leading to the alteration of biological communities.Weathering and erosion of continental areas act as a major source of sediment in coastal areas. Sediments are mainly transported by rivers in the form of suspended load and most of the aquatic system especially river system is facing flow restriction due to the construction of dams and reservoirs. It acts as an obstacle for the movement of sediment and forms permanent sediment traps.

Sediments are significant because many toxic substances which are found in trace amounts in water are found in elevated levels in them. As such, sediments serve both as reservoirs and as potential sources of contaminants to the water column. Besides this, their potential to degrade surface water quality, sediment-associated contaminants have the potential to affect benthic and other sediment-associated organisms directly (Chapman, 1989). The presence of chemicals and toxic pollutants in sediment will also reduce the water holding capacity of the soil. Sediment contaminants are transferred to the water column through physical disturbance, diffusion, and biological activities. Therefore, sediment quality data provide essential information of ambient environmental conditions in aquatic ecosystems.

5.2 Results

5.2.1 Sediment temperature

During flood, the sediment temperature ranged between 27 to 30 °C (av. 28.56 ± 0.64 °C). The minimum temperature of 27 °C was observed at St.11 and maximum value of 30°C was recorded at St.3 and St.7 (Fig. 5.1). During post flood, the average sediment temperature was found to be 28.82 ± 0.68 °C and it ranged between 27 to 30 °C. The highest value recorded at stations 5, 7, 15, 25 and 32 whereas the lowest value recorded at St.17. In the present study, the average sediment temperature was maximum during post flood period compared to the flood period.

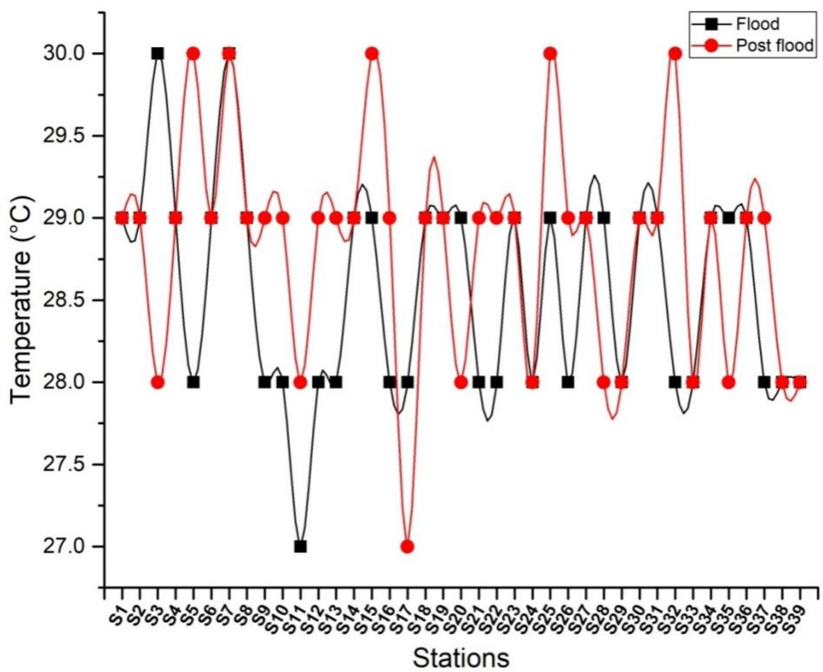

Fig 5.1 Spatial variation of sediment temperature (°C) in Vembanad wetland system during flood and post flood, 2018

5.2.2 Total Nitrogen

In the present study during flood, the TN in Vembanad wetland system ranged from 1.75 g kg^{-1} to 7 g kg^{-1}. The highest concentration was found in station 7 and lowest concentration in stations 2, 13, 31 and 36. During post flood, highest concentration was found in stations 1, 6, 12, 17, 22, 26, 30, 31, 37 and 39 (Fig. 5.2). TN was found positively correlated with sediment bound Ni (r = 0.163) [$p<0.05$] and silicate (r = 0.403) [$p<0.01$]. TN was also found negatively correlated to pH (r = 0.187), NPP (r = 0.185), sulphide (r = 0.200) [$p<0.05$], GPP (r = 0.478), ammonia (r = 0.294), water bound metals like Cu (r = 0.297) and Ni (r = 0.230) [$p<0.01$].

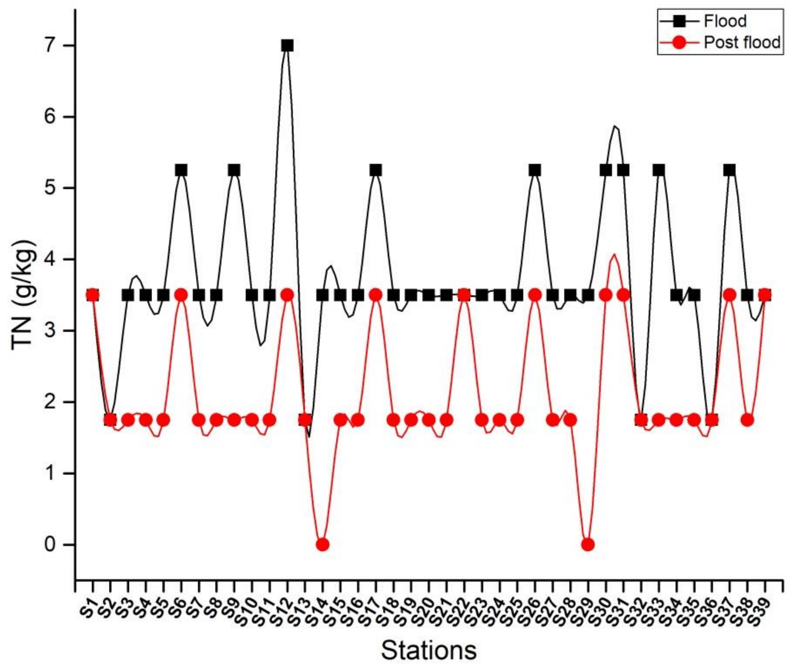

Fig. 5.2 Spatial variation of total nitrogen (g kg^{-1}) in Vembanad wetland system during flood and post flood, 2018

5.2.3 Distribution of heavy metals in sediment samples

In the study, the distribution of **copper** in sediment samples of Vembanad wetland system during flood period ranged from 3.05 to 242.5 mg kg^{-1} (Fig. 5.3). The highest value of copper was noted in station 1 and the lowest value in station 3. During post flood, the concentration ranged from 0.4 to 91.5 mg kg^{-1} (Fig. 5.4). The highest value was noted in station 22 and the lowest in station 36 (Fig 5.4). In the present study, Cu showed a positive correlation with salinity (r = 0.160), alkalinity (r = 0.161), water bound metals like Ni (r = 0.161), Pb (r = 0.185) [$p<0.05$], GPP (r = 0.446), NPP (r = 0.250), ammonia (r = 460), sulphide (r = 0.593), nitrate (r = 0.234) and water bound Zn (r = 0.218) [$p<0.01$].

The **nickel** concentration during flood ranged from 6 mg kg^{-1} (Station 36) to 78.35 mg kg^{-1} (Station 16). During post flood, the Ni concentration ranged from 4.1 to 118.5 mg kg^{-1}. The highest value was found in station 14 and the lowest in station 36. The Ni was found to be positively correlated with salinity (r = 0.175), alkalinity (r = 0.164), pH (r = 0.162), GPP (r = 0.181), water bound metals like Cu (r = 0.161) [$p<0.05$] and Pb (r = 0.679) [$p<0.01$].

The **cadmium** concentration in study stations ranged from BDL to 1.32 mg kg^{-1} and the highest value was found in station 34. During post flood, the concentration of cadmium ranged from BDL to 7.5 mg kg^{-1} and the highest value was observed in station 37. Cd showed a positive correlation with DO (r = 0.162), nitrite (r = 0.168) [$p<0.05$], salinity (r = 0.274), pH (r = 0.223), NPP (r = 0.401), ammonia (r = 0.295), water bound Fe (r = 0.584), sediment bound metals like Cd (r = 0.562), Pb (r = 0.576) and Zn (r = 0.521) [$p<0.01$].

The concentration of **lead** in Vembanad wetland during flood ranged from BDL to 322.5 mg kg^{-1}. The high concentration was found in station 34 and the lowest in station 39. During post flood, concentration ranged from 1.05 to 472.5 mg kg^{-1}. The highest concentration was found in station 34 and lowest in 33. Pb was positively correlated with water bound Cu (r = 0.185) [$p<0.05$], nitrate (r = 0.218), water bound metals like Ni (r = 0.679) and Zn (r = 0.212) [$p<0.01$].

The concentration of **zinc** was maximum (1392 mg kg^{-1}) in station 34 and minimum (46.55 mg kg^{-1}) in station 3 during flood. During post flood, the concentration ranged from 68 to 1758 mg kg^{-1}. The maximum concentration was found in station 37 and minimum in station 15. Zn showed a positive correlation with sediment bound Zn (r = 0.179) [$p<0.05$], salinity (r = 0.457), pH (r = 0.358), GPP (r = 0.262), NPP (r = 0.322), nitrate (r = 0.544), water bound metals like Cu (r = 0.218) and Pb (r = 0.212), sediment bound metals like Cd (r = 0.315) and lead (r = 0.407) [$p<0.01$].

During flood, high **iron** concentration of 54150 mg kg^{-1} was found in station 23 and low concentration of 4377 mg kg^{-1} in station 7 (Fig 5.3). During post flood, concentration ranged from 3236.5 to 58450 mg kg^{-1}. The highest concentration was found in station 34 and lowest in station 7 (Fig 5.4). In the present study, Fe showed a positive correlation with sediment bound Cu (r = 0.173), Pb (r = 0.204), water bound Cd (r = 0.584), sediment bound Cd (r = 0.225), Zn (r = 0.235) and Fe (r = 268).

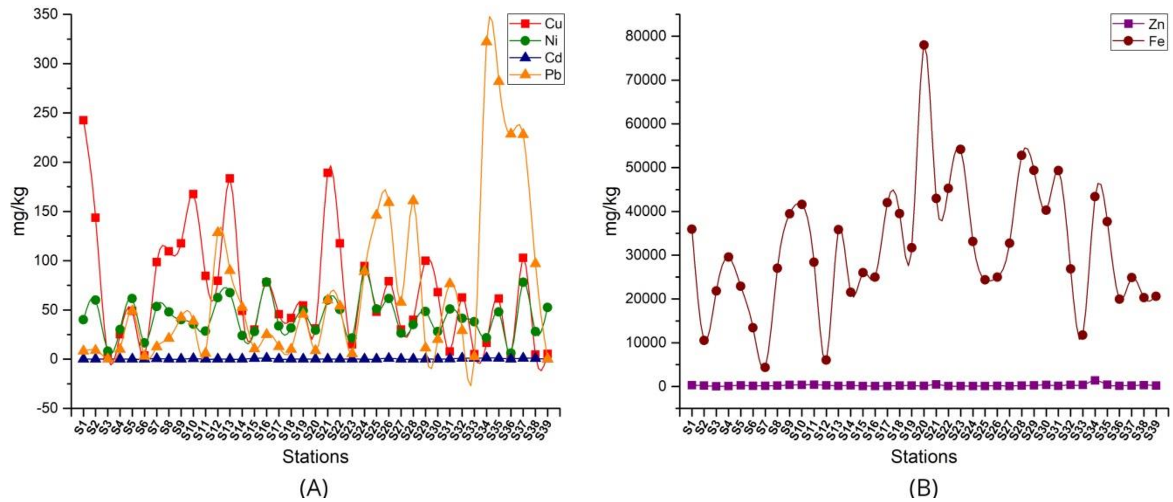

Fig. 5.3 Spatial variation of heavy metals in sediment samples (mg kg^{-1}) in Vembanad wetland system during flood, 2018

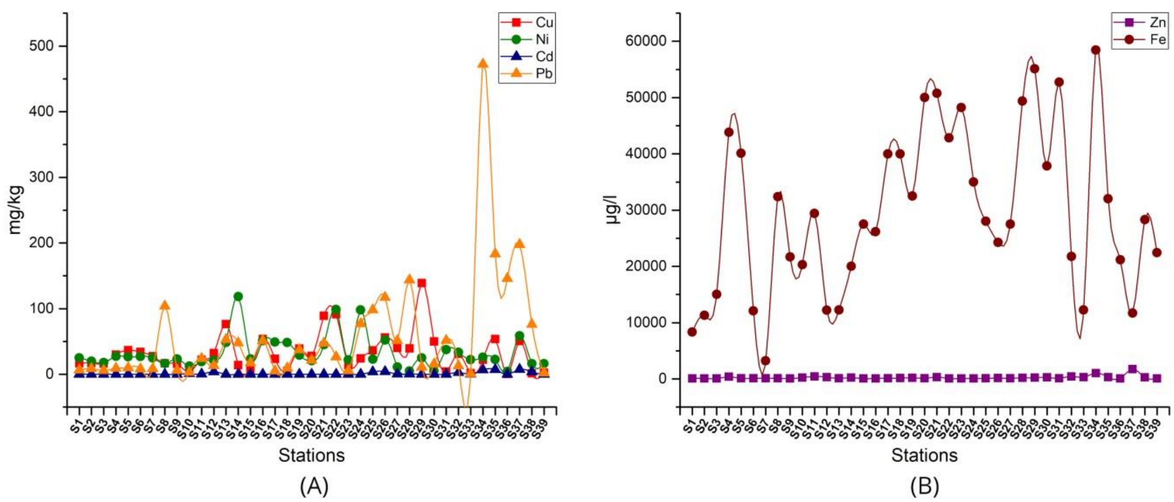

Fig. 5.4 Spatial variation of heavy metals in sediment samples (mg kg^{-1}) in Vembanad wetland system during post flood, 2018

5.2.3.1 Pollution indices

a. Geoaccumulation index (Igeo) values of heavy metals in sediment samples

Copper

In the present study period, Igeo value of Cu during flood ranged from a minimum value of 0.05 at station 3 to a maximum value of 3.59 at station 1 (Fig. 5.5). During post flood, the value was maximum (2.06) in station 29 and minimum (0.01) in station 36. The analysis revealed that during flood, stations 7, 8, 9, 11, 12, 16, 22, 24, 26, 29, 30 and 37 were in class 2 (moderately contaminated), stations 2, 10 13 and 21in class 3 (moderately to strongly contaminated), station 1 in class 4 (strongly contaminated) and all other stations in class 1 (uncontaminated to moderately contaminated). But during post flood, stations 13, 21 and 22 werein class 2 (moderately contaminated), station 29 in class 3 (moderately to strongly contaminated) and all other stations in class 1 (uncontaminated to moderately contaminated).

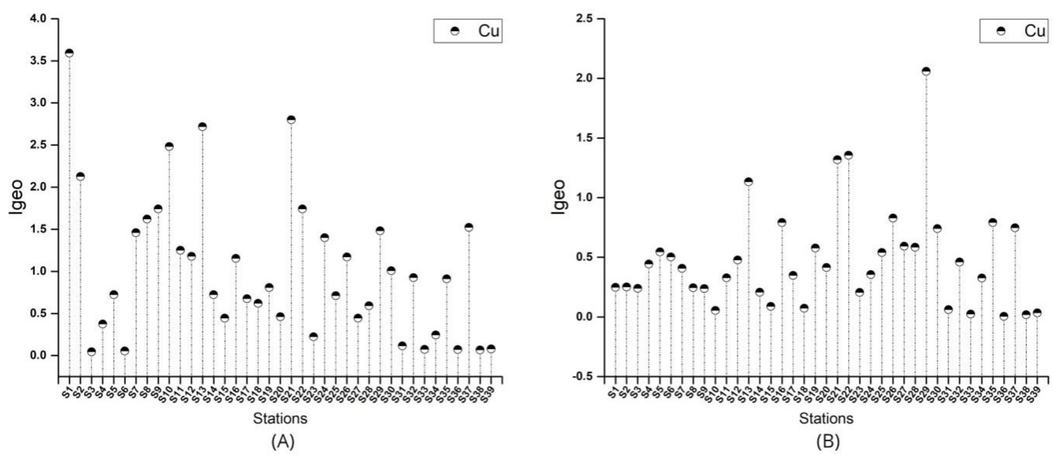

Fig. 5.5 Spatial variation of Geoaccumulation index in Cu in Vembanad wetland system during flood (A) & post flood (B), 2018

Nickel

During flood, the Igeo value of Ni ranged from a minimum value of 0.2 at station 36 to a maximum value of 2.98 at station 24 (Fig. 5.6). In the case of post flood, the value was maximum (3.95) in station 14 and minimum (0.14) in station 36. The study showed that stations 3, 4, 6, 11, 14, 15, 20, 23, 27, 30, 34, 36 and 38 were found to be in class 1 (uncontaminated to moderately contaminated), stations 5, 12, 13, 16, 21, 24, 26 and 37 in class 3 (moderately to strongly contaminated) and all other stations in class 2 (moderately contaminated) during flood. In case of post flood, stations 13, 16, 17, 18, 21, 26, 31, 32 and 37 in class 3 (moderately to strongly contaminated), stations 14, 22 and 24 in class 4 (strongly contaminated) and all other stations were in class 1 (uncontaminated to moderately contaminated) .

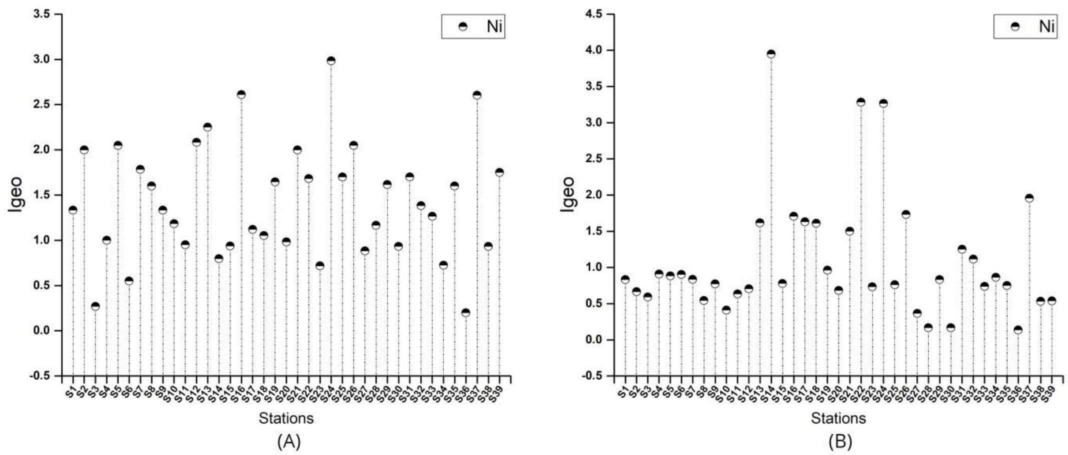

Fig. 5.6 Spatial variation of Geoaccumulation index in Ni in Vembanad wetland system during flood (A) & post flood (B), 2018

Cadmium

The Igeo value of Cd during flood ranged from 0 to 2.93. The high value was noticed in station 34 (Fig. 5.7). During post flood, the values ranged from 0 to 16.67 and the high value was found in station 37. It was observed that during flood, stations 31, 36 and 39 were found in class 1 (uncontaminated to moderately contaminated), stations 7, 10, 15, 26 and 38 in class 2 (moderately contaminated) and stations 16, 32, 33, 34, 35 and 37 in class 3 (moderately to strongly contaminated). In the case of post flood, stations 11 and 27 were found in class 1 (uncontaminated to moderately contaminated), stations 10, 28 and 33 in class 2 (moderately contaminated) and stations 12, 25, 26, 32, 34, 35, 37 and 38 in class 6 (extremely contaminated).

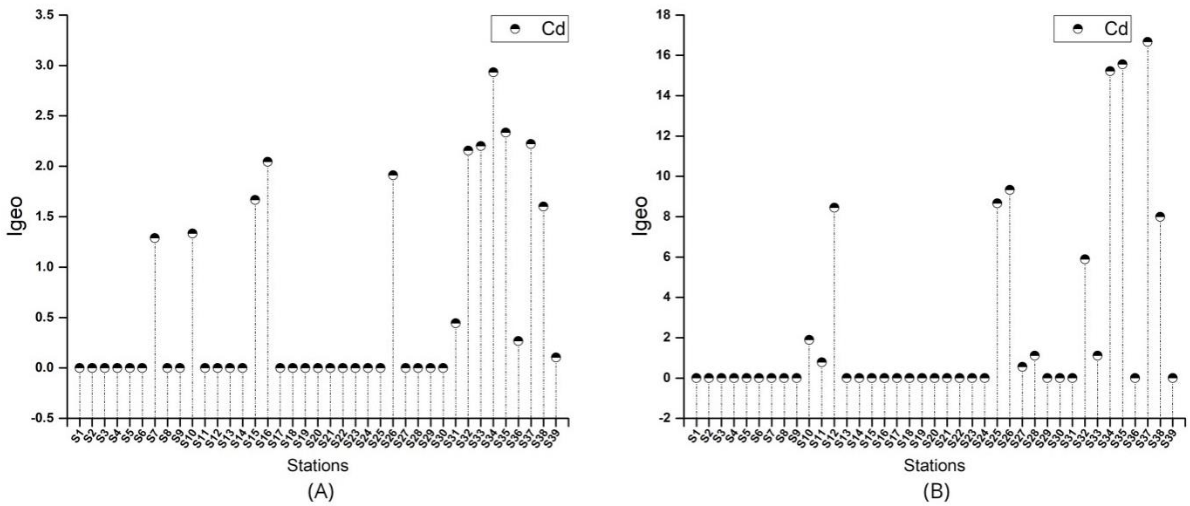

Fig. 5.7 Spatial variation of Geoaccumulation index in Cd in Vembanad wetland system during flood (A) & post flood (B), 2018

Lead

In the present study, the Igeo value of Pb during flood ranged from a minimum value of 0.01 at station 39 to a maximum value of 10.74 at station 34 (Fig. 5.8). During post flood, the value was maximum (15.75) in station 34 and minimum (0.04) in station 33. The study showed that during flood, the stations 5, 9, 10, 14, 19, 21, 22 and 27 were found in class 2 (moderately contaminated), stations 24 and 31 in class 3 (moderately to strongly contaminated), stations 13 and 38 in class 4 (strongly contaminated), stations 12 and 25 in class 5 (strongly to extremely strongly contaminated), stations 26, 28, 34, 35, 36 and 37 in class 6 (extremely contaminated) and all other stations in class 1 (uncontaminated to moderately contaminated). If we take the case during post flood, the stations 13, 14, 16, 19, 21, 27 and 31 in class 2 (moderately contaminated), stations 24 and 38 in class 3 (moderately to strongly contaminated), stations 8, 25 and 26 in class 4 (strongly contaminated), stations 28 and 36 in class 5 (strongly to extremely strongly contaminated), stations 34, 35 and 37 in class 6 (extremely contaminated) and all other stations in class 1 (uncontaminated to moderately contaminated).

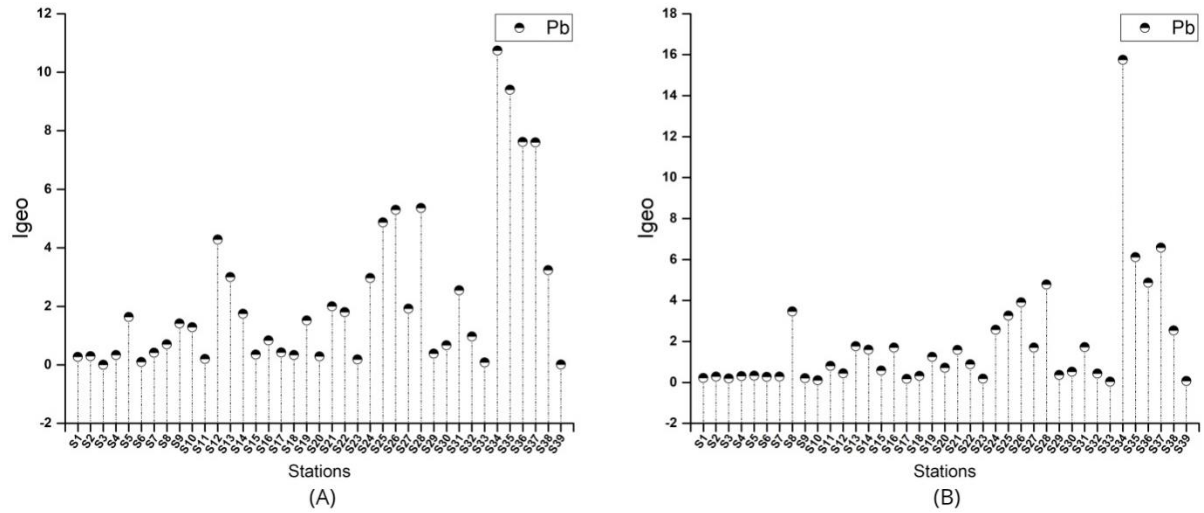

Fig. 5.8 Spatial variation of Geoaccumulation index in Pb in Vembanad wetland system during flood (A) & post flood (B), 2018

Zinc

During flood, Igeo value of Zn ranged from a minimum value of 0.33 at station 3 to a maximum value of 9.77 at station 34 (Fig. 5.9). During post flood, the value was maximum (12.34) in station 37 and minimum (0.04) in stations 9 and 3. The present study revealed that during flood, stations 3, 4, 15, 16, 17, 22, 23, 24, 24, 25 and 27 were in class 1 (uncontaminated to moderately contaminated), stations 1, 9, 10, 11, 30, 32, 33, 35 and 38 inclass 3 (moderately to strongly contaminated), station 21 in class 4 (strongly contaminated), station 34 in class 6 (extremely contaminated) and all other stations inclass 2 (moderately contaminated). But in post flood, stations 10, 14, 18, 19, 26, 28, 29 and 30 were found in class 2 (moderately contaminated), stations 4, 12, 21, 33, 35 and 38 in class 3 (moderately to strongly contaminated), stations 11 and 32 in 4 (strongly contaminated), stations 28 and 36 in class 5 (strongly to extremely strongly contaminated), stations 34 and 37 in class 6 (extremely contaminated) and all other stations in class 1 (uncontaminated to moderately contaminated).

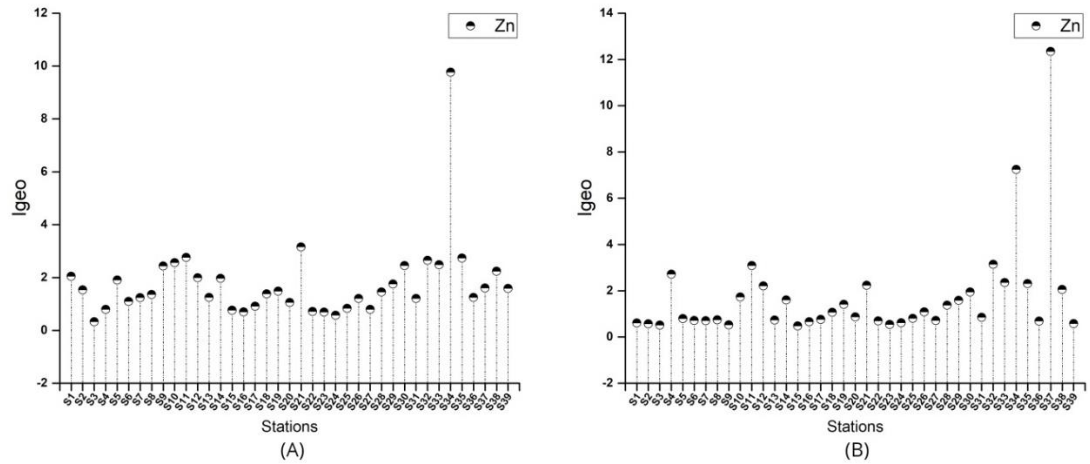

Fig. 5.9 Spatial variation of Geoaccumulation index in Zn in Vembanad wetland system during flood (A) & post flood (B), 2018

Iron

In the present study, the Igeo value of Fe during flood ranged from a minimum value of 0.06 at station 7 to a maximum value of 1.10 at station 20 (Fig. 5.10). During post flood, the value was maximum (0.83) in station 34 and minimum (0.05) in station 7. The study showed that during flood, station 10 was found in class 2 (moderately contaminated) and all other stations in class 1 (uncontaminated to moderately contaminated). In the case of post flood, all stations were found in class 1 (uncontaminated to moderately contaminated).

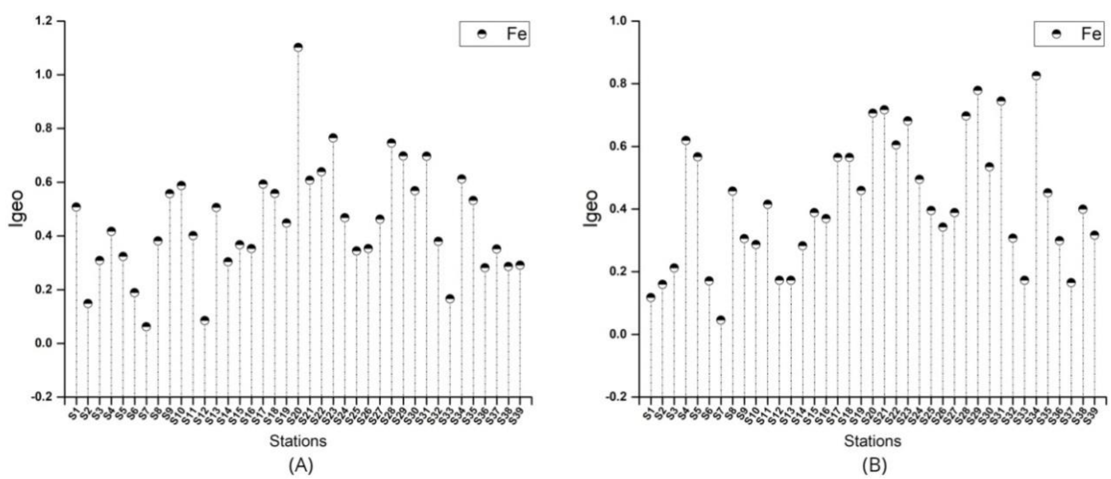

Fig. 5.10 Spatial variation of Geoaccumulation index in Fe in Vembanad wetland system during flood (A) & post flood (B), 2018

b. Contamination factor (CF) values of heavy metals in sediment samples

Copper

During the study period, contamination factor (CF) value of Cu during flood ranged from a minimum value of 0.07 at station 3 to a maximum value of 5.39 at station 1 (Fig. 5.11). During post flood, the CF was maximum (3.09) in station 29 and minimum (0.03) in station 39. As per the present study, stations 3, 4, 6, 15, 18, 20, 23, 27, 28, 31, 33, 34, 36, 38 and 39 showed low contamination factor, stations 1, 2, 10, 13 and 21 showed considerable contamination factor and all other stations showed moderate contamination factor during flood. In case of post flood, the stations 13, 16, 21, 22, 26, 30, 35 and 37 showed moderate contamination factor, station 29 showed considerable contamination factor and all other stations showed low contamination factor.

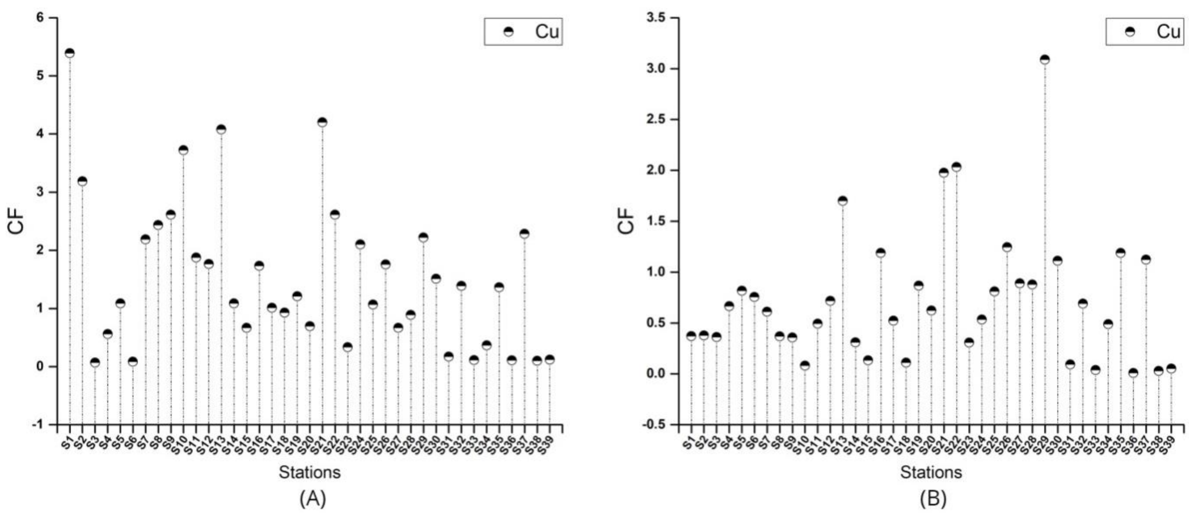

Fig. 5.11 Spatial variation of CF in Cu in Vembanad wetland system during flood (A) & post flood (B), 2018

Nickel

The CF value of Ni ranged from a minimum value of 0.3 at station 36 to a maximum value of 4.48 at station 24 during flood (Fig. 5.12). In post flood, the CF was maximum (5.93) in station 14 and minimum (0.21) in station 36. In the present study during flood, station 3, 6 and 36 showed low concentration factor, stations 12, 13, 16, 24, 26 and 37 showed considerable contamination factor and all other stations showed moderate contamination factor. During post flood, stations 3, 8, 10, 11, 27, 28, 30, 36, 38 and 39 showed low concentration factor, stations 14, 22 and 24 showed considerable contamination factor and all other stations showed moderate contamination factor.

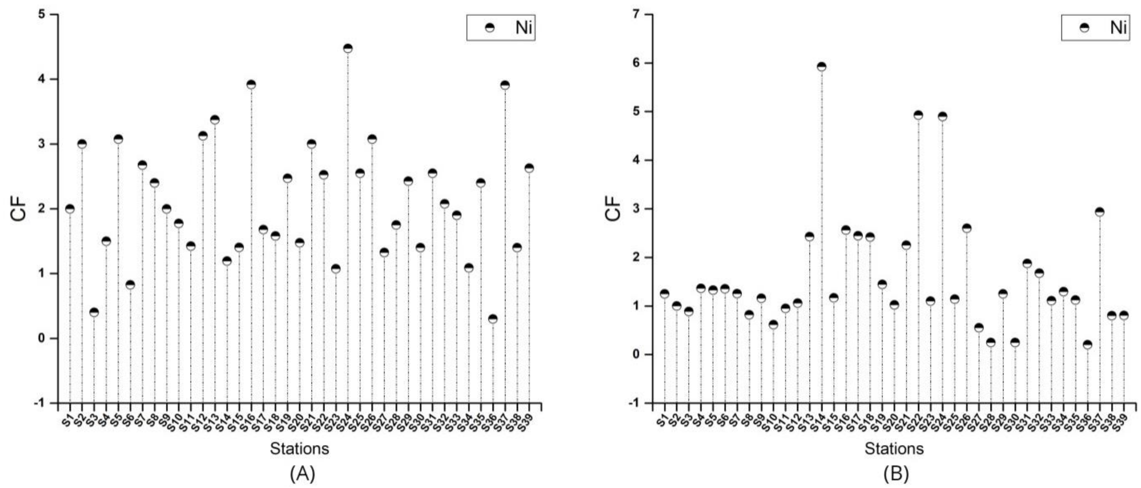

Fig. 5.12 Spatial variation of CF in Ni in Vembanad wetland system during flood (A) & post flood (B), 2018

Cadmium

The CF value of Cd during flood ranged from a minimum value of 0 to a maximum value of 4.4 at station 34 (Fig. 5.13). During post flood, the CF value ranged from 0 to a maximum value of 23.33 at station 35. In the case of Cd, stations 7, 15, 26 and 38 showed moderate contamination factor, stations 16, 32, 33, 34, 35 and 37 showed considerable contamination factor and all other stations were having low contamination factor during summer. But in case of post flood, stations 10, 11, 28 and 33 showed moderate contamination factor, stations 12, 25, 26, 32, 34, 35, 37 and 38 showed very high contamination factor and all other stations showed low contamination factor.

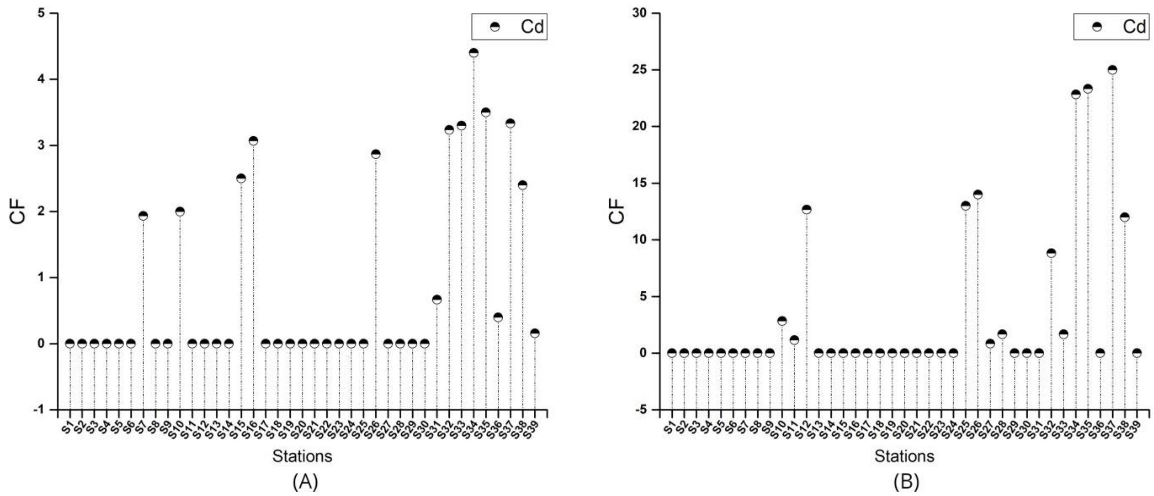

Fig. 5.13 Spatial variation of CF in Cd in Vembanad wetland system during flood (A) & post flood (B), 2018

Lead

During flood, the CF value of Cd ranged from a minimum value of 0 at station 3 to a maximum value of 16.11 at station 34 (Fig. 5.14). But in post flood, the CF value was maximum (23.67) in station 34 and minimum (0.05) in station 33. As per the study during flood, the stations 5,8, 9, 10, 14, 16, 19, 21, 22, 27 and 32 had moderate contamination factor, stations 13, 24, 31 and 38 had considerable contamination factor, stations 12, 25, 26, 28, 34, 35, 36 and 37 showed very high contamination factor and all other stations showed low concentration factor. During post flood, stations 11, 13, 14, 16, 19, 20, 21, 21, 22, 27 and 31 showed moderate contamination factor, stations 8, 24, 25, 26 and 38 showed considerable contamination factor, stations 28, 34, 35, 36 and 37 showed very high contamination factor and all other stations showed low concentration factor.

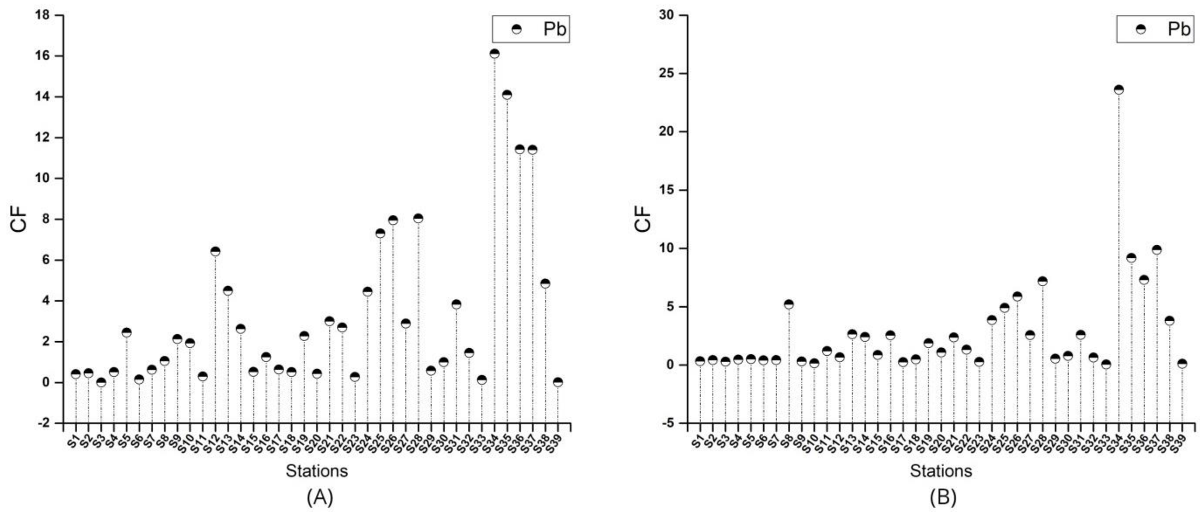

Fig. 5.14 Spatial variation of CF in Pb in Vembanad wetland system during flood (A) & post flood (B), 2018

Zinc

During flood, the CF value of Zn ranged from a minimum value of 0.49 at station 3 to a maximum value of 14.65 at station 34 (Fig. 5.15). In the case of post flood, the CF was maximum (18.51) in station 37 and minimum (0.72) in station 15. In the case of Zn, stations 3 and 24 showed low contamination factor, stations 1, 9, 10, 11, 21, 30, 32, 33, 36 and 38 showed considerable contamination factor, station 34 showed very high contamination factor and all other stations showed moderate contamination factor during flood. In post flood, stations 1, 2, 3, 9, 15, 16, 23, 24 and 39 showed low contamination, stations 4, 11, 12, 21, 32, 33, 35 and 38 showed considerable contamination factor, stations 34 and 37 showed very high contamination factor and all other stations showed moderate contamination factor.

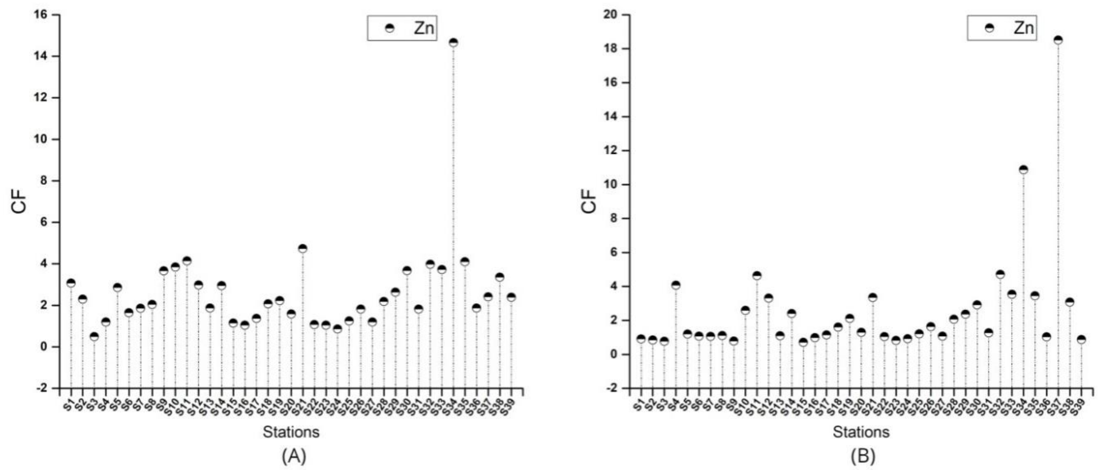

Fig. 5.15 Spatial variation of CF in Zn in Vembanad wetland system during flood (A) & post flood (B), 2018

Iron

During flood, the CF value of Fe ranged from a minimum value of 0.09 at station 7 to a maximum value of 1.65 at station 20 (Fig. 5.16). In the case of post flood, the CF was maximum (1.24) in station 34 and minimum (0.07) in station 7. The study showed that during flood, the stations 20, 23, 28, 29 and 31 showed moderate contamination factor and all other stations showed low contamination factor. But in case of post flood, stations 20, 21, 23, 28, 29, 31 and 34 showed moderate contamination factor and all other stations showed low contamination factor.

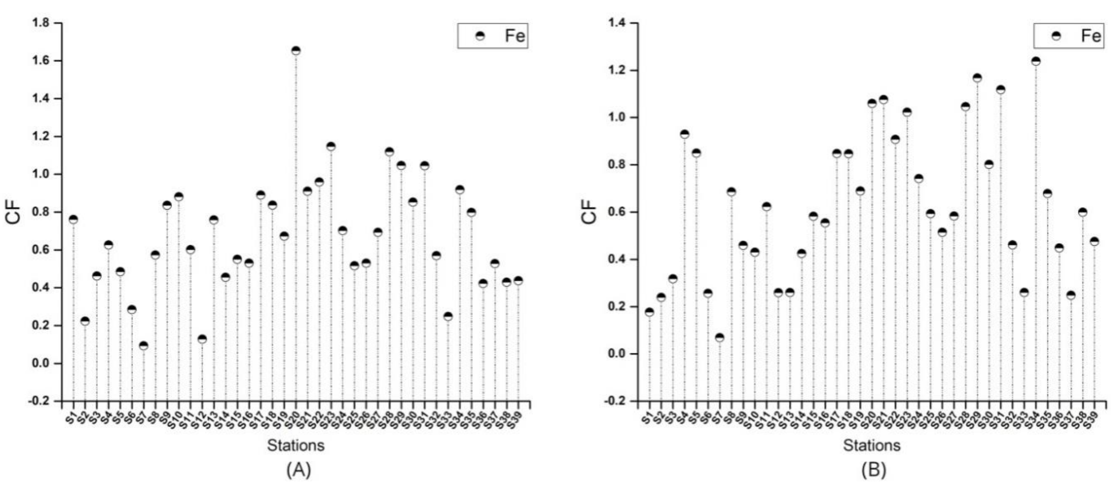

Fig. 5.16 Spatial variation of CF in Fe in Vembanad wetland system during flood (A) & post flood (B), 2018

5.2.4 Data analysis

5.2.4.1 Principal Component Analysis (PCA)

The data for the flood and post flood period were processed by applying PCA in order to gain information on the distribution of sediment parameters in Vembanad wetland (Fig. 4.19). Principal component analysis (PCA) extracted two principal components (PCs) from the variance present in the data. The PCA was carried out with factors having eigenvectors higher than one. Factor loadings (correlations between the variables and the extracted factors) for the two retain Eigen values are given in Table 4.1. The first PC accounted for 21.8 % variability with an Eigen value of 6.1 and second PC accounted for 10.6 % variability with Eigen value of 2.98, whereas the remaining PCs each explained < 10 % of the variation. The variables with highest loadings on PC1 were sediment bound Cu and Ni.

5.2.4.2 Multiple regression analysis

Multiple regression analysis of edaphic factors like rainfall and river discharge were carried with sediment characteristics revealed that, rainfall had significant influence on sediment bound metals like Cu and Zn during flood ($p<0.05$) (Table 4.2). Similarly, river discharge showed significant influences on sediment bound Cu ($p<0.05$) and sediment bound Ni and Pb during flood period ($p<0.01$) (Table 4.3).

5.3 Discussion

Sediment temperature is considered as one of the key environmental factors affecting the life of marine organisms. Any variation in temperature affects the geographic and bathymetric species distribution patterns (Portner, 2001). Spatial and seasonal variation in sediment temperature influences the CO_2 production in lake sediments and out of the total production, 83 % was released during the spring and summer season (Bergstrom *et al.*, 2010). In the present study, the spatial variations in temperature occurred mainly due to the differences in sampling times. The sediment temperature fluctuations are influenced by atmospheric and water temperature. Similarly it presumably increases in relation to bottom water temperatures. In the present investigation, comparatively lower value observed during flood period (av. 28.56 ± 0.64 °C) and higher value observed during post flood period (28.82 ± 0.68 °C). The increased rainfall and river discharge during flood might be contributed to the lower value during flood period whereas diminishing river discharge and rainfall may increases the sediment temperature during post flood.

The result shows that there was a good impact of flood in total nitrogen concentration in sediments. The study revealed that nitrogen load in the estuary was boosted up by the recent flood compared to previous study conducted in Vembanad wetland (Verma and Subramanian, 2002). The increased river and agricultural discharges during flood period may form a major source of nitrogen in the estuary. Apart from this, sewage discharges from houseboats, human settlements and municipal waste from Alappuzha town also contribute a major share. The sediment nitrogen was mainly derived by decomposition of plants and animals or plankton or anthropogenic sources such as chemical contaminants, fertilizers or organic rich waste (Avramidis *et al*., 2015).

Nitrogen is a vital element for life, but most of the nitrogen in the biosphere is unreactive and unavailable to organisms. Unreactive nitrogen can be converted into reactive nitrogen by natural processes and human activities (Castro *et al*., 2003). In recent decades, due to increased human activities along with greater use of nitrogen fertilizer and fossil fuel combustion have greatly modified the balance of the nitrogen cycle in estuarine and coastal environments (Bricker *et al*., 2008) and has caused widespread eutrophication, hypoxia and anoxia, loss of biodiversity, and increased harmful algal blooms (Anderson, 2002). Most of the nitrogen leading to eutrophic estuaries comes from land-based sources and not from the ocean, so the coastal nutrient pollution is mainly from the modification of nitrogen sources made by human controlled alterations with the natural nitrogen fixation (Nixon *et al*., 1996). From this point of view, human-controlled processes may now exceed the natural processes or at least are approaching this if the natural rate of nitrogen fixation is at the higher end of the range suggested by Cleveland *et al*. (1999). In estuarine and marine habitats, sediments are important sites for organic matter deposition and nutrient cycling (Dunn *et al*., 2012). The methods of sediment nitrogen mineralization are closely linked with sediment nitrogen input and less, which has great ecological role in maintain the ecosystem health (Bai *et al*., 2012).

Floods play a key role in the remobilization of heavy metals from historically polluted deposits. In addition, floods which usually account for just a small percentage of the annual discharge are a phenomenon that creates and reshapes the floodplain and is responsible for the transfer of metal contaminants from temporary sinks in the channel. In both dissolved and solid phases, heavy metals are discharged in amounts that differ greatly depending on the properties of the element, sources of contamination and chemistry of the receiving river waters. Heavy metals are discharged in both dissolved and solid phases in proportions that vary greatly depending on the element properties, pollution sources and chemistry of receiving river waters. Owing to their extended residence period (tens to thousands of years) in river sediments, heavy metals transported in the particulate phase or attached to suspended solids pose a significant environmental danger (Hudson-Edwards *et al.*, 2001).

The present study in the Vembanad wetland system shows a decrease in overall accumulation of heavy metals in sediment during flood compared to the previous studies. The average concentration of heavy metals in the study period followed the trend Fe>Zn>Cu>Pb>Ni>Cd during flood and Fe>Zn>Pb>Ni>Cu>Cd during post flood period. Similarly, in Cochin estuary, the average concentration of heavy metals in sediments followed the order Pb>Cd>Hg and exhibited the highest values at harbour region (Xavier *et al*., 2019). According to Robin *et al*. (2012), the reduced flushing along with industrial discharge entering to the harbour via Thanneermukkom could be responsible for the enrichment of these metals in the estuary. In the present study, the average values of Cu, Ni, Cd, Pb, Zn and Fe during flood were 68.96, 42.64, 0.26, 67, 251.21 and 31674 mg kg^{-1} respectively. In case of post flood, the average values of Cu, Ni, Cd, Pb, Zn and Fe were 32.34, 32.56, 1.08, 56.05, 239.89 and 29700 mg kg^{-1}.

The qualitative analysis of the sediment based on Sediment Quality Guidelines (SQG) showed that the wetland system was heavily polluted with the metals Cu and Zn during flood. To an extend Pb is also showing heavy pollution. As the discharge increases, the concentrations of suspended particulate matter and pollutant contents increase, particularly in the early stage of floods. Their values sometimes remain high even during the flood attenuation (Resongles *et al.*, 2015; Müller and Wessels, 1995). In Kuttanad region, a mass area of agricultural fields was flooded in the 2018 flood. As per many reports, the copper and zinc based pesticides and fungicides are known to be used for cropping in these areas. Some manures and bio solids are also reported to contain high concentrations of copper and zinc, and their application over time may lead to soil contamination (Hargreaves *et al*., 2008). So, the stripping of top soils from these areas that are potentially enriched in these metals may partly explain the high input of Zn and Cu into wetland system. A study conducted by Coates-Marnane *et al.* (2016) reported that the 2011 flood is responsible for a considerable input of Zn, Cu, and Pb to central Moreton Bay. In this study also, Zn and Cu was paired with high concentrations of Pb, which is not a component of productsused in irrigated agriculture.

The study revealed that the northern stretch of the Vembanad wetland system, the Cochin estuary, is still the major hub of heavy metal accumulation. Cochin estuary does not permit periodic flushing out of pollutants due to its low-lying nature leading the area to become a large heavy-metal sink. The industrialization and rapid urban development during the recent past around Cochin area have led to the elevated metal concentrations. Most of major industries (70 %) of Kerala are located in the study area, and a huge amount of effluent wastes from these industries are released into the Cochin backwaters, which contribute to the increase of metal contents. The Igeo values showed that the wetland was moderately polluted with the metals during both flood and post flood period in the study. In case of CF, the Pb showed considerable contamination factor during flood. Cheranelloor and Eloor were the stations with high amount of Pb in the study. In a previous study conducted by CUSAT (2019) during pre-flood, Cd showed a higher contamination factor. But during flood, the value was low and in case of post flood, it again reached to considerable contamination.

According to Leenaers *et al.* (1989), slight increase in river discharge can cause the erosion of thin layer of the fine-grained contaminated channel sediments as they may be suspended at relatively low shear stress. The alluvial floor of the channel and bank deposits are mobilised and sediments are added from the catchment through tributary and over land flow during high flood discharges (Miller *et al.*, 1999; Marcus, 1987). The addition of unpolluted sediments from tributaries or overland flow often results in dilution of the suspension load and in a decrease of heavy metal concentrations in the redeposited channel-fill sediment (Hellmann, 1994; Bradley, 1984). It is comprehensible that within 1 year or less, the general level of pollution is likely to be restored in the system. So it is high time to give more attention to the crisis. More precise environmental conservation measures to monitor the discharge of heavy metals from anthropogenic sources should be taken.

Principal Component Analysis (PCA) was carried in order to find out the sediment characteristics, which was influencing the study area. The high loading observed for sediment bound Cu and Ni was mainly due to the intense pollution problems in the Vembanad wetland system. In addition, increased tourism activities, organic load and waste discharge from nearby cities are also major contributing factors.

The soil structure of Kerala has changed drastically. Soil is very sensitive and any interference with its nature and structure will have consequences. Kerala's rain is traditionally spread over a period of two to two-and-a-half months. But now about half the annual rain is received in about one or two weeks. This is making a big impact on the soil structure. It is clearly visible over the last two years and in this year also, the case is not changed. It was a verdant green hill that was razed to the ground with rocks boulders and earth falling over the living quarters of Pettimudy estate employees near Rajamala within the Eravikulam National Park. One of the most common human activities has been massive deforestation, mostly for plantations. Another significant interference with the structure and lay of the land is monocropping and quarrying.

Over the last two years, a worrying new threat has emerged in the state in the form of soil piping. During heavy rains, cracks develop in earth and muddy water containing deep sand and soil pumps through these cracks. This phenomenon is called “soil piping”. Rains cause continual erosion of surface layer of the soil and it leaves nothing beneath to sustain leading to an eventual ground collapse. It begins as an erosion of underground water, creating an underground tunnel called the soil pipe. The continuous flux of water along the pipe erodes the surface earth over a period of time, resulting in a collapse of the earth above. Scientists from the National Centre for Earth Science Studies (NCESS) said that, land subsidence, lateral spread and soil piping were immediate threats to life and property, especially in the high lands. In the wake of heavy rains during 2018 flood, 10 families of Paikadan Mala in Kozhikode district were temporarily rehabilitated in concerns about soil piping in the area. When trees are cut and their roots are left to rot, they decay over decades to form pipes through which the soil substrata are directly injected with rain water. This leads to the formation of a sludge-like slippery layer that oozes to the hard rock, resulting in loss of grip and stability in the layer above. Unless pre-emptive steps are taken, land will continue to slip and slide and kill lives, says Dr. V. R. Haridas, hydro-geologist, who had extensively researched the August 2019 Kavalappara and Puthumala landslips as advisor, Climate Adaptive Project for the National Bank for Agriculture and Rural Development (NABARD) last year. The phenomenon of piping from large-scale root decay after deforestation takes about three decades. This was very evident in areas where landslips had occurred in the past, including at Kavalappara, where 59 people lost their lives. If there is not a proper management system, and if rains continue to be erratic, as predicted by climate change scientists, a disaster of is likely to occur more often than once in a century.

Preventing soil piping is one of the most overlooked issues in piping research as well as in the field of soil erosion control. There is scarcity in detailed study on effective measures to prevent soil piping in different climatic regions and with different soil types. Some studies at present suggesting only possible techniques without detailed testing and are mainly focus on reducing soil erosion by piping rather than stabilizing entire hillslopes against piping. In humid climates lowering of the groundwater table and draining the areas affected by soil piping might be tested, whereas in dry climates raising the water table height and irrigating the soil might limit piping erosion (Frankl *et al*., 2016). In humid regions one should avoid water supply to macropores, and in the piped zones excess water should be evacuated. In contrast, water supply to piping-susceptible soils in dry regions may decrease the formation of desiccation cracks and hence pipe formation (Frankl *et al*., 2016). At the end, it has to be underlined that all control measures should be always adjusted to the individual sites, as different processes are involved in soil pipe initiation (Crouch *et al*., 1986). Studies are to be conducted to get a clear picture of detailed, quantitative information on the morphological characteristics of pipes and pipe networks such as pipe size which changes laterally and vertically along the pipe, the extension of pipe networks and the length of pipes. Kerala needs to act bold on land utilisation strategy. The data that are made available by agencies like the Geological Survey of India indicate that, out of the 38863 km^2 area of Kerala, the hill area having slopes higher than 10 degree constitutes about 19,000 km^2 and most of the scarps are thinly forested and further weakened by human activities.

Table 5.1 Variation in the sediment quality status in Vembanad wetland during flood and post flood, 2018

Parameters	Flood (August, 2018)			Post flood (November, 2018)		
	Values/ Range	**Average**	**Status/ change**	**Values/ Range**	**Average**	**Status/ change**
Heavy metal						
Copper (mg kg^{-1})	3.05-242.5	69.0 ± 58.0	Higher	0.4-91.5	32 ± 29	Decreased
Nickel (mg kg^{-1})	6-78.35	42.6 ± 19.1	Higher	4.1-118.5	33 ± 25	Decreased
Cadmium (mg kg^{-1})	BDL-1.32	0.3 ± 0.4	Higher	BDL-7.5	1 ± 2	Decreased
Lead (mg kg^{-1})	BDL-322.5	67.0 ± 82.2	Higher	1.05-472.5	56 ± 86	Decreased
Zinc (mg kg^{-1})	46.55-1392	251.2 ± 213.8	Higher	68-1758	240 ± 305	Decreased
Iron (mg kg^{-1})	4377-54150	31674.2 ± 14669.9	Higher	3236.5 -58450	29700 ±14643	Increased
Geoaccumulation index (Igeo)						
Copper	0.05-3.59	1.02 ± 0.86	Higher	0.01-2.06	0.48 ± 0.43	Decreased
Nickel	0.2-2.98	1.42 ± 0.64	Higher	0.14-3.95	1.09 ± 0.84	Decreased
Cadmium	0-2.93	0.58 ± 0.92	Higher	0-16.67	2.39 ± 4.78	Increased
Lead	0.01-10.74	2.23 ± 2.74	Higher	0.04-15.75	1.87 ± 2.87	Decreased
Zinc	0.33-9.77	1.76 ± 1.50	Higher	0.04-12.34	1.68 ± 2.14	Decreased
Iron	0.06-1.10	0.45 ± 0.21	Higher	0.05-0.83	0.42 ± 0.21	Decreased

Contamination Factor (CF)						
Copper	0.07-5.39	1.53 ± 1.29	Higher	0.03-3.09	0.72 ± 0.64	Decreased
Nickel	0.3-4.48	2.13 ± 0.96	Higher	0.21-5.93	1.63 ± 1.26	Decreased
Cadmium	0-4.4	0.87 ± 1.38	Higher	0-23.33	3.59 ± 7.17	Increased
Lead	0-16.11	3.35 ± 4.11	Higher	0.05-23.67	2.80 ± 4.29	Increased
Zinc	0.49-14.65	2.64 ± 2.25	Higher	0.72-18.51	2.53 ± 3.21	Decreased
Iron	0.09-1.65	0.67 ± 0.31	Higher	0.07-1.24	0.63 ± 0.31	Decreased

Salient findings…

- *Nitrogen loading in Vembanad backwater increased due to the heavy river and agricultural discharges during flood period.*
- *The wetland system was heavily polluted with the metals Cu and Zn during flood. Pb was also showed higher concentration in the study period.*
- *An overall decrease in accumulation of heavy metals was observed during flood compared to pre flood period.*

6. BIODIVERSITY OF VEMBANAD WETLAND SYSTEM DURING FLOOD AND POST FLOOD PERIOD, 2018

6.1 Introduction

Wetlands are recognized as ecosystems that harbor high biological diversity, provide sustenance for millions of people and face ongoing threats as result of human activities throughout the world (Gopal and Chauhan, 2001). Wetland ecosystems are extremely fragile and are particularly vulnerable to environmental fluctuations. According to Gopal and Krishnamurthy (1993), wetlands of South Asia are strongly influenced by the seasonal monsoons that vary significantly in intensity and duration depending on the regional climatic variation. In Indian subcontinent, the wetland biodiversity constitutes a significant portion of the total biodiversity (e.g., 15-20 %, Gopal and Krishnamurthy, 1993). In India, the coastal wetland habitats are facing serious anthropogenic impacts that have remarkably influenced the biodiversity and ecosystem character of the organisms inhabiting in it. Temporal changes in ecosystems are normally unpredictable mainly due to the undocumented natural events occurring at various periodicities (Gray and Christie, 1983).

The Vembanad wetland system supports a wide diversity of flora and fauna hence having a great importance to the local economy due to the abundance of rich floodplain fisheries. The region around Vembanad wetland system is one of the most thickly populated areas of Kerala and the Vembanad wetland is the single ecosystem only next to the Arabian Sea in terms of supporting maximum livelihood activities. The degradation of wetlands, therefore, creates a great threat for sustainability of economic growth for the entire region. Over the past few decades, Vembanad wetland facing severe ecological problems due to massive reclamation associated with rapid urbanization and industrialization. Construction of Thanneermukkom barrage across the Vembanad wetland system restrained the seasonal intermixing of fresh and saline water and thereby interfering with the natural cleansing mechanism of the wetland system, threatening accelerated loss of habitats and biodiversity (MSSRF, 2007). Further, this results in gross changes in physical, chemical and biological characteristics of the ecosystem. Increased agriculture, industrialization, urbanization and tourism development caused the shrinkage of wetland system both horizontally and vertically resulting in its drastic environmental alterations (Menon et *al*., 2000; Gopalan *et al*., 1983). Besides this, sewage pollution with increasing faecal coliforms, in conjunction with intense tourism related activities has seriously distress the major parts of the wetland system by pollution problems from indiscriminate operation of houseboats, waste dumping, oil and other contaminants in the ecosystem. In the present study, the effects of 2018 flood on the phytoplankton, mesozooplankton and macrobenthic communities in Vembanad wetland system was assessed to understand the changes observed in its abundance, distribution pattern and diversity as a result of the great flood of 2018.

Phytoplankton is unicellular microscopic algae which comprised of several taxonomic groups, such as Bacillariophyceae, Cyanophyceae, Chlorophyceae, Zygnemophyceae, Euglenophyceae, Chrysophyceae, Cryptophyceae, Dinophyceae and so on. According to size, phytoplankton are classified into picoplankton (<2 µm), nanoplankton (2-20 µm) and microplankton (>20 µm). The compositional makeup of a community of phytoplankton with each of these sub-groups exerts considerable influence by way of fuelling energy to higher trophic level organisms with the product of their photosynthesis. Populations dominated by large-sized phytoplankton have a great potential to export organic matter to upper trophic levels, through a short, classical food chain, and to adjacent systems. By contrast, populations dominated by small-sized phytoplankton are characterized mainly by complex microbial food webs that favour the recycling of organic matter within the euphotic layer (Cermeno *et al*., 2006). Additionally, quality of water is also influenced by the composition of the phytoplankton community (Goercike, 2011). Composition of phytoplankton and rates of photosynthesis have been affected by the increased emission of CO_2 and greenhouse gases due to industrialization. Stratification of the water column due to global warming prevents replenishment of nutrients in the surface waters. (Beardall *et al*., 2009). Phytoplankton dynamics are regulated by bottom-up controls (light, nutrients) as well as top-down controls (grazing). The interactions between these controls are influenced by flushing rate and residence time. Phytoplankton dynamics have been affected by man-made as well as climatically-induced environmental changes. These changes have also affected trophic states, biogeochemical cycles, quality of water as well as the overall condition of the habitat. (Paerl and Justic, 2011). There are many other factors that can influence the spatial distribution of phytoplankton besides nutrient availability, such as the magnitude and position of the turbidity, the tidal amplitude and freshwater discharge, water column stratification and grazing rates of zooplankton (Cloern *et al*., 1985). Thus the information obtained from phytoplankton communities can significantly contribute to assessing eutrophication levels in aquatic areas. Diversity and similarity indices are used to estimate biological quality through the structure of the community. Studies on phytoplankton diversity are an important contribution to the understanding of the system dynamics (Odum, 1971).

Mesozooplankton are taxonomically comprised of organisms of size range 200 µm-20 mm, primarily by copepods, fish eggs, fish larvae, rotifers, small hydromedusae, older stages of crustacean plankton and meroplanktonic larval forms. They act as an intermediate link in the plankton food web and as a major player in nutrient recycling hence; have crucial roles in estuaries (Sterner *et al*., 1992). On being strongly influenced by climatic changes mesozooplankton can be used as reliable bioindicators of ecosystem health (Rakhesh *et al*., 2013). Mesozooplankton community dynamics is often influenced by the composition and size structure of phytoplankton and microzooplankton and could consume around 10-40 % of primary production in different environment conditions (Calb *et al*., 2001). They are also enabled with immense adaptive measures to cope up with highly varying estuarine environment gradient, among which salinity and nutrient availability form the most important factors determining their size structure and composition. Salinity gradient and the nutrient availability thus, play a key role in their diversity attributes (Horvath *et al*., 2014) in an estuarine environment. As they are rarely collected, comparative analysis of changes in their abundance can greatly enhance our ability to evaluate the importance and interaction between physical environment, food web and fishery harvest as causal mechanisms driving ecosystem level changes (Mackas and Beaugrand, 2010). Therefore, a systematic monitoring programme, gives a comprehensive baseline assessment of this component in an estuarine ecosystem.

Benthos are the organisms which are found on or in the bottom sediments of aquatic system. The term benthos, was coined by Haeckel in 1891, meaning “depth of the sea”; derived from the Greek word "Ben" meaning the collection of organisms living in or on the sea or lakes and "Thos" the bottom of sea or lakes (Kabir *et al*., 2012). According to Odum (1971), benthos are mainly detritivorous among decomposers, breaking down organic matter and substances, releasing compounds and elements back into the environment and carrying energy to the next trophic level. Based on the size, benthos can be divided into three group’s macrobenthos, meiobenthos and microbenthos. Macrobenthos are those organisms which retain in a sieve of mesh size 0.5 mm. These are the largest benthic animals including star fish, mussels, most clams and so on. Meiobenthos are smaller than 0.5 mm but larger the microbenthos, which are less than 0.1 mm in size (Levinton, 2001).

Macrobenthic organisms are important functional constituents of aquatic ecosystems. Macrobenthos show different body shapes, feeding styles and reproductive modes. It consumes all types of organic matter including bacteria, planktonic and benthic organisms, detritus and so on. Benthic macro invertebrates are essential components of aquatic food webs that link organic matter and nutrient resources present in the sediments with higher trophic levels (Wallace and Webster 1996). Its role as a link between primary producers, decomposers and higher trophic levels in the ecosystem is well known (Pandit *et al*., 1991). The survival, distribution and abundance of macrobenthos depend on the characteristics of their environment such as salinity, organic matter, soil texture, sediment particles and the ability to build permanent burrows in the substratum (Perkins, 1974). Benthos play a vital role in the storage, transformation, release and recycling of nutrients to the overlying water column and promote primary productivity. The physical, chemical and geological process by both natural and manmade effects, disturb all the communities. Members of the macrobenthic community serve as suitable bio indicators of environmental variation and key elements of many aquatic monitoring programs, due to their sedentary behaviour and reduced responses to environmental changes (Tweedley *et al*., 2012). Macro invertebrate's vulnerability to environmental quality changes makes them an important part of any biomonitoring programme. In an aquatic environment, macro invertebrate populations live long enough to reflect the chronic effects of pollutants and yet short enough to respond to relatively acute changes in water quality. They tend to be relatively immobile and are thus continually exposed to the components of the surface water in which they live. Benthic organisms are among the most sensitive faunal communities and are important in observing the changes of an aquatic body (Dauer 1993).

6.2 Results

6.2.1 Abundance and community structure of phytoplankton in Vembanad wetland system during flood and post flood, 2018

Bacillariophyceae, Chlorophyceae and Cyanophyceae were the major phytoplankton groups observed during flood period. A total of 6 genera of phytoplankton were identified. Groups Bacillariophyceae, Cyanophyceae and Chlorophyceae were represented primarily by *Nitzschia* sp., *Melosira* sp., *Odontella* sp., *Skeletonema costatum*, *Rhizosolenia* sp., Cyanobacterial filament and *pediastrum*. Among the Bacillariophyceae, 5 genera of diatoms contributed to the numerical abundance of phytoplankton and it formed the dominant group (51 %) during flood period. Among the Bacillariophyceae, *Nitzschia* sp. contributed majorly with 27 % followed by *Melosira* sp. (9 %), *Odontella* sp. (6 %), *Rhizosolenia* sp. (5 %) and *Skeletonema costatum* (4 %) (Fig. 6.1). Cyanobacterial filaments contributed with 37 % of composition. Chlorophyceae comprised of 1 genera i.e. *pediastrum* and it contributed with 12 %. During post flood period, Bacillariophyceae formed the dominant group. Among this, *Leptocylindrus* spp. contributed majorly with 32 % followed by *Skeletonema costatum* (9 %), *Chaetoceros* sp. and *Pleurosigma normanii* (8 % each) and *Rhizosolenia hyaline* (7 %). Cyanobacterial filaments contributed with 36 % (Fig. 6.2). Chlorophyceae was absent during post flood period.

During flood, St.14 showed the highest abundance of 153 ind.m^{-3} (av. 21.86 ± 24.98 ind.m^{-3}) and the lowest of 12 ind.m^{-3} (av. 1.71 ± 3.73 ind.m^{-3}) in St.34. While during post flood, the highest abundance of 123 ind.m^{-3} (av. 20.50 ± 11.43 ind.m^{-3}) was observed in St.39 and the lowest of 2 ind.m^{-3} (av. 0.33 ± 0.82 ind.m^{-3}) in St.25.

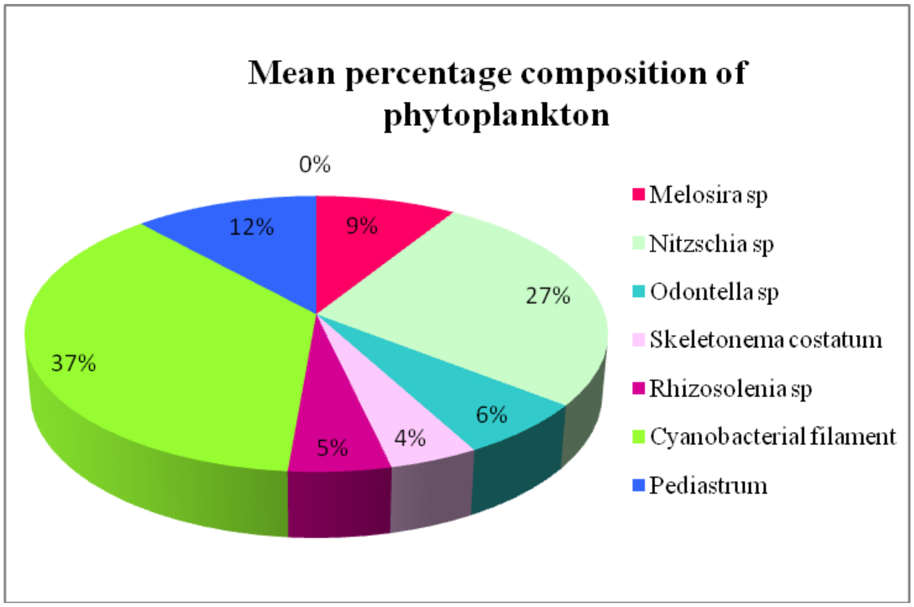

Fig. 6.1 Mean percentage composition of phytoplankton in Vembanad wetland during flood, 2018

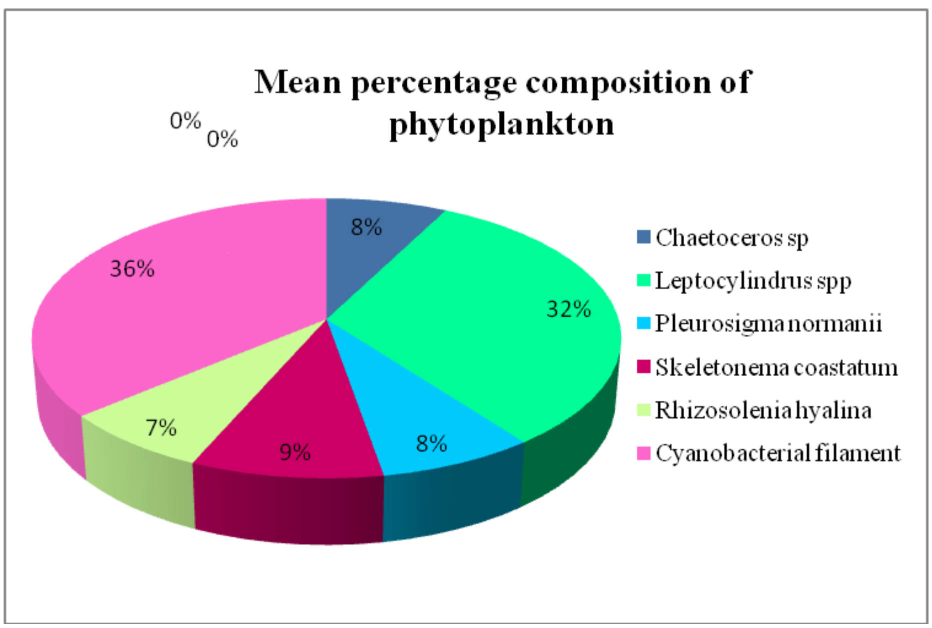

Fig. 6.2 Mean percentage composition of phytoplankton in Vembanad wetland during post flood, 2018

6.2.1.1 Diversity analysis of phytoplankton groups

During flood, the Shannon diversity index (H') and Pielou's evenness index (J') was maximum in St.1 (H' = 1.58; J' = 0.98) and minimum in St.34 and St.37 (H' = 0.45; J' = 0.65). The richness (Margalef's index, d) index varied from a minimum of 0.27 in St.5 to a maximum of 1.2 in St.32. The dominance index (Simpson's index, D) ranged from 0.29 to 0.80 with lowest value observed in St.37 and highest in St.1 (Fig. 6.3). However, during post flood period, the Shannon diversity index varied from 0 to 1.79. The minimum diversity value was observed in stations 1, 5, 12, 14, 22, 25 and 29 whereas the maximum diversity observed in St.33 (Fig. 6.4). The richness values fluctuated between 0 and 2.04 with minimum value in stations 1, 5, 12, 14, 22, 25 and 29 and maximum in St.34. The evenness index ranged from 0 to 1 with lowest value observed in stations 1, 5, 12, 14, 22, 25 and 29 whereas the highest value recorded in St.6. The dominance index ranged from 0 (stations 1, 5, 12, 14, 22, 25 and 29) to 0.89 (St.34).

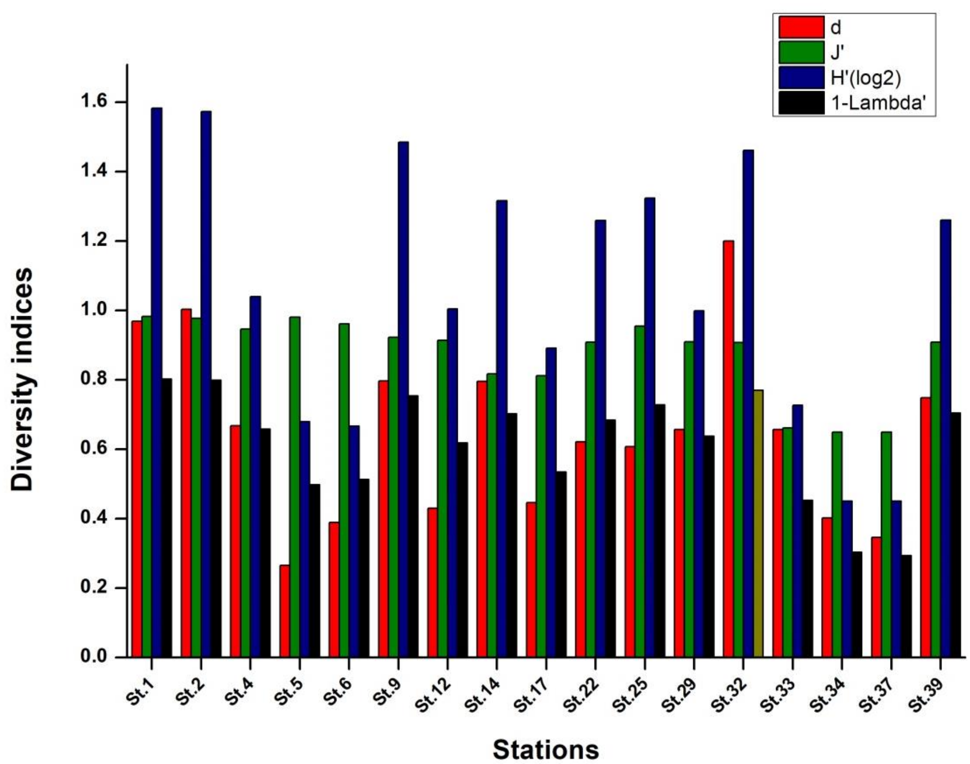

Fig. 6.3 Diversity indices of phytoplankton in Vembanad wetland system during flood, 2018

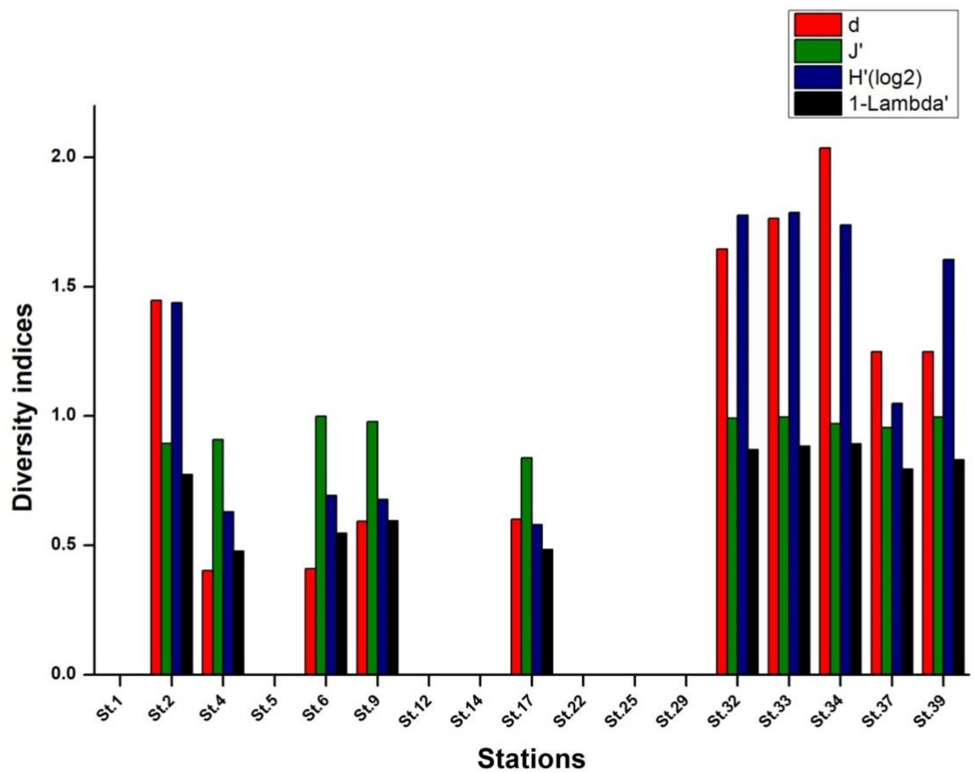

Fig. 6.4 Diversity indices of phytoplankton in Vembanad wetland system during post flood, 2018

6.2.1.2 Cluster analysis: SIMPROF (Similarity Profile Analysis) Test

During flood period, similarities of the phytoplankton assemblages between stations were determined using cluster analysis and it showed significant spatial similarities between stations. The resulting dendrogram depicted two major clusters (Fig. 6.5). In the first cluster, St.1, 2, 32 and 39 together formed one group of which St.1 and St.2 clustered together with 90 % similarity. The second cluster was further divided into two clusters. In this, St.9, 12, 14, 17, 22 and 25 grouped together and formed a cluster. However, St.22 and St.25 observed with 90 % similarity. Similarly, St.4, 5, 6, 29, 33, 34 and 37 formed another group of which St.4 and St.33 formed a cluster with 85 % similarity. Dendrogram of post flood period depicted two major clusters with 20 % similarity (Fig. 6.6). The first cluster was formed by St.5, 12, 14, 17, 22, 25 and 29 while St.25 stood apart from others with >40 %. Stations 12 and 29 formed a significant cluster with >95 % similarity and it agglomerated with St.22 (95 %), whereas St.5 and St.14 formed a cluster with 85 % similarity. However, in the second cluster, St.37 stood apart (>20 %) and it further divided in to two clusters. Stations 1, 6 and 9 formed one group. Stations 2 and 4 formed another cluster with 65 % similarity, which together with the cluster formed by stations 32, 33, 34 and 39 (Northernmost high saline stations, >60 % similarity) formed a cluster with >50 % similarity.

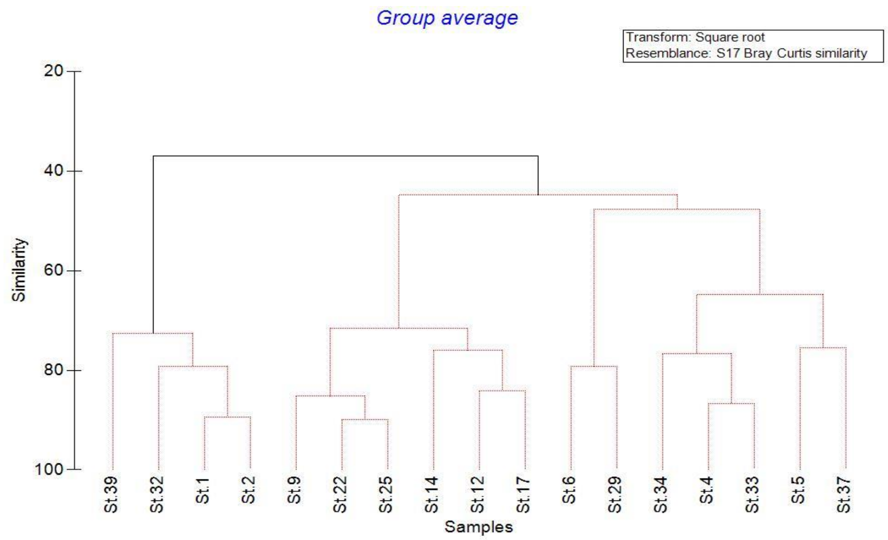

Fig. 6.5 Dendrogram showing the spatial similarities of phytoplankton abundance in the Vembanad wetland during flood, 2018

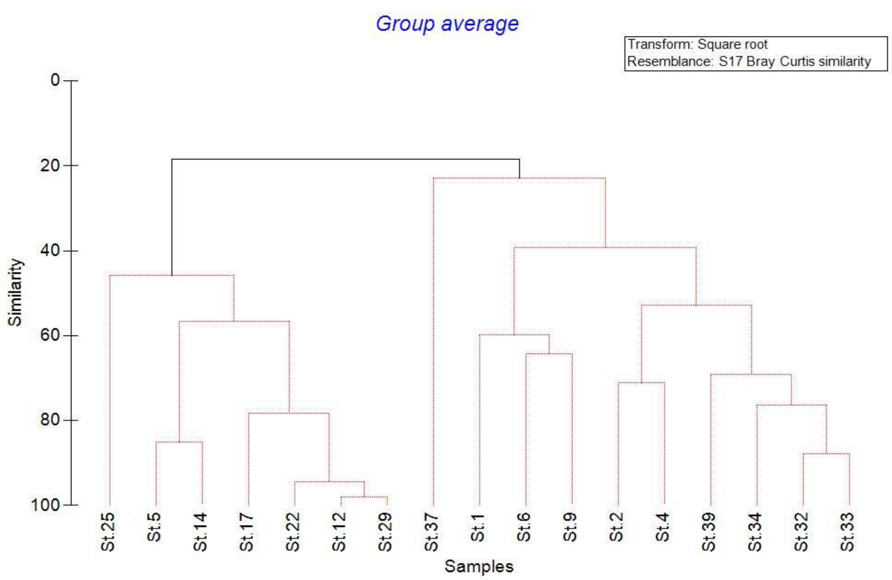

Fig. 6.6 Dendrogram showing the spatial similarities of phytoplankton abundance in the Vembanad wetland during post flood, 2018

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

MDS was calculated on square root transformed species abundance data to analyse the similarity of phytoplankton groups between stations. For the two-dimensional plots a stress less than 0.1 corresponds to good ordination, with no real risk of drawing false inferences. In the present study, MDS plot gave an ordination having the stress value of 0.1 during flood period whereas during post flood period it was 0.07, indicating a good representation of inter-station similarities. In MDS plot, samples showing similarities were clustered together and dissimilar ones, far away. The similar stations have either a few species in common or the same species. During flood, multivariate analysis of phytoplankton groups showed an overall similarity of 20 % between stations (Fig. 6.7). The MDS ordination plot showed two subsets, each with 40 % of similarity. In the first set, stations 6 and 29 together formed one subset with 60 % similarity likewise that of the subset formed by stations 4, 5, 33, 34 and 37 and that of stations 9, 12, 14, 17, 22 and 25. Similarly, stations 9, 22 and 25 formed one subset with 80 % likewise that of the subset formed by stations 12 and 17 and that of stations 33 and 34. In the second set, St.1, 2, 32 and 39 showed 60 % similarity of which stations 1 and 2 formed one subset with 80 % similarity.

During post flood period, the MDS ordination plot showed two subsets, each with 20 % of similarity (Fig. 6.8). Stations 5, 14, 17, 22, 25 and 29 together formed one subset with 40 % of which St.5 and 14 together formed one subset with 60 % likewise that of the subset formed by stations 17, 22 and 29, whereas station 25 stood apart. Stations 5 and 14 again formed one subset with 80 % similarity likewise another subset formed by St.22 and 29. In the second set, St.37 stood apart and showed only 20 % similarity between other stations in the group. Stations 1, 6 and 9 together formed one subset with 40 % likewise that of the subset formed by stations 2, 4, 32, 33, 34 and 39. Station 6 and 9 together formed one subset with 60 % likewise that of the subset formed by stations 2 and 4 and that of stations 32, 33, 34 and 39. In this, stations 32 and 33 formed one subset with 80 % similarity.

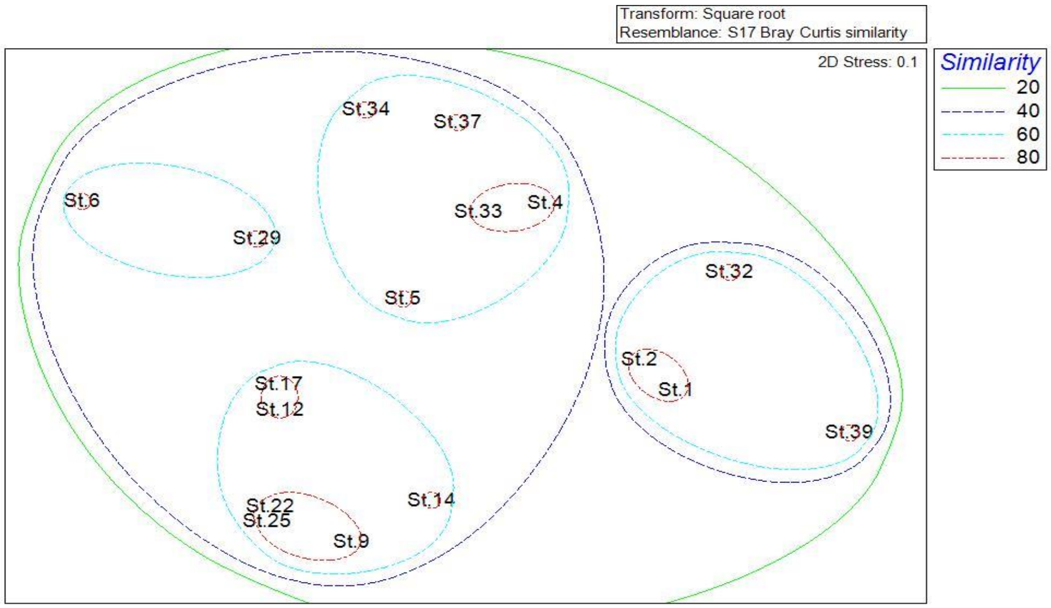

Fig. 6.7 MDS plot of mean station wise phytoplankton abundance in the Vembanad wetland during flood, 2018

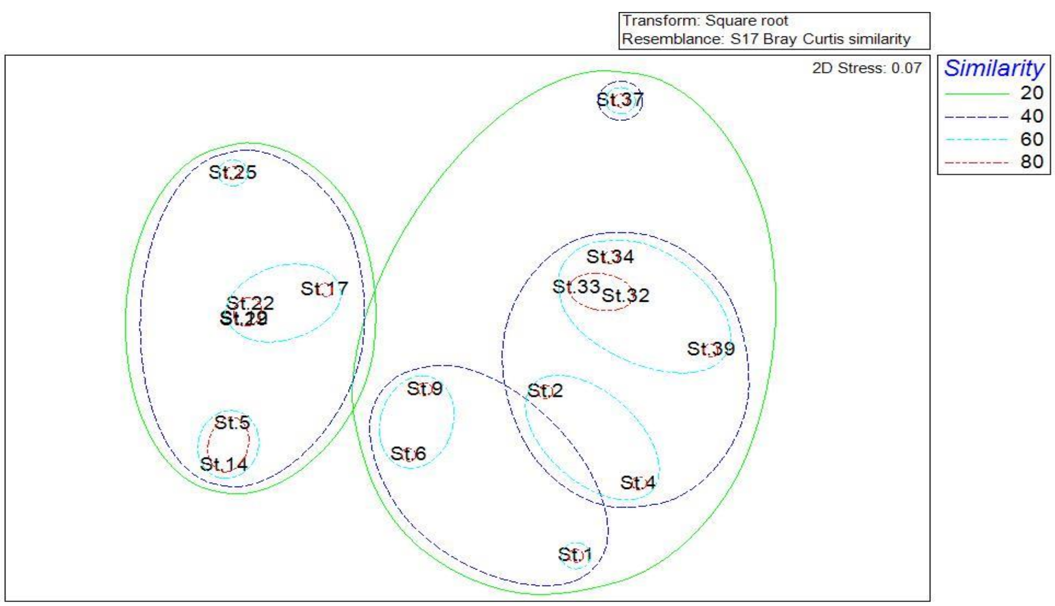

Fig. 6.8 MDS plot of mean station wise phytoplankton abundance in the Vembanad wetland during post flood, 2018

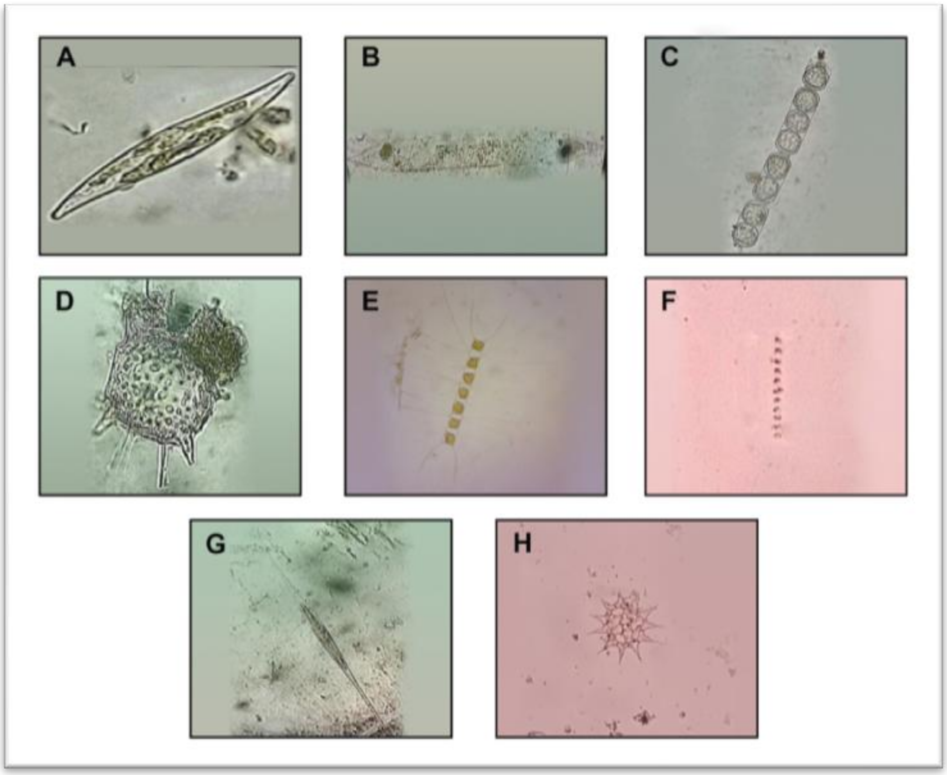

Plate 6.1 Major phytoplankton observed in the Vembanad wetland during flood & post flood, 2018
(A) *Pleurosigma* sp. (B) *Rhizosolenia* sp. (C) *Melosira* sp. (D) *Odontella* sp. (E) *Chaetoceros* sp. (F) *Skeletonima* sp. (G) *Nitzschia* sp. (H) *Pediastrum* sp.

6.2.2 Abundance and community structure of mesozooplankton in Vembanad wetland system during flood and post flood, 2018

The mesozooplankton belonging to 13 groups were observed during flood in Vembanad wetland. This comprised of copepods (Calanoida, cyclopoida and harpacticoida), zoea, fish egg, polychaete larvae, cladocera, gastropod larvae, megalopa, ostracoda, mysid, hydromedusae and cumaceans. Among the 13 groups, cyclopoida contributed majorly with 40 % composition followed by calanoida (19 %), mysid (10 %), zoea (7 %), fish egg (7 %), polychaete larvae (5 %), ostracoda (4 %), hydromedusae (2 %), gastropod larvae (2 %), cladocera (2 %), cumaceans (1 %), harpacticoida (1 %) and megalopa (1 %) (Fig. 6.9). However, during post flood of Vembanad wetland comprised of 14 groups. The major share of 44 % was contributed by cladocera followed by Mysid (18 %), cyclopoida (13 %), calanoida (10 %), fish egg (6 %), cumaceans (5 %), zoea (2 %), 1 % each by crustacean nauplii and rotifers, harpacticoids, molluscan larvae, fish larvae, Amphipod and polychaete larvae were showed 0 % (Fig. 6.10). Gastropod larvae, megalopa, hydromedusae and ostracoda groups were completely absent during post flood period.

During flood, St.10 witnessed the highest abundance of 84275 ind.m^{-3} (av. 6483 ± 15536 ind.m^{-3}) and the lowest of 6 ind.m^{-3} (av. 0.5 ± 1.7 ind.m^{-3}) in St.37. While during post flood, the highest abundance of 108564 ind.m^{-3} (av. 7755 ± 13600 ind.m^{-3}) was observed in St.1 and the lowest of 64 ind.m^{-3} (av. 5 ± 8 ind.m^{-3}) in St.32.

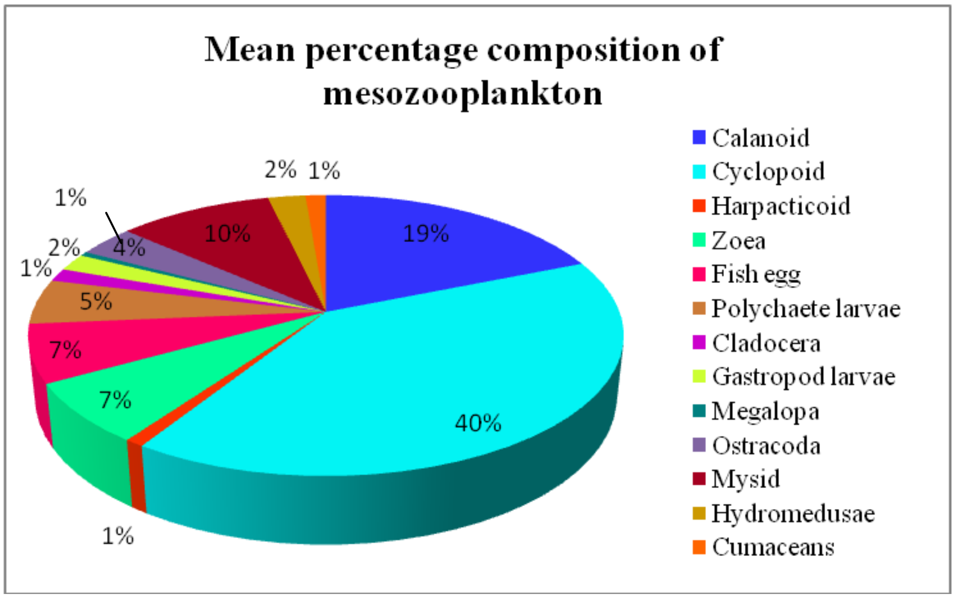

Fig. 6.9 Mean percentage composition of mesozooplankton in Vembanad wetland during flood, 2018

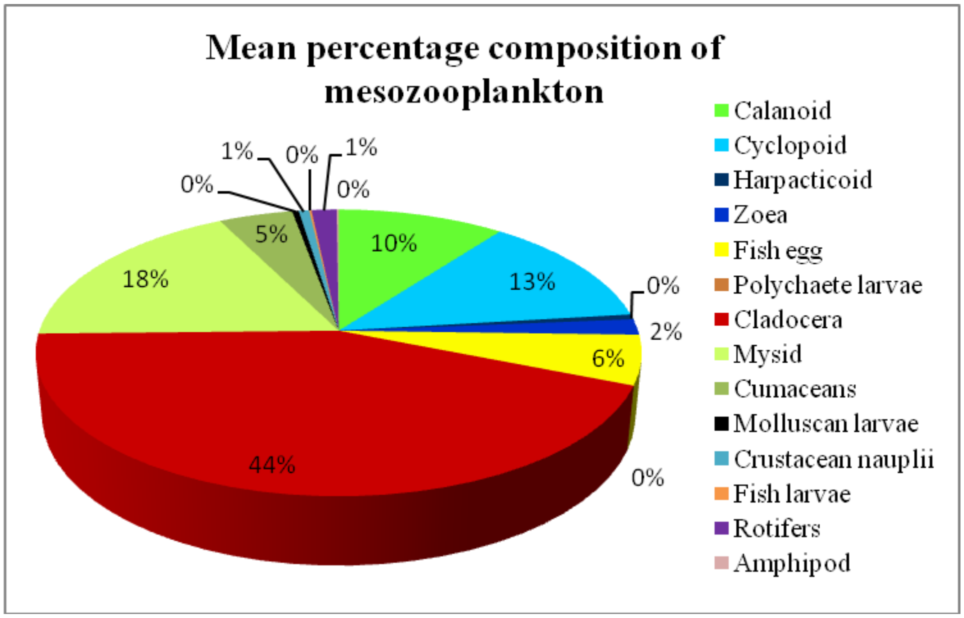

Fig. 6.10 Mean percentage composition of mesozooplankton in Vembanad wetland during post flood, 2018

6.2.2.1 Diversity analysis of mesozooplankton groups

During flood, the maximum richness was recorded in St.22 (d = 1) and the least in St.37 (d = 0) (Fig. 6.11). The evenness based on mesozooplankton was high in St.33 (J' = 0.98) and the least in St.37 (J' = 0) whereas Shannon diversity index was higher in St.22 (H' = 2.07) and the least diversity was shown by St.37 (H' = 0). Comparing the dominance of mesozooplankton in Vembanad wetland study stations, highest dominance was observed in St.22 (D = 0.84) while lowest in St.37 (D = 0). However, during post flood period, the maximum richness was recorded in St.39 (d = 1.30) and the least in St.17 (d = 0.19). The evenness index was high in St.25 (J' = 1) and the least in St.37 (J' = 0.06). Whereas Shannon diversity index was higher in St.1 (H' = 1.55) and the least diversity was shown by St.37 (H' = 0.10). The highest dominance value was recorded in St.12 (D = 0.76) and the lowest in St.37 (D = 0.03) (Fig. 6.12).

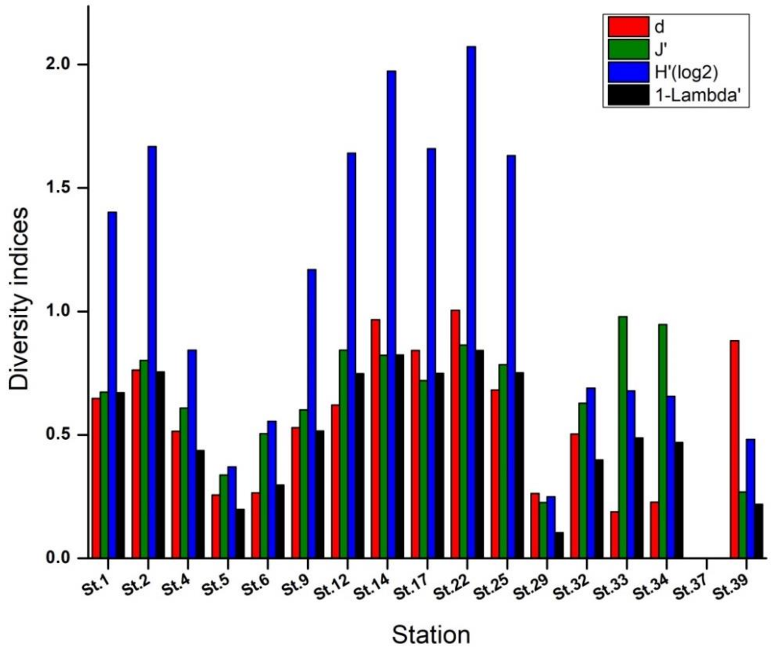

Fig. 6.11 Diversity indices of mesozooplankton in Vembanad wetland during flood, 2018

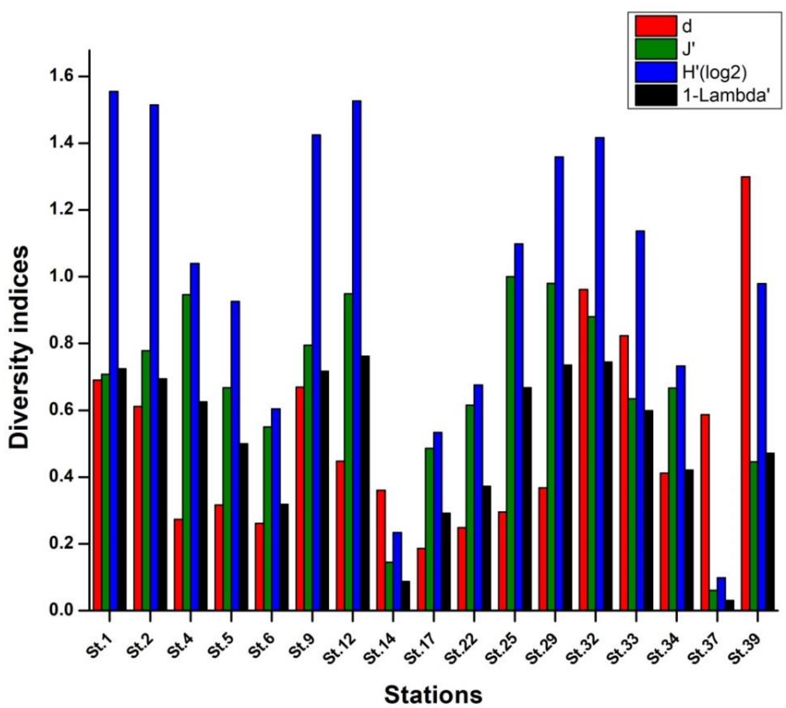

Fig. 6.12 Diversity indices of mesozooplankton in Vembanad wetland during post flood, 2018

6.2.2.2 Cluster analysis: SIMPROF (Similarity Profile Analysis) Test

During flood, the resulting dendrogram showed two major clusters, depicting the similarities between stations in spatial distribution of mesozooplankton groups (Fig. 6.13). Cluster one was further divided into two clusters where St.9 stood apart and St.1, St.2, and St.12 formed one group. While in the second cluster, St.37 stood apart whereas St.5, St.6 and St.29 formed one group and St.4, St.32, St.33, St.34 and St.39 formed another group of which St.32 and St.34 showed 80 % similarity. In the second cluster, St.6 and St.29 showed 90 % similarity. During post flood, the dendrogram formed two major clusters similar to flood period. In the first cluster, stations 9 and 37 formed a significant cluster (>40 % similarity) and St.25, St.32, St.33, St.34 and St.39 formed another group (Fig. 6.14). In the second cluster, St.1 and St.4 stood apart whereas stations 2, 5, 6, 12, 14, 17, 22 and 29 clustered together (indicating its limnetic nature). In the second cluster, St.6 and St. 22 showed 90 % similarity.

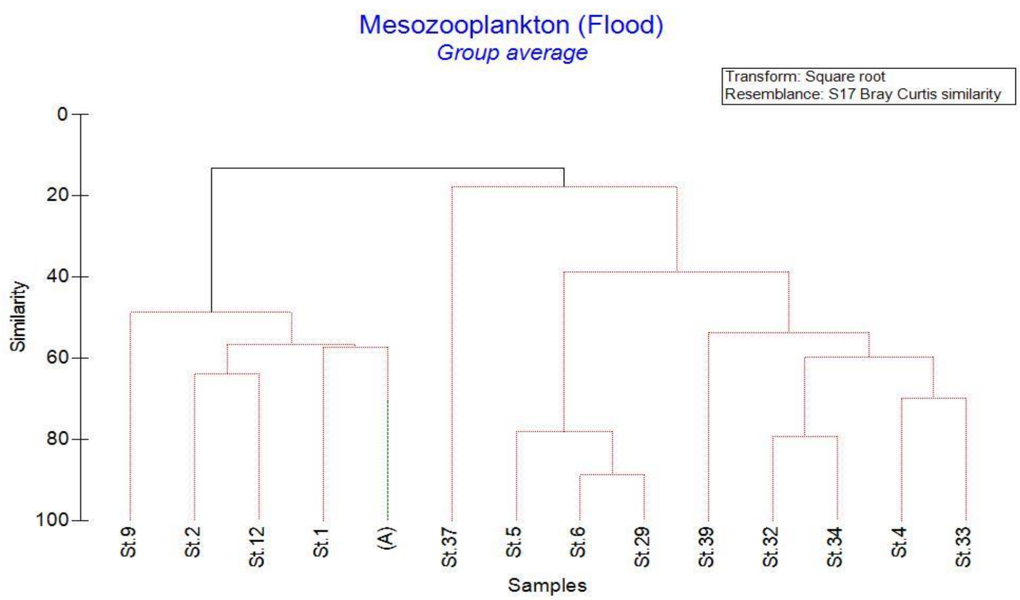

Fig. 6.13 Dendrogram showing the spatial similarities of mesozooplankton abundance in the Vembanad wetland during flood, 2018

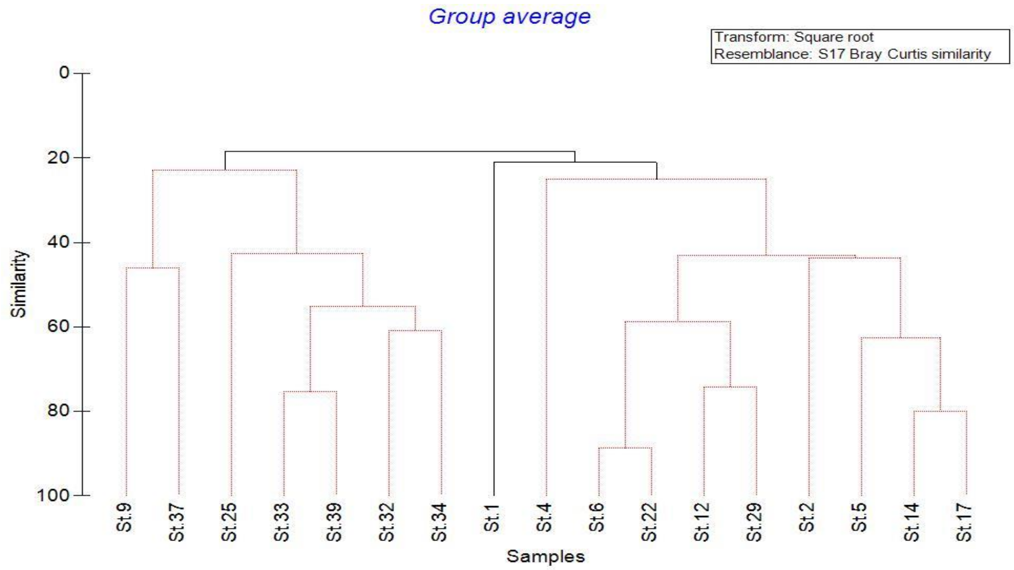

Fig. 6.14 Dendrogram showing the spatial similarities of mesozooplankton abundance in the Vembanad wetland during post flood, 2018

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

Multi-Dimensional Scaling (MDS) was calculated on square root transformed species abundance data to analyse the similarity of mesozooplankton groups between stations. MDS analysis indicated that zooplankton assemblage significantly varied within the wetland system. For the two-dimensional plots a stress value less than 0.05 is an excellent representation. In the present study, MDS plot gave an ordination having the stress value of 0.03 (excellent similarity) during flood and 0.12 during post flood period. Multivariate analysis of most of the zooplankton groups showed 20 % similarity between stations. During flood period, the MDS ordination plot showed three subsets, each with 20 % of similarity (Fig. 6.15). In the first set, stations 1, 2, 9, 12, 14, 17, 22 and 25 formed one subset with 40 % similarity. In this, stations 2 and 12 together formed one subset with 60 % likewise, that of the subset formed by St.14, St.17, St.22 and St.25. Stations 14 and 17 together formed one subset with 80 %. While St.1 and St.9 stood apart. In the second set, stations 4, 32, 33, 34 and 39 formed one subset with 40 % similarly; stations 5, 6 and 29 formed one subset with 40 %. Stations 6 and 29 together formed one subset and showed 80 % similarity. During flood, station 37 was formed one subset and stood apart from other stations.

During post flood period, the MDS ordination plot showed two subsets, each with 20

% of similarity. Stations 1, 2, 4, 5, 6, 12, 14, 17, 22 and 29 together formed the first set of which, stations 1 and 4 stood apart and all other stations together formed a subset with 40 % similarity (Fig. 6.16). In this, stations 5, 14 and 17 formed a subset with 60 % likewise, that of the subset formed by St.6 and St.22 and that of stations 12 and 29. Stations 6 and 22 together formed a subset with 80 % similarity. In the second set, St.9 and St.37 together formed a subset (40 %) and stations 25, 32, 33, 34 and 39 formed another subset with 40 % similarity. In this set, St.32 and St.34 together formed a subset and showed 60 % similarity.

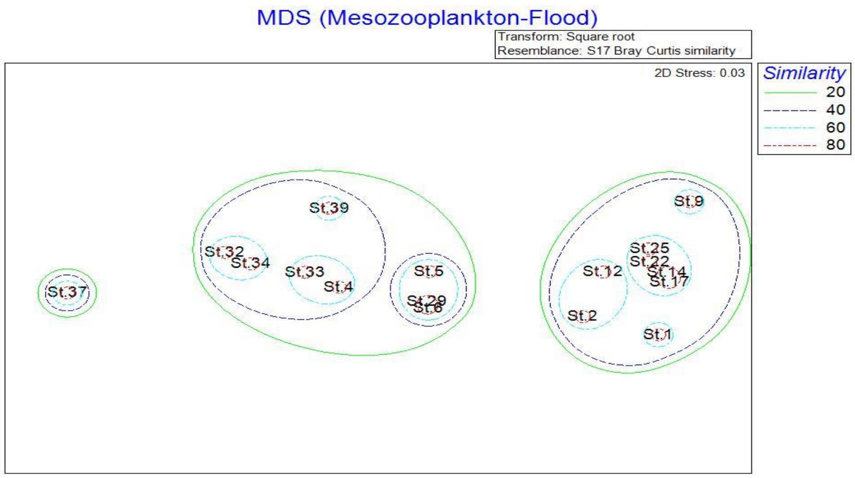

Fig. 6.15 MDS plot of mean station wise mesozooplankton abundance in the Vembanad wetland during flood, 2018

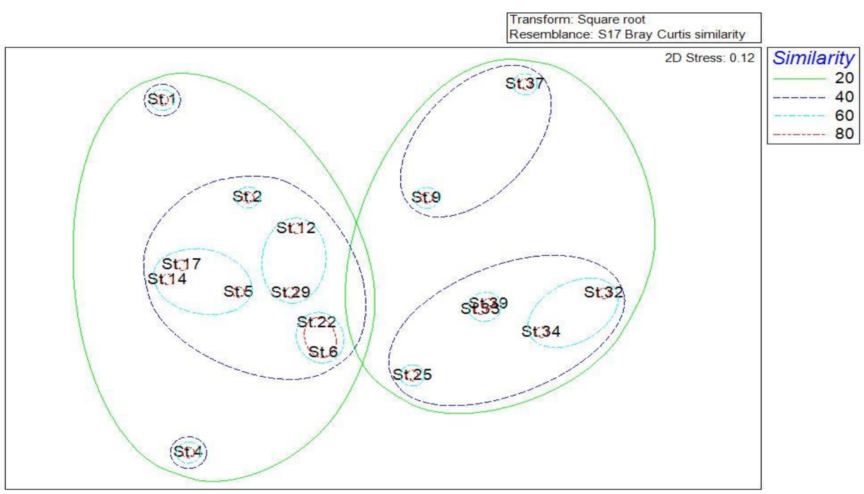

Fig. 6.16 MDS plot of mean station wise mesozooplankton abundance in the Vembanad wetland during post flood, 2018

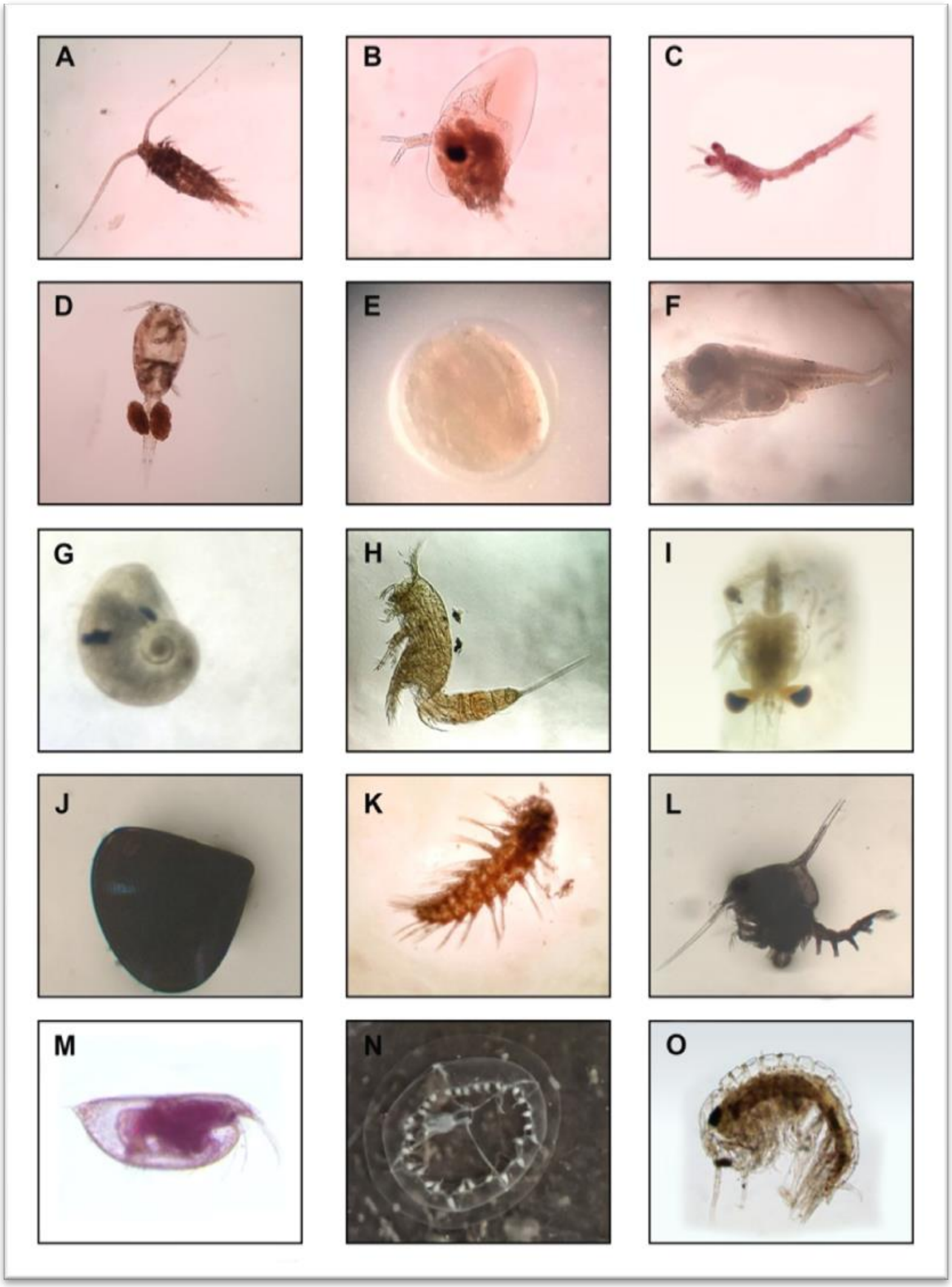

Plate 6.2 Major mesozooplankton observed in the Vembanad during flood & post flood, 2018 (A) Calanoid copepod (B) *Cladocera* sp. (C) Mysids (D) Cyclopoid copepod (E) Fish egg (F) Fish larva (G) Gastropod larva (H) Harpacticoid copepod (I) Megalopa (J) Molluscan larva (K) Polychaete larva (L) Zoea (M) Ostracoda (N) Hydrozoa (O) Amphipoda

6.2.3 Abundance and community structure of macrobenthos in the Vembanad wetland system during flood and post flood period, 2018

During flood, 10 groups of macrobenthic organisms belonging to phyla Annelida, Arthropoda, Mollusca, Nemertea and Chordata were observed. Polychaetes, oligochaetes and bivalves were the most abundant macrobenthic groups. Polychaetes constituted 44 % of the total organisms, followed by oligochaetes (19 %), bivalves (18 %), amphipods (4 %), crustaceans (4 %), gastropods (3 %), nemerteans (3 %), tanaids (3 %), insects (1 %) and pisces (1 %) (Fig. 6.17). The polychaete species observed in this study were *Dendronereis estuarina*, *Namalycastis indica*, *Par-heteromastus tenuis*, *Nereis glandicincta*, *Polydora antennata*, *Glycera Alba*, *Goniada emerita* and *Sigambra parva*. During post flood, 9 groups were observed viz. polychaetes, bivalves, oligochaetes, insects, amphipods, isopods, nematodes, gastropods and tanaids. Among these polychaetes were the dominant group in most of the stations constituted 50 % of the total organisms followed by bivalves (27 %), insects (11 %), oligochaetes (6 %), amphipods and nematodes (2 % each), gastropods and isopods constitutes 1 % and tanaids (0 %) (Fig. 6.18).

During flood, the maximum abundance of 1344 ind.m^{-2} observed at St.5 (av. 134.4 ± 183.5 ind.m^{-2}) whereas St.32, St.34 and St.37 showed nil values. While during post flood period, the highest abundance of 3382.40 ind.m^{-2} (av. 375.82 ± 688.85 ind.m^{-2}) was observed in St.6 and the lowest of 44.80 ind.m^{-2} (av. 4.98 ± 14.93 ind.m^{-2}) in St.39. Polychaetes formed the dominant group during the present study period. The average abundance of polychaetes during flood period was 183.15± 247.57 ind.m^{-2} followed by oligochaetes (80.38 ± 117.75) and bivalves (73.79 ± 125.16 ind.m^{-2}). During post flood period, polychaetes showed an average value of 390.02 ± 457.01 ind.m^{-2} followed by bivalves (208.19 ± 488.89 ind.m^{-2}) and insects (85.65 ± 219.94 ind.m^{-2}).

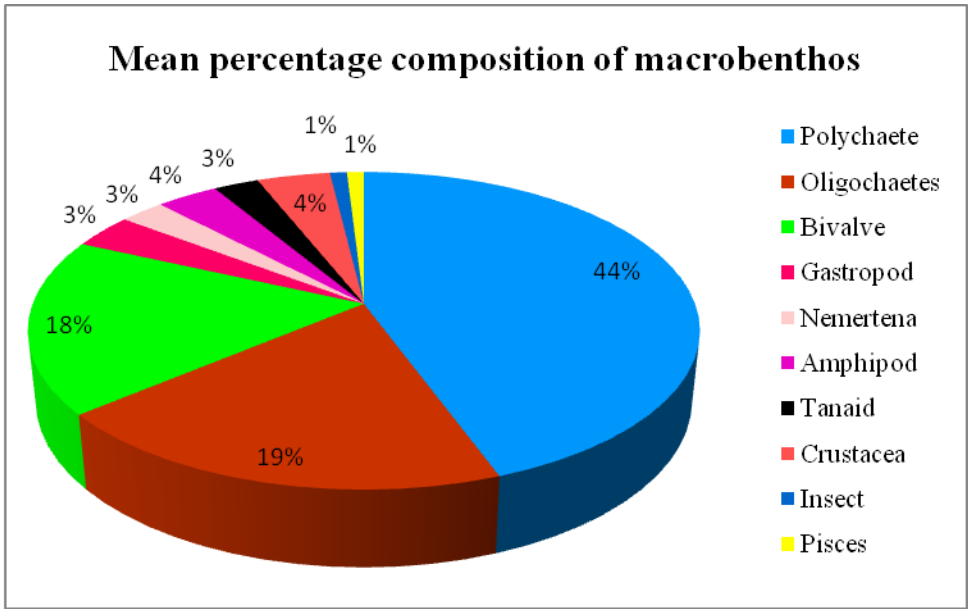

Fig. 6.17 Mean percentage composition of macrobenthos in Vembanad wetland during flood, 2018

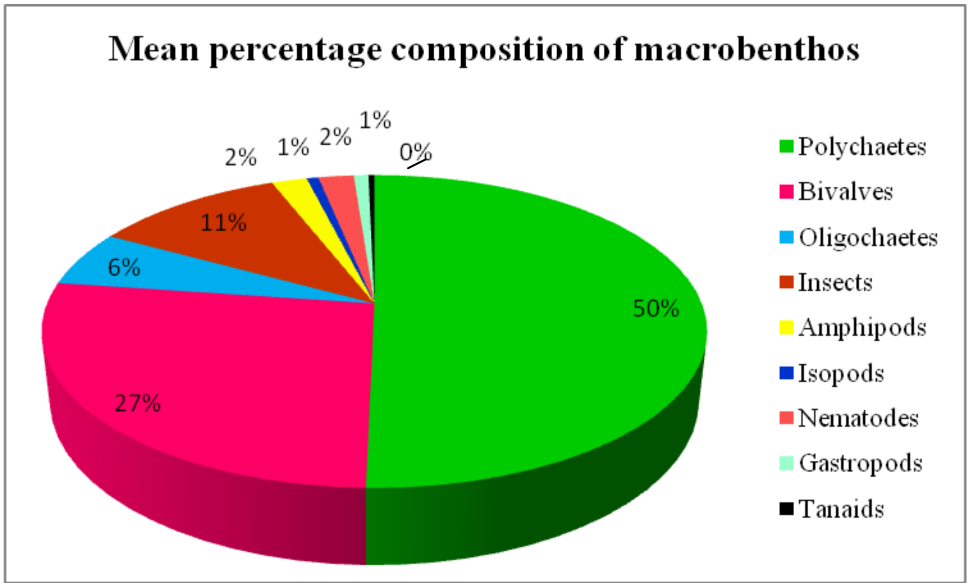

Fig. 6.18 Mean percentage composition of macrobenthos in Vembanad wetland during post flood, 2018

6.2.3.1 Diversity analysis of macrobenthic groups

The diversity indices such as species richness (Margalefs index, d), species evenness (Pielou's index, J), species diversity (Shannon index, H') and species dominance (Simpson's index, D) were computed for macrobenthic groups. The average value of species richness, (d), in the Vembanad ecosystem during the study period was 0.75. The station 2 had higher value for species richness (1.53) followed by station 5 (1.38) and station 9 (1.13). Species diversity (H') had an average value of 1.605. Diversity was found to be highest in the station 2 (0.82) followed by station 29 (0.77). Lowest diversity was found at station 12 (0.47). Pielou's evenness index, (J) showed an average value of 0.914 during the study period. The species evenness was higher at station 14 (0.99) and lower at station 39 (0). The average value for species dominance was 0.62. The highest species dominance was found at station 2 (0.82) followed by station 9 (0.80) (Fig. 6.19 and 6.20).

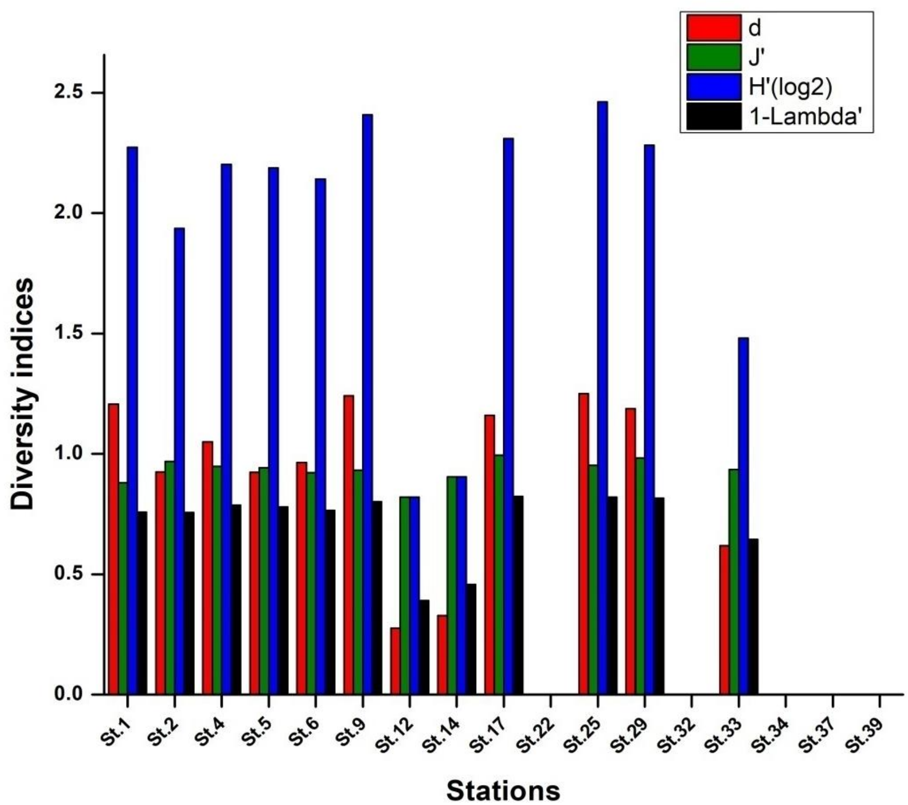

Fig. 6.19 Diversity indices of macrobenthos in Vembanad wetland during flood, 2018

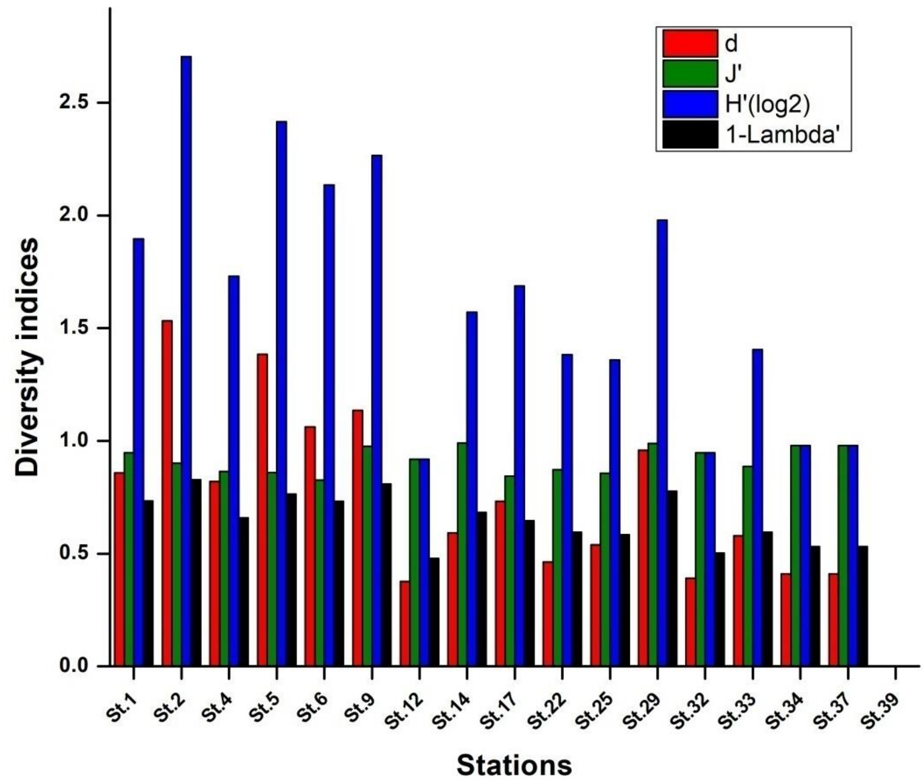

Fig. 6.20 Diversity indices of macrobenthos in Vembanad wetland during post flood, 2018

6.2.3.2 Cluster analysis: SIMPROF (Similarity Profile Analysis) Test

Dendrogram of flood period depicted two major clusters, showing the spatial similarities of macrofaunal abundance between stations (Fig. 6.21). In the first cluster, St.32, St.34 and St.37 stood apart. The second cluster was further divided into two clusters of which the first one included stations 1, 4, 5, 6, 9, 12 and 14 whereas stations 2, 17, 22, 25, 29, 33 and 39 formed another group. In the second cluster, stations 22 and 39 showed >80 % similarity. However during post flood, the dendrogram formed two main clusters of which station 34 stood apart and the second cluster further divided into two clusters (Fig. 6.22). In this, St.37 stood apart. It further divided into two clusters of which stations 12, 32 and 39 together formed one cluster whereas stations 2, 5, 6, 17 and 22 formed one group. In this, St.5 and St.17 clustered together and showed 80 % similarity. This was again agglomerated with the stations 1, 4, 9, 14, 25, 29 and 33 formed another cluster. Station 4 and 33 showed >80 % similarity.

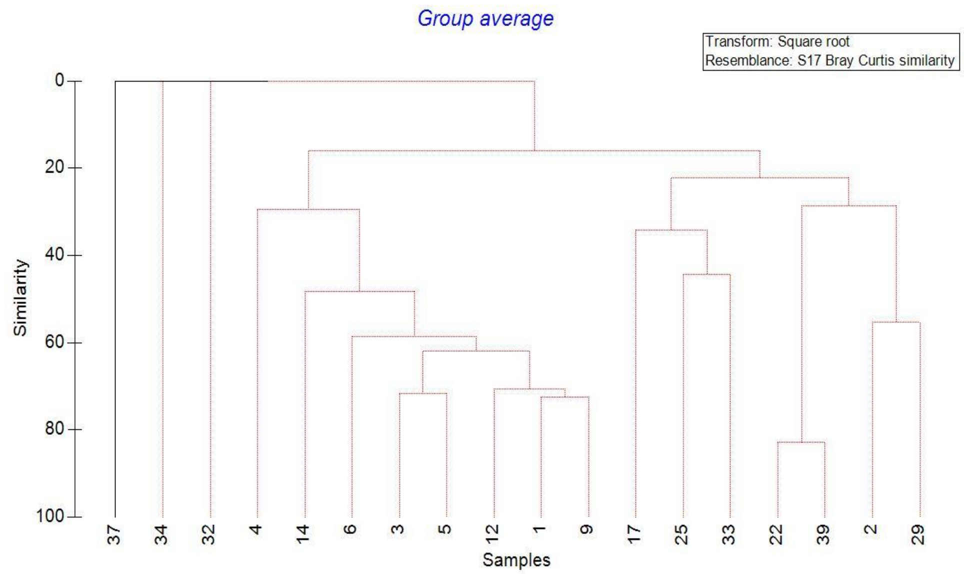

Fig. 6.21 Dendrogram showing the spatial similarities of macrofaunal abundance in the Vembanad wetland system during flood, 2018

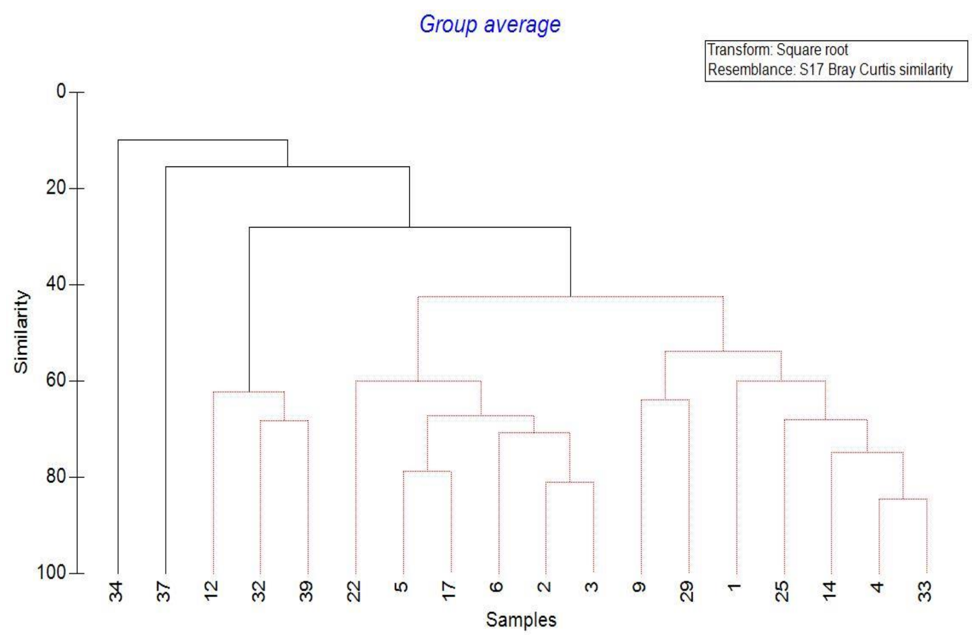

Fig. 6.22 Dendrogram showing the spatial similarities of macrofaunal abundance in the Vembanad wetland system during post flood, 2018

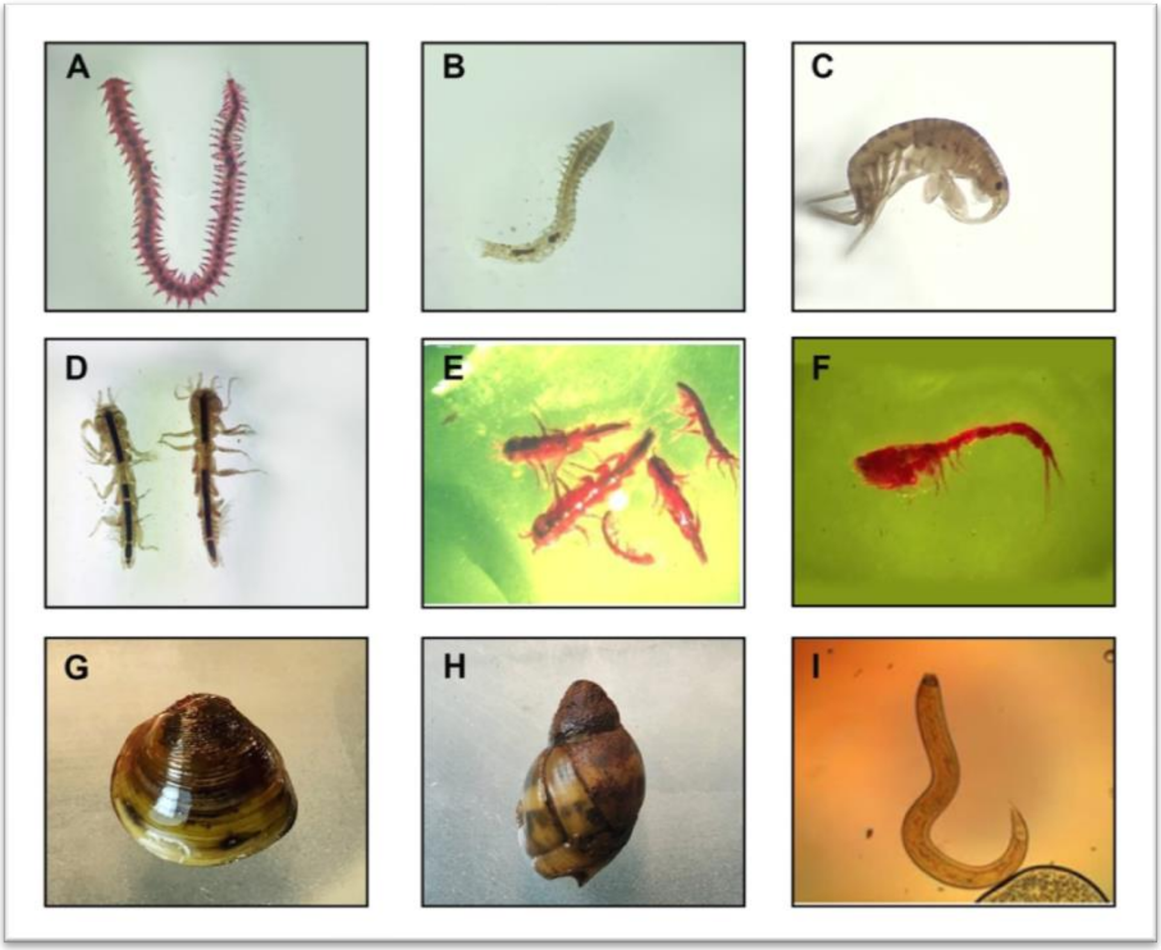

Plate 6.3 Major macrobenthos observed in Vembanad wetland during flood and post flood, 2018

6.2.4 Data analysis

6.2.4.1 Multiple regression analysis

Multiple regression analysis of edaphic factors like rainfall and river discharge were carried with biodiversity revealed that, rainfall had significant influence on zooplankton abundance and diversity during flood ($p<0.05$), but during post flood, it was influenced the phytoplankton distribution ($p<0.05$) (Table 4.2).

6.3 Discussion

6.3.1 Analysis of biodiversity in Vembanad wetland during flood and post flood period, 2018

Natural disasters are becoming more recurrent, classy and intimidating worldwide. The most hazardous and widespread events of all, are floods that generally develop over a period of days, when excess rainwater above the carrying capacity of the channel spreads over the land next to it (floodplain). Floods being the major determinants of ecological patterns and processes in river-floodplain systems, act as “rubber erasers” plummeting the environmental and ecological eccentricities created during low water periods.

The outcome of the present study carried out in 2018 flood and post flood period was to fulfill one of the main objectives of assessing the impact of catastrophic flooding on the phytoplankton, mesozooplankton, macrobenthic community and other resources in the Vembanad wetland system demonstrated that the flood waters caused a decrease in the number, diversity and abundance. The magnitude of flooding was apparent from the dramatic reduction in salinity to nil along the study stations. However the water temperature was lowered only by 1 to 2 °C.

The composition of phytoplankton groups were more or less similar compared to the previous studies conducted in Vembanad wetland system, but its abundance and number showed drastic variations. According to Joseph and Pillai (1975) the major phytoplankton groups observed in the Vembanad backwater were *Chaetoceros* sp., *Ceratium* sp., *Synechococcus, Nitzschia* sp., *Surirella* sp., *Gyrosigma* sp., *Synedra* sp., *Thalassiosira* sp., *Merismopedia* sp. *and Fragilaria* sp. Anon (2001) reported major phytoplankton groups of *Spirogyra* sp., *Microspora* sp., *Botryococcus* sp., *Anabena* sp., *Lyngbya* sp., *Desmidium* sp., *Micrasterias* sp. and *Stuarastrum* sp. Bijoy Nandan and Sajeevan (2018) reported *Coscinodiscus* sp., *Melosira* sp., *Oscilatoria* sp., *Campylodiscus* sp., *Ulotrix* sp., *Oedogonium* sp., *Spirulina* sp; *Microspora* sp. and *Pediastrum* sp. In the present study, the major phytoplankton groups observed were *Nitzschia* sp., *Melosira* sp., *Odontella* sp., *Skeletonema costatum*, *Rhizosolenia* sp., *pediastrum*, *Leptocylindrus* spp., *Chaetoceros* sp. and *Pleurosigma normanii*. Among the phytoplankton groups Bacillariophyceae was dominant during the study period (i.e. 51 % during flood and 64 % during post flood). Among this, *Nitzschia* sp. showed the maximum abundance of 295 ind.m^{-3} (av. 17.35 ±17.98 ind.m^{-3}) during flood period whereas during post flood *Leptocylindrus* spp. showed maximum abundance of 242 ind.m^{-3} (av. 14.24 ± 19.96 ind. m^{-3}). *Nitzchia* sp. are generally found in organically polluted waters (Panigrahi *et al*., 2009).

Hence, the organic rich water during the flood period might contribute the maximum abundance of *Nitzchia* sp. Cyanobacterial filaments were also observed in higher number (av. 24.06 ± 21.17 ind.m^{-3} during flood; 16.0 ± 25.9 ind.m^{-3}during post flood) and its maximum abundance observed in southernmost stations, which may be due to the nutrient rich flood water occurred during flood period.

A number of indices have been developed for the assessment of qualities of water and biota. Shannon diversity Index (H'), the most commonly accepted index in past few decades, is based on both the number of species present and the relative abundance of each species. This index is usually used to calculate species diversity but comparisons are also made using the different taxonomic levels (Hellawell, 1978). During flood, the Shannon diversity index (H') was maximum in St.1 (H' = 1.58) and minimum in St.34 and St.37 (H' = 0.45) and it was lower compared to the previous study (0.63 to 1.59). During the present study, most of the stations showed comparatively low diversity. Bajpai (1997) reported that the low diversity of the species would be due to the disturbance. Rajagopal (2010) and Adesalu and Nwankwo (2008) reported that the low value of Shannon index of phytoplankton population in rainy season is due to dilution of area. It was also observed that a low diversity characterizes young settlements of species. The average diversity index observed during post flood period was 0.70 and it varied from 0 to 1.79. The average species richness (Margalef's index, d) value observed was 0.65 (varied from a minimum of 0.27 to a maximum of 1.2) during flood period and 0.67 (varied from 0 to 2.04) during post flood. The increased river discharge and heavy rainfall during the flood period and reduction in salinity (purely limnetic condition in most of the stations) could be reduced the phytoplankton diversity and abundance in the Vembanad wetland during the study period. Southernmost stations of the wetland were recorded with the freshwater form such as *Pediastrum* sp. during the flood period, indicating the higher freshwater discharge. The northernmost stations showed higher number during post flood period, indicating salinity influence. The diversity and abundance were low during the present study compared to previous studies. This might be due to the drastic variation of salinity and other environmental parameters occurred during the flood period.

According to the studies in 1970s in Vembanad wetland around 16 groups of zooplankton were recorded by Pillai *et al*. (1975), 10 major zooplankton groups by Rao *et al*. (1975) and Madhupratap and Haridas (1975) reported 12 major zooplankton groups from Cochin to Alappuzha. Recently, Cleetus *et al*. (2016) recorded 18 groups of mesozooplankton from Vembanad wetland. The current study accounted a total of 13 zooplankton groups during flood and 14 groups during post flood. These variations in the abundance and number of zooplankton taxa could be due to the impact of decadal changes in the water quality parameters (salinity, temperature and pH) at different magnitude (Bhattacharya *et al*., 2014) along with biological interactions like predation and competition in each trophic level and climate induced factors. The physico-chemical and biological fluctuations that occurred during the great flood of 2018 might have laid an additional stress on estuarine organisms to a great extent, affecting their abundance, diversity and community structure. All these factors may lead to the succession of zooplankton, so that many groups and species appear in a sequence and a few communities among them tend to dominate in the estuary. In response to flooding the zooplankton abundances decreased sharply at first but retained to the normal values within months.

Spatial and temporal distribution of mesozooplankton in Vembanad wetland displayed demarcated seasonal rhythms of occurrence, associated with environmental fluctuations during the study period. The abundance displayed a drastic decline in high waters during the present study even if the composition of zooplankton was more or less similar to that of previous reports. The average abundance of mesozooplankton was 22322 ± 31905 ind.m^{-3}; that varied from nil to 29,0191 ind.m^{-3} observed during flood whereas during post flood it was 19670± 32729 ind.m^{-3}; that varied from nil to 27,5383 and it was considerably low to that detected during flood period. Compared to previous studies in Vembanad wetland, the average abundance showed drastic variation (22514 ± 4516.87 ind.m^{-3} in 2011-2012 period). This might be due to the fact of decreasing beta diversity of zooplankton during high water periods (Bonecker *et al*., 2005); which here, could a "zero-salinity ", be the contributing gradient factor.

The higher abundance of mesozooplankton observed during post flood in St.1 (Aroor) which is north of TMB, clearly validates the role of salinity in its distribution when compared with flood season where salinity was nearly zero. Reports stating salinity as one of the factor influencing zooplankton dynamics (Vineetha *et al*., 2015; Madhu *et al*., 2007; Lawrence *et al*., 2004; Divakaran *et al*., 1982; Madhupratap, 1976; Pillai *et al*., 1975; Rao *et al*., 1975) duly states that saline incursion, discharge from sea food industries makes Aroor (St.1) organic enriched providing suitable ground for flourishing high saline plankton population. Another notifying fact was the appearance of rotifers (*Keratella* sp.) swarms during post flood period at different sites i.e. St.2 (Perumbalam), St.9 (Nehru trophy ward 17) and St.12 (Punnamada) and St.37 (FACT). The physico-chemical conditions by flooding favorably could have triggered the development of rotifer plankton especially *Keratella* sp. which was similar to the previous flood or post flood reports (Pawel and Teresa, 2015). Moreover, the higher rotifer density shows advancing eutrophication (Gannon and Stemberger, 1978) as the trophic status and rotifer assemblages of an ecosystem are very much related (Kaushik and Saksena, 1995). Also the higher occurrence or rather swarms of freshwater forms like cladocerans during flood (maximum 1714 ind.m^{-3}in St.22) as well as post flood (maximum 63212 ind.m^{-3}in St.14) in some stations of the estuary owe to its limnetic habitat, which was evident its increasing abundance. High phytoplankton biomass and abundance observed in the south of TMB during post flood period also forms a major factor for higher rotifer abundance. El-Tohamy (2015) has earlier discussed about such an impact of phytoplankton biomass on rotifer community or rather the whole zooplankton community.

Several studies related to the predominance of copepoda group in the mesozooplankton community have been documented previously. Predominance of copepods during the present study was in agreement with earlier records from GoM (Gulf of Mannar) and Palk Bay (Kartha, 1959; Prasad, 1954), coastal waters of Arabian Sea (Madhuprathap *et al*., 1992, 1990) and BoB (Rakesh *et al.*, 2008, 2006; Fernandes, 2008). The studies on zooplankton assemblage along the southwest coast by Asha *et al*. (2016) has revealed the prominence of copepods in terms of species richness and numerical abundance which was in total agreement with the current study during both flood and post flood. Conditions caused by flooding which was conducive to the development of copepoda might have persisted for long so that the same group could dominate the post flood period (but in lower abundance than that in flood period) too. The rich population of copepods observed during the present investigation in Vembanad wetland supports the presence of increased rotifers. This is in complete agreement with that of Varghese (2009) who claims that a good copepod population flourishes well, if only a rich population of rotifers exists and forms productive areas for rich fishery wealth. Rotifers (*Brachionus* sp.) along with *Acartiatropica*, copepod nauplii, *Chironomus calligaster* and *Pentaneura* sp. as indicators of pollution in retting zones of the Kadinamkulam estuary, Kerala has been investigated by Bijoy Nandan and Azis (1994). All these reveal the fact that higher distribution and abundance of rotifers, cyclopoids and cladocerans can be interrelated.

The Shannon diversity index was higher in St.22 (H' = 2.07) and the least diversity was shown by St.37 (H' = 0) during flood period. Whereas during post flood, St.1 showed maximum diversity (H' = 1.55) and the least diversity was shown by St.37 (H' = 0.10) similar to that of flood period. Diversity could be explained to some extent based on salinity fluctuations and is the interrelation with relative species abundance in a community (Hulbert, 1971; Whittaker, 1965). High riverine inflow coupled with the strong monsoonal rain is attributed to the low species diversity observed in the monsoon season, i.e. the interannual variation of zooplankton is greatly influenced by rainfall pattern, river flow and salinity in the estuary. The maximum richness was recorded in St.22 (d = 1) and the least in St.37 (d = 0) during flood, whereas during post flood the maximum richness was recorded in St.39 (d = 1.30) and the least in St.17 (d = 0.19). According to Khan *et al*. (2004), the Margalef richness index will be higher (2.5-3.5) in a healthy environment. In the present study the richness index was below this range during the study period, indicating an unhealthy system.

Results demonstrated that, the flood waters caused a decrease in the number, diversity and abundance of most of the mesozooplankton community. However, the detailed analysis of the post flood (November, 2018) samples shows that some zooplankton community has regained/improved in terms of its diversity and abundance which is evident from the increased abundance and occurrence of rotifers as well as cladoceran swarms in some study stations. The production of phytoplankton in the high waters might have attracted the zooplankton which fed on it. This could be correlated to the high mesozooplankton abundance with the bulk manifestations of the diatom *Coscinodiscus* sp. in St.1 during post flood. Thus a distinct succession pattern of rotifer *Keratella* sp. occurred in the current investigation. When some species like polychaete larvae which rose to extreme densities in most of the study stations during flood season, soon diminished and got confined to three stations (St.9, St.32 and St.33) during post flood, that too in minimal number.

The macrobenthic fauna of Vembanad wetland has been a major area of research interest by several researchers; hence the information on benthic fauna is documented since 1960s. According to a study in 1960s, the macrobenthic faunal groups observed in Vembanad wetland was polychaetes, decapods, gastropods, bivalves, ophiuroids, sea anemones, sipunculids and fish (Desai and Krishnan Kutty, 1967). Based on the studies in 1970s, the macrobenthic fauna was mainly composed of polychaetes, isopods, amphipods, decapods, gastropods, bivalves, sea anemone, goboid fishes, cumaceans, and tanids (Pillai, 1977; Kurian *et al*., 1975; Ansari, 1974). Polychaetes, isopods, tanids, amphipods, decapods, bivalves, echinoderms, sea anemones and fish larvae were the macrobenthic groups observed in 1980s (Gopalan *et al*., 1987). During 2000s polychaetes, oligochaetes, nemerteans, amphipods, gastropods and bivalves were the macrobenthic groups observed (Anon, 2001). According to the recent study, during 2011-2013 periods, hydrozoans, nemerteans, turbellarians, nematodes, oligochaetes, polychaetes, insects, ostracods, harpacticoid copepods, amphipods, cumaceans, tanaids, isopods, mysids, decapods, gastropods, bivalves and fishes were the different macro faunal observed in the Vembanad wetland system. During the present study, carried out in great flood of 2018, the benthic macro faunal community of the Vembanad wetland, mainly consisted of polychaetes, bivalves and oligochaetes, which carry out important functions such as breakdown of organic matter, nutrient recycling and materials transfer (McLenaghan *et al*., 2011; Hutchings 1998). Gastropods, amphipods, crustaceans, insects, nemerteans, tanaids and pisces were also obtained. The composition of macrobenthic fauna was comparable to that of previous studies cited above.

Even though the composition of macrobenthic fauna was more or less similar to that of previous studies, the abundance showed a drastic decline during the present study. The average abundance of macro fauna during flood period was 701 ± 972 ind.m^{-2}; that varied from nil to 7011ind.m^{-2} whereas during post flood, the average abundance of macrobenthic communities were increased (av. 1463 ± 2238 ind.m^{-2}) than the flood period and it varied from nil to 13171 ind.m^{-2}. The average abundance was noticeably lower compared to previous studies from Vembanad wetlands (2737 ± 2383 ind.m^{-2} in 2011-12 and 5556 ± 4392 ind.m^{-2} in 2012-13). The maximum density of macro fauna in this study (i.e. 13171 ind.m^{-2} during post flood period) was higher than the density of macro fauna observed during the time of flood (7011 ind.m^{-2}) but it was even more reduced than previous studies; that is, 46036 ind.m^{-2} in 2011-2013 (Asha, 2017); 73500 ind.m^{-2} in 1987 (Gopalan *et al*., 1987); and 44340 ind.m^{-2} in 1977 (Pillai, 1977). The average species richness during flood period was 0.65 and it varied from 0 to 1.25, which was also considerably low compared to previous studies (1.27 in 2011-2012 and 1.20 in 2012-2013). Whereas the average richness value increased during post flood (0.72) and it varied from 0 to 1.53. During flood period, the Shannon Wiener diversity of macro benthic groups ranged from 0 to 2.46 with an average of 1.38 similarly, during post flood, it ranged from 0 to 2.70 with an average value of 1.55 which was comparable to that of previous studies (1.62 in 2011-2012 and 1.99 in 2012-2013). The peculiarity of this study was that it was conducted during the catastrophic flood in Kerala during 2018; hence a strict comparison between previous results is not always reasonable. In an ecological sense, the term ‘flood’ embodies any increase in discharge. Almost all rivers are subject to discharge increases; these can stem from natural events (such as increased precipitation) or anthropogenic modifications. Increased flows due to flooding or increased reservoir discharge are known to reorganize substrates through changing scour and fill patterns (Bond and Downes, 2003; Matthaei *et al*., 1999). Periods of high flows lead to sediment transport including scouring of the fine benthic sediments as well as removal or relocation of macrophytes and larger substrates (Jakob *et al*., 2003; Patten *et al*., 2001; Poff *et al*., 1997). During periods of flooding, invertebrates are affected directly and indirectly through habitat changes caused by water velocity and physical scouring from the initiation of bed movement (Bunn & Arthington, 2002). Scouring can cause damage to them and their food source. The dynamics of flow play crucial role in the lives of lotic aquatic organisms (Hart *et al*., 1996; Craig, 1990) and their community structure (Nelson and Lieberman, 2002; Giller, 1991; Resh *et al*., 1988). Flows affect the dispersion of larvae and adults, as well as the movement of gametes, nutrients, food particles, and waste removal (Gaylord and Gaines, 2000; Rudek *et al*., 1991; Wotton, 1988). The morphology, physiology and behaviour of lotic organisms are greatly affected by flow variation (Lancaster *et al*., 2006; Craig, 1990; Statzner, 1988). When catastrophic floods occur, torrential flows carrying abundant debris can completely reshape the substratum with huge deposits of bank sediments which can have multiple impacts on aquatic organisms (Snyder and Johnson, 2006). During flood events many invertebrates may get dislodged from within the river bed resulting in a lower abundance. Floods that result in movement of bed materials also bring about disturbance of stone surface organic layers (epilithon), and consequently affect gross primary production, community respiration and net community production; the reduction in epilithic biomass can result in limited food availability for benthic fauna which can eventually reduce the benthic abundance (Scrimgeour and Winterbourne, 1978). The result of our study was in agreement with that of similar studies of invertebrate communities in rivers exposed to floods in Thailand (Netpae, 2014), Switzerland (Jakob *et al*., 2003) and New Zealand (Rounick and Winterbourn, 1983; Winterbourn 1976) which showed substantial reductions in taxonomic richness, and invertebrate densities.

In the present study, polychaetes (44 % during flood and 50 % during post flood), bivalves (18 % during flood and 27 % during post flood) and oligochaetes (19 % during flood and 6 % during post flood) formed the most abundant macrofaunal group. Among these, polychaetes showed highest abundance (3113.6 ind.m^{-2} during flood; 6630.4 ind.m^{-2} during post flood) during the study period. In the soft bottom habitats, polychaetes are qualitative and quantitative key components of the benthic fauna (Fauchald, 1977). Polychaetes are segmented worms belonging to phylum Annelida, class Polychaeta and formed the dominant and abundant group, actively involved in bioturbation, burial of organic matter, recycling and reworking of bottom sediments (Gholizadeh *et al*., 2012; Hutchings, 1998). It forms a major component because of their high species richness, biomass and density and their tolerance to pollution and other natural disturbances (Tomassetti and Porrello, 2005; Mendez *et al*., 1998). So they play a great role in stability and functioning of the benthic communities and the ecology in general (Hutchings, 1998). In majority of the estuarine and coastal environments, polychaetes formed the dominant macrofaunal groups. In the Mumbai port area polychaetes were the most dominant macrobenthic group (72.09 %) followed by decapods, amphipods and bivalves (4.56 %) (Mandal *et al*., 2013). Similar observations were made by Thilagavathi *et al*. (2011) in the mangrove ecosystems of Tamil Nadu. In the shelf waters of Visakhapatnam, more than forty groups of benthic fauna were reported by Vijayakumaran (2003). Among the benthic fauna, polychaetes were the dominant taxa contributing 62.5 % followed by amphipods (17 %). Previous studies documented the survivorship of dislodged polychaetes during flood scenarios. (Malakauskas *et al*., 2012). Polychaetes showed a number of behaviours for preventing increases in flow, including mucus extrusion, burrowing into sediments, and transfer to lower-flow microhabitats, thereby demonstrating high flow resistance. Apart from physical disturbances to the substratum, decreased salinity was an important factor observed during flood. According to Brady and Somero (2006), the decreased salinity in estuarine habitats formed an important factor in controlling distributions of species. The polychaete species *Dendronereis estuarina* and *Namalycastis indica,* the most predominant in this study are commonly found in the fresh to brackish water environment (Misra, 1995). Previous studies showed that, over the last 30 years, decreased salinity and increased organic matter in the southern zone of Vembanad wetland reduced the overall polychaete species diversity, only *Dendronereis estuarina* and *Namalycastis indica* were exceptional (Asha, 2017). Moreover *Dendronereis estuarina* and *Namalycastis indica* were capable for a wide tolerance level to environmental parameters attributing with the dynamic nature of estuarine ecosystems (Saraladevi, 1986).

The persistence of fauna during flood disturbance could be also explained due to the morphological peculiarities. In the case of molluscs, calcified shells limited the risk of injuries during dislodgment, which could be the probable reason for its presence. (Evanno *al*., 2009). Moreover, the Vembanad wetland system is famous for its clam fishery and the bivalve, *Villorita* is a major benthic species reported from Vembanad backwater (Anon, 2006); which was observed in this study also. *Villorita cyprinoides* was the species obtained in the present investigation. Flood is one of the most influential factors affecting the structure and function of benthic macro invertebrate assemblages in aquatic ecosystems. Even if these natural disturbances occur at the same magnitude at multiple locations, the responses may differ. Seasonal variations of benthic fauna in tropical estuaries were prominent due to the monsoonal rains and its life cycle pattern was synchronized with monsoonal rain (Alongi, 1990), in which heavy rains caused increased mortality of benthic communities and ultimately lead to its defaunation. According to Sivadas *et al*. (2011) the faunal diversity was negatively impacted with monsoon. Monsoon onset regime characterised by effects in defaunation, migration and spawning of the macrofauna and increased organic matter and primary productivity during the peak monsoon regime and post monsoon period supported the recruitment process (Gaonkar *et al*., 2013). In the present study, the extreme variation of salinity (pure limnetic condition) in the whole wetland system was highly related to rainfall and river discharge during flood. Salinity formed the key factor of spatial heterogeneity among macrobenthos (Fujii, 2007; McLusky and Elliot, 2004; Day *et al*., 1989). In Vembanad wetland, the low salinity during monsoon was attributed to the increased riverine runoff which fully flushed the estuary, turning the estuarine water fresh (Shivaprasad *et al*., 2013b). Over the years the percentage contribution of macrofaunal groups varied considerably. During earlier studies bivalves were the dominant group (77 %) followed by polychaetes (12 %) and amphipods (11 %) (Gopalan *et al*., 1987). Whereas in the present investigation, polychaetes become dominant (44 % during flood; 50 % during post flood) followed by bivalves (18 % during flood; 27 % during post flood) and oligochaetes (19 % during flood; 6 % during post flood). This was supported by the study conducted in Vembanad wetland by Asha (2017). The decreased abundance of bivalves during the present study compared to previous studies in the region was mainly due to the salinity variation. In the southern zone of Vembanad wetland, monsoon rain and flood water brought large amount of mud and silt, which was carried by the major rivers into the lower reaches and this causes mortality of live clams (Anon, 2006). This might have happened in the present study also. Besides this, after the construction of TMB, the southernmost part of Vembanad wetland system remained fresh or limnetic condition. According to Suja and Mohamed (2010), the black clams could not reproduce well in low salinity and it required 10-12 ppt salinity for spawning. In the southern region, the average bottom water salinity decreased up to <3 ppt during pre flood whereas during the catastrophic flood of 2018, it decreased to zero. The results of the present study of benthic fauna during the great flood of 2018 could be useful in management and conservation aspects as such information is scanty from this Ramsar site.

6.3.2 Effect of invasive species on wetland ecology due to the flood, 2018

Kerala is considered to be a global hotspot for fresh water fish diversity (~200 sp.) and endemism (30 %). Some rivers like Periyar and Chalakudy harbours several threatened species (Kumar *et al.*, 2019). These sites are already under threat due to many anthropogenic activities including hydropower dams, alien invasive species, over harvest and pollution. Globally floodwaters have proved to be a major route for the spread of invasive species. The recent flood in August, 2018 also became one of the most significant threats to the freshwater ecosystems of Kerala. The flood caused extensive state-wide havoc and released many alien species of fish into water bodies, posing a threat to the endemic aquatic ecosystem and biodiversity (Raghavan, 2019). The flood has resulted in increasing the number of many invasive fish species and other organisms in the water bodies of Kerala. This makes a precarious condition in the fresh water ecosystem as these invasive species are mostly predatory exotic species, which are rapidly spreading, acclimatizing and flourishing in new environments across the globe. A study conducted by Biju Kumar *et al.* (2018) in Periyar, Chalakudy, Muvattupuzha and Pamba rivers showed that during post flood, 'fugitive' Arapaima (*Arapaima gigas*) was recorded from the Chalakudy, the Malankara reservoir on the Muvattupuzha River and the backwaters near Kodungallur (Plate 6.4). They are air-breathers, a trait that could help them survive even in polluted environments. This alien fish species will affect the native species, which in turn impact the local fisher livelihoods. The Alligator gar (*Atractosteus spatula*) was also recorded from the Periyar and Kurumali rivers and Perumbalam Lake near Cochin. These Jurassic invaders have the potential to threaten Kerala's exceptionally rich native ichthyofauna. Recently, invasion of a freshwater snail species *Physella acuta* (Draparnaud, 1805), is commonly known as 'Acute bladder snail' reported for the first time from Edappally Canal of Kochi city. This is the first record of *Physella acuta* (Draparnaud, 1805) from the southern part of India. This species is globally considered as a highly invasive snail species with air-breathing capability. Hence, this air-breathing capability and hermaphroditic life support them for an invasive life even in eutrophicated water bodies (Burch, 1989). They display a high degree of fertility and temperature resistance. These species often come to the surface of the water body to breathe and are usually seen in association with the aquatic ornamental plant, *Ceratophyllum demersum* (Linnaeus, 1753), a commonly used aquarium plant, which may be the potential cause for the introduction and spread of the species in Kochi. The trade in aquarium is considered as a significant vector for the introduction of nearly 150 exotic animal species in freshwater habitat around the world (Chang *et al.*, 2009). The growing demand for exotic ornamental species thus results in the human-mediated spread of species such as *P. acuta* that are globally invasive. As they are host to many human foodborne trematode diseases, including swimmer's itch in humans, their dissemination is also medically significant.

Stocking of illegally imported ornamental and commercially important fish species is considered as a good business in many states of the country. Kolathur in north Chennai is renowned for its ornamental fish trade and most of the residents in the area are involved in breeding and selling 150-200 exotic ornamental fish species. The Red Belly (Nattar) is one of the most common foreign fish breed (i.e. it is from South America) that is cultured in Kerala. Red Belly species were largely farmed in Kuttanad. Small fishes and leaves near the river banks are the feed for this fish. In a week since the flood, the red-bellied piranha, one of the deadliest freshwater fish known to man has also been reported by fishermen.

African catfish (*Clarias gariepinus*) which is locally known as 'African Mushi' is another threat to the local fish species. Though African catfish farming in Kerala is forbidden, after the floods, a large number of these species were captured from the Periyar and Chalakudy rivers. Similarly, alien species such as catla (*Catla catla*), rohu (*Laboe rohita*) and mrigal (*Cyrrhinus mrigala*) have been cultured in most of the lakes and ponds of Kerala, and this has contributed to a steady decline of the endemic fish stocks in these water bodies. As these invasive fishes forage and consume whatever that comes across, causing a major challenge to local and endemic fishery.

Plate 6.4 Invasive species caught during the flood, 2018
***(A) Physella acuta* (B) *Arapaima* sp. (C) Alligator gar**
(Source: www.firstpost.com)

Invasion of the biofouling, black-striped mussel, *Mytilopsis sallei* was also reported in Vembanad wetland (Cochin backwater) by Jayachandran *et al*. (2018). These are filter-feeding bivalve are able to tolerate a wide range of temperature, salinity and oxygen. This tolerance power can make them very dangerous to the indigenous species in coastal waters of Kerala. It is also capable of living in the turbid water column of estuarine environment. They are fast growing opportunistic mussels that can attain maturity within a month of a larval settlement and causes serious fouling damage to the costal infrastructure. Recently, invasion of another mussel species (*Mytella strigata*) was also reported in Cochin backwater. It is a highly invasive alien American brackish water mussel, which is adapted to live in a wide range of salinity between 5 to 35 ppt. As the density of these mussels gets high, they die and sink, covering the bottom sediment resulting in depletion of dissolved oxygen. Thus the present Kerala flood may have paved an entry of various invasive species to the wetland that can be a threat to the endemic biodiversity of the state as well as the country.

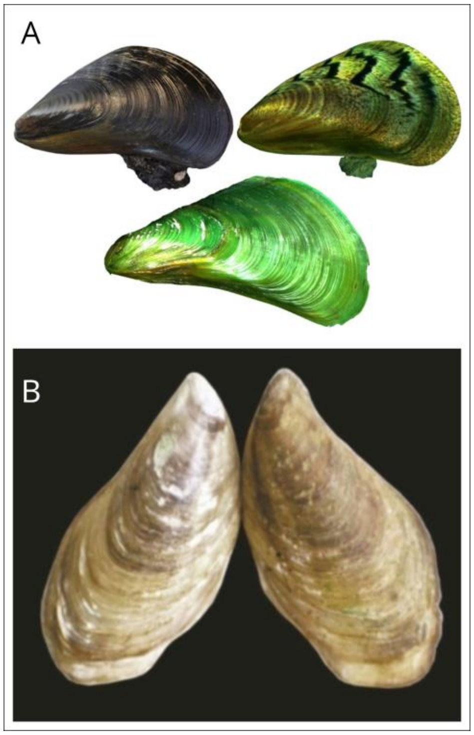

Plate 6.5 Exterior valve of A) *Mytella strigata* B) *Mytilopsis sallei* collected from Cochin backwater

The effect of flood (August 2018) continues to seriously and significantly impact biodiversity through the spread and distribution of invasive, resilient species of fauna like the fishes, snails and bivalves as described above. However, detailed studies are required further, in this direction.

Salient findings…

- *Due to very low salinity, stenohaline forms of phytoplankton (e.g. Pediastrum sp.), mesozooplankton and macrobenthic species prevailed in the wetland.*
- *Generally, the abundance, diversity and distribution of species were decreased.*
- *Because of heavy land drainage (leachates from land, waste discharge, pollution and so on.) and also changing water quality conditions, impacted the biodiversity and its productivity.*
- *Dominant opportunistic indicator forms like Nitzchia sp. (phytoplankton; indicating organic pollution), cyclopoids (mesozooplankton; freshwater forms rapidly proliferate), Dendronereis estuarina and Namalycastis indica (macrobenthos; wide tolerant level to changing environmental parameters) survived well during the flood period.*
- *Swarming or mass occurrence of zooplankton like rotifers (Keratella sp., indicating eutrophication) and cladocerans (freshwater forms) observed during post flood compared to pre flood period.*
- *The presence and occurrence of invasive opportunistic species of fish (i.e. Arapaima gigas and Alligator gar: Atractosteus spatula), mussels (Mytilopsis sallei and Mytella strigata) and 'Acute bladder snail' (Physella acuta) during the flood and the continuing post flood period can have far reaching repercussions on the biodiversity and food web structure of the wetland in future. These invasive alien species find their entry during flood from aquarium and other land based fishing activities that can significantly affect the trophic characteristics of the wetland ecosystem, which needs further studies.*
- *The impact of flood on biota continued to influence even during the post flood period due to the changing environmental conditions and human interventions. The inherent modification in the wetland posed to affect the biodiversity and distribution of the plankton, benthos and fishery without notably differentiating between the flood and post flood period.*

7. SUMMARY AND CONCLUSION

The main reasons for the devastating 2018 Kerala floods were the degradation of wetlands, unsustainable land use pattern and encroachment and deforestation that has taken place in the Western Ghats along with quarrying for stones and minerals. Along with very heavy rainfall, an analysis of the floods shows that the huge number of deaths in the floods could be linked to the rampant destruction of the Western Ghats the biodiversity hotspot that covers about half of Kerala. According to various experts, if the destruction goes on unchecked, future floods could bring even bigger disasters in India's monsoon gateway. Massive destruction of Western Ghats began when tropical forests were cleared for large-scale commercial plantations. Large-scale internal migration from coastal and midland areas to the Western Ghats contributed to the forest destruction. Urbanization has also made major demands on resources for construction and infrastructure projects.

Moreover, the wetlands and the floodplains of rivers have also been encroached. Some parts of Kerala have been marooned during the flood time because wetlands and lakes has served as natural flood defenses have vanished due to rampant urbanization and construction of infrastructure. During 2018 flood, when all the dams were opened, and the water rushed downstream, the natural destination was towards the wetlands, which has now been encroached upon, also reducing the water holding capacity. The areas in which wetland reclamation had been most significant were also the ones to bear the severest of the impacts. The problem was that many of the wetlands have been drained in the past century to create rice fields to make way for development. These land reclamation projects, in Kuttanad and elsewhere, took away the capacity of the wetlands to absorb floods. Nearly, two-third of Kuttanad is presently under agriculture. The nearby Ashtamudi wetland has, also shrunk by one-fourth in last four decades. The wetlands have become shallower. What has happened in Kerala has played out all over the world in the past century as wetlands have been drained, diked, and dammed for agricultural development and flood control. Many of the mangroves that dotted Vembanad wetland have been removed to make way for tourist lodges and to improve their views of the water. The natural shorelines of Vembanad wetland were converted, encroached upon, and in-flowing rivers recklessly mined for sand. Half a century ago, newly independent India rushed to drain the rich wetland soils of the plain for growing rice, as part of a national drive to achieve local food self-sufficiency. Urbanization grabbed the wetlands too. The fast urbanization has led to the conversion of wetlands and paddy fields which have played a major role in conserving the ecosystem. The modification and encroachment of paddy fields has reduced the area from 8.5 lakh hectares to just around 2 lakhs hectares. With paddy fields being converted into commercial plots, many natural streams have disappeared. In Kochi, Kerala's fastest-growing city and main port, a few scraps of mangrove on riverbanks remind visitors of its wetland past. Like this, many of the Kol wetlands in Kerala had been reclaimed for various developmental purposes. All these activities have together increased the runoff and also decreased the water holding capacity of the hills and the plains.

The absence of significant storage reservoirs in the upstream of the major rivers, reduction of depth and shrinkage in carrying capacity of Vembanad wetland and the structural limitations of Thottappally spillway and the Thanneermukkom barrage that played a major role in worsening the situation in the Kuttanad region during 2018 flooding. The overall degradation, pollution from various sources and waste accumulation has led to the destruction and reclamation in large areas of the rivers and wetland habitat significantly modifying the carrying capacity, causing severe flood condition in the area. As being a notable part of the larger Western Ghats and its ecological conditions, the floods in 2018 and the subsequent period have impacted the river flow, storage capacity of dams and reservoirs in the Ecologically Sensitive Zones (ESZ1, ESZ2 and ESZ3) of the wetland system. So, it is inevitable to implement a decentralized river basin planning for west-flowing rivers and maintaining environmental flow in these rivers. New scientific and development oriented initiatives should be proposed and implemented in the Western Ghats region considering the ESZ zones and its conservation strategies. The recent report of the IUCN (2020) has also highlighted the urgent need for implementation of the Gadgil and Kasthurirangan recommendations of the WGEEP (2011) report in total. At present due to various anthropogenic interventions and looming climate change issues, the Vembanad wetland area under the Western Ghats region has degraded miserably, also the 2018 floods and subsequent periods have worsened the situations in the area.

The hydrographic condition of Vembanad wetland system was more affected by the unprecedented monsoon and associated river discharge that occurred during 2018 flood period. This resulted in pronounced variations in the environmental parameters that affected the primary and secondary productivity of the water body to a large extent. Changes in the environmental parameters and production rates are also caused by the tidal influx, nutrient distribution, incident solar radiation, nature of the medium and species composition of the primary and secondary producers.

The terms of reference of the study was to conduct field work in the selected study stations in Vembanad wetland, covering the upstream, downstream and riverine areas of Alappuzha, Kottayam, Ernakulam and Pathanamthitta districts during the flood and post flood period to understand the status and changes on the water and sediment quality, productivity and biodiversity represented mostly by the plankton, benthos and fishery. The study also mandated to refer secondary data on rainfall, river discharge and dam storage and relate it to the observations and conclusions of the study. Because of its significance on biodiversity and the large number of people depending directly or indirectly on the wetland system, the impact of flood on the environmental quality is quite significant. In this context, the Kerala State Pollution Control Board (KSPCB) entrusted a study, to be conducted in the Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology (CUSAT) on the impact of flood and post flood scenario on the general ecology and biodiversity of Vembanad wetland ecosystem.

In the present study during flood period, most of the physical and chemical parameters showed wide variations compared to pre flood period. Depth showed drastic decrease in most of the stations, particularly in stations south of TMB (Thanneermukkom barrage). Station 7 (Aryad) had the lowest value of 0.7 m. According to MSSRF (2007), the rapid shrinkage of flood carrying capacity of Vembanad wetland occurred by 78 % (i.e. from 2.4 km^3 to a mere 0.6 km^3) due to the reduction in the wetland area and depth. Unrestricted encroachments and reclamation of wetland and raising lakebed due to silting was the main cause of this rapid decrease in wetland area. Besides this, the depth of the Vembanad wetland is decreasing 1 % per year and its rate has been increasing after the construction of TMB particularly the cofferdam situated in the middle of the wetland. In the present study, the depth of the wetland showed a decreasing trend which is in agreement with the previous studies. Anthropogenic activities like waste dumping and various other pollution problems in Vembanad wetland system might be attributed to this decreasing trend. The study conducted in Vembanad-Cochin estuarine zone during non flood period, revealed the abundance of micro plastics in water (451 no. of microplastics) and sediment (804 no. of microplastics) samples (Anon, 2019). Hence, the presence of pollutants, waste accumulation and reclamation activities in various sectors in the wetland system is reducing the water absorbing efficiency of soil which inturn decreases the water holding capacity. The shrinkage of carrying capacity of Vembanad wetland plays a significant role in worsening the 2018 flooding in the Kuttanad region and the backwater flows to the low-lying areas in the upper reaches of the lake. This was one of the major reasons for the heavy flooding experienced in the low-lying areas closer to the Vembanad wetland system in the Alappuzha, Kottayam, Ernakulam, Thrissur and Pathanamthitta districts. The average depth of the Vembanad wetland decreased during post flood (av. 3.26 ± 1.66 m) compared to flood (av. 3.29 ± 1.78 m) period. This could possibly be due to the post flood sedimentation. The transparency values showed lower values during the present study (0.2 to 1 m) compared to pre flood period (0.2 to 4 m). The heavy river discharge during flood brings large scale suspended sediments and along with this extensive land runoff results in turbid water which reduces the transparency in most of the study stations. Salinity values showed drastic variation compared to pre flood period and most of the southern stations were showed limnetic condition during the study period. Salinity at station 1 (Aroor) recorded at zero during flood period whereas during pre flood period it was 27 ppt. Extreme river discharge from Pamba, Manimala, Achankovil, Meenachil, Muvattupuzha and Periyar was responsible for this freshwater condition. During flood, heavy spill of monsoon and associated river discharge reduces the pH (4.35) and alkalinity (15 mg L^{-1}) in most of the southernmost stations whereas the northernmost stations showed slightly higher values (100 mg L^{-1}), indicating the sea water influence through Cochin barmouth. Compared to the permissible limits of standard values prescribed in various agencies, the pH values showed values below acceptable limit during the present study period (i.e. 4.8 in SW and 4.35 in BW during flood; 4.92 in SW and 6.02 in BW during post flood). The alkalinity values showed significant variations during flood compared to the pre flood period, which was very clear in station 1 (Aroor), which showed lower values compared to previous study (alkalinity - 20 mg L^{-1} during flood; 100 mg L^{-1} during pre flood). The enormous freshwater discharge contributed higher DO values during flood period (av. 7.33 ± 1.38 mg L^{-1}) whereas during post flood the values showed decreasing trend (av. 7.11± 1.52 mg L^{-1}), signified the diminishing river discharge. During the study period, DO values of some stations showed values below acceptable limit of standard values prescribed by various agencies such as CPCB and ICMR. During flood period, DO of 3.15 mg L^{-1} was observed in bottom water at station 8. Similarly, lower values were observed during post flood period also (i.e. 3.1 mg L^{-1} in SW and 3.07 mg L^{-1} in BW at St.31). During flood, higher BOD values observed in both southern and northern stations denoted increasing organic pollution in the Vembanad wetland system (av. 3.71 ± 1.42 mg L^{-1}), in which, station 37 recorded higher values during the entire study period. This was mainly due to the effluent discharge from nearby chemical industries. Station 13 (Pallathuruthy) showed maximum sulphide concentration (9.62 µmol L^{-1}) during flood. Station 12 (Punnamada) was also recorded with higher concentration (7.93 µmol L^{-1}) similar to pre flood period. The various pollution problems in southern region and increased organic load during flood contributed higher sulphide concentration. Intense monsoonal rainfall with heavy fresh water discharge and land drainage together contributed higher phosphate concentration in the Vembanad wetland during flood period, in which southern stations showed higher values, indicating agricultural runoff. While sea water influence through Cochin barmouth, land runoff and effluent discharge were responsible for the maximum PO_4-P values in northernmost stations (av. 10.44 ± 6.36 µmol L^{-1}). The increased river fall and land runoff during flood contributed higher silicate concentration (158.13 µmol L^{-1}) and it was higher compared to pre flood period (129.72 µmol L^{-1}). The higher ammonia concentration observed during the study period indicated increased organic load and it was maximum during post flood (av. 9.44 ± 5.88 µmol L^{-1}). The northernmost stations (St.37 and St.39) recorded with higher nitrate concentration. Heavy rainfall and river discharge during flood period, sea water influence and effluent discharge together contributed higher NO_3-N values in northernmost stations. Among inorganic nitrogen, nitrite-nitrogen showed lowest values and it did not depict any noticeable pattern in its distribution. The GPP showed maximum value during post flood (av. 4.10 ± 1.00 g C m^{-3} day^{-1}) compared to flood (av. 1.70 ± 0.81 g C m^{-3} day^{-1}) period. The lower GPP value observed during flood period revealed that, rainfall beyond an optimum level is not favourable for phytoplankton production in the estuarine environment because it affects other environmental factors such as intensity of flood flow, turbidity, light penetration, salinity, even though enormous quantity of nutrients were brought into the estuary by the consequent freshwater discharge from land drainage. Increased organic load during flood and eutrophication accounts for the greater respiration which corroborates with the lower NPP values in most of the stations (av. 1.10 ± 0.47 g C m^{-3} day^{-1} during flood; av. 2.02 ± 1.25 g C m^{-3} day^{-1} during post flood). In addition to this, increased grazing of phytoplankton by zooplankton could be one of the reasons for a relatively low level of primary production even though the environmental conditions remained conducive for maximum phytoplankton growth. In the present investigation, the average concentration of heavy metals in water followed the trend Fe > Zn > Pb > Cu during flood and Fe > Zn > Pb > Cu > Ni > Cd during post flood. The average concentration of Fe was higher than its acceptable limit during both the flood and post flood period based on water quality standards of US EPA (2017). Cd concentration in stations 34 and 37 were also higher than the acceptable limit. The flood impact created on the water quality and primary productivity continued to influencing the wetland even during the post flood period to a large extent. This indicates that, the environmental degradation of the wetland due to various anthropogenic factors is inherently influencing the overall ecological status and well-being of the ecosystem inspite of the prevailing flood and post flood condition in 2018.

The total nitrogen concentration in sediment showed an increasing trend compared to pre flood period. The extreme river discharge and agricultural runoff during flood period might be contributed to this higher level. In sediment, the average concentration of heavy metals followed the trend Fe > Zn > Cu > Pb > Ni > Cd during flood and Fe > Zn > Pb > Ni > Cu > Cd during post flood. The Cu and Zn showed heavy pollution when compared with SQG. The pollution load indices showed moderate to considerable contamination with the heavy metals. In Cheranelloor and Eloor regions, Pb showed considerable contamination during flood. It is evident from the study that the northern stretch of the Vembanad wetland system, the Cochin estuarine zone, is still the major hub of heavy metal accumulation. The present study showed a decrease in heavy metal concentration both in water and sediment when compared to previous studies conducted in the Vembanad wetland system. It is mainly due to the flushing of heavy metals that happened because of the increase in river discharge and heavy rainfall that occurred during the deluge.

Drastic variations were observed in the distribution, abundance and diversity of phytoplankton, zooplankton and benthic communities compared to pre flood period. The diversity was affected by the heavy rainfall, extreme river discharge and low salinity during flood period. Moreover, heavy land runoff and waste discharge from various sources in the backwater during flood period affected the biodiversity and its productivity. During the study period, freshwater forms were dominant indicating enormous freshwater discharge during flood. Besides this, dominant opportunistic indicator forms of species such as *Nitzchia* sp. (phytoplankton), *Dendronereis estuarina* and *Namalycastis indica* (polychaete) were survived during the flood period. The decreased abundance of bivalves during the present study compared to previous studies in the region might be due to the salinity variation. Higher occurrence or swarms of zooplankton was observed during the post flood compared to pre flood period. The mass occurrence of rotifers (*Keratella* sp.) was observed during post flood indicating the increasing eutrophication in the backwater. The 2018 flood has also resulted in increasing number of many invasive fish species and other organisms in the water bodies of Kerala. The presence and occurrence of invasive opportunistic species of fish (i.e. *Arapaima gigas* and Alligator gar: *Atractosteus spatula*), mussels (*Mytilopsis sallei* and *Mytella strigata*) and 'Acute bladder snail' (*Physella acuta*) during the flood and the continuing post flood period can have far reaching repercussions on the biodiversity and food web structure of the wetland in future. These invasive alien species find their entry during flood from aquarium and other land based fishing activities that can significantly affect the trophic characteristics of the wetland ecosystem, which needs further studies. They are able to tolerate a wide range of temperature, salinity and oxygen. Hence, this tolerance level can make these types of species very dangerous to the indigenous species in coastal waters of the state as well as the country. The impact of flood on biota continued to influence even during the post flood period due to the changing environmental conditions and human interventions. The inherent modification in the wetland posed to affect the biodiversity and distribution of the plankton, benthos and fishery without notably differentiating between the flood and post flood period.

The amount of CO_2 and other greenhouse gases released into the atmosphere is increasing day by day leading to warming of the air temperature. Theoretically, the warmer air will hold more moisture that can result in excess rainfall leading to intense flooding and other calamities. Similarly, the increasing temperature at the poles can also lead to slower movement of storms in the mid-latitudes. This can further result in storms that can linger in the atmosphere for longer period. So, therefore the combination of slow moving storms and excess moisture in the atmosphere can lead to intense rainfall in a particular location.

The high intensity of rainfall during the southwest monsoon season causes severe floods in recent years. Increasing floodplain occupancy, land use changes and reclamation of water bodies and wetlands results in increasing flood damages. Nearly, 14.5 % of the total area in the state is prone to floods. In Alappuzha district, more than 50 % area is identified as flood-prone. These are mostly confined to Kuttanad region that hosts seasonally waterlogged flat lands with anastomosing waterways linked to Vembanad wetland system. Due to its importance as being a Ramsar site, implementation of better management remedies and practices must be urgently developed in order to avoid future flood impacts. Hence, it is necessary to take a holistic ecosystem based approach for the conservation and management of wetland system for the effective flood control in future. Therefore, based on the study the following recommendations are put forth for proper management of Vembanad wetland system from floods and other calamities.

- A detailed evaluation of rainfall, river discharges, flood water extent and duration should be undertaken and structural limitations of Thanneermukkom barrage (TMB) and Thottappally spillway has to be rectified. One of the major reasons for the devastation of Kuttanad during August 2018 flood was that the Thanneermukkom barrage across the Vembanad wetland system, affects the free flow of water from Kuttanad region to the Arabian Sea and its carrying capacity. Hence, the scientific management of the cofferdams in terms of the river discharge and rainfall should be synchronized.

- There is a need for mapping the floodplains. Ideally, no construction should be allowed in this region. Flood Hazard Maps for the designated rivers should also be adopted. So, the flood mapping would help identify the risk zones. Furthermore, the number of gauging stations should be increased for obtaining more data related to river discharge during such intense flood.

- Monitoring flow rate or surface water velocity during flood events could be useful for mitigating the flood impacts. For this, remote methods such as LSPIV (Large Scale Particle Image Velocimetry) could be adopted. This is an optical method, which computes surface water velocity maps from videos recorded with a camera. Such type of optical methods should be preferred in extreme conditions. The technique aims at quantifying the surface flow without the need of deploying instrumentation, but only analyzing video frames of the river flow. But, in challenging experimental conditions, such as mirror-like surfaces, LSPIV algorithms may systematically result in underestimated velocities. Such criticalities may be partially relieved through artificial tracer seeding. However, practical difficulties to homogeneously seed the water surface of large rivers considerably limit the applicability of the method. Hence, the combined use of image analysis and UAVs (Unmanned Aerial Vehicles) is expected to be highly beneficial for remote and large scale observations in difficult-to-access areas (Tauro *et al.*, 2015 a, b).

- The study indicates that, ecological decay of the wetland is on the rise due to anthropogenic activities such as unauthorized dredging, sand mining, intense pollution problems such as sewage and waste disposal and further encroachment, reclamation and illegal construction activities takes place in the wetland system. This should be regulated by local self-government and other governing agencies, under the Environment and Wetland laws. The violation and relaxation of Coastal Regulation Zone (CRZ) norms has been observed in many regions. Especially, the urbanization and developmental activities in the Punnamada, Perumbalam (eg., luxury resorts in Perumbalam) and Aroor region. So strict enforcement of the CRZ norms for the backwaters have to be implemented. The National Green Tribunal can enforce laws to prevent the reclamation in the estuarine and wetland region.

- To prevent encroachment and reclamation activities, the boundaries of Vembanad backwater along with that of rivers and canal networks have to be demarcated by using landmarks and detailed satellite imagery. Removal of all illegal encroachments into the backwater is recommended. In addition, it is important to segregate a demarcated narrow strip (4-6 m) of ‘ecotone’, planted with mangroves or coconut between the main land and water body all around the Vembanad backwater as a measure of conservation. Such an ecotone could possibly be owned and managed by the respective private institutions, individuals or panchayat. This is essential for preventing further encroachment and destruction of the backwater.

- Massive destruction of forests along the banks of the Vembanad wetland for developmental activities have resulted in soil erosion and sedimentation. Afforestation of mangroves can be done in ecologically selected areas with species like *Avicennia officinalis*, *Rhizophora mucronata*, *Exocoecaria agallocha* and *Kandelia candel*.

- The Vembanad wetland system receive large quantities of untreated solid and liquid waste, which needs to be properly treated and recycled, so that zero discharge and waste disposal is achieved. The presence of pollutants such as microplastics, heavy metals, pesticide residues and other contaminants were reported from the wetland system during previous studies and the significant level of heavy metals during the present study as well, which is significantly reducing the water absorbing efficiency of soils and resulting decreased water holding capacity and increases the flood occurrence. Hence improving and monitoring of waste management programs should be adopted as part of the flood control and conservation of wetland system. Also, micro level study in the areas of high heavy metal content zone and high organic matter zone to develop suitable action plan for improvement.

- Over 66,000 houses have already been partially or fully damaged in the 2018 and 2019 floods. Hence, construction of floating houses and flood-resilient buildings in flood prone areas especially in Kuttanad region (which is highly susceptible to floods) could be useful for reducing the future flood impacts.

- Much of the flood related damages in recent decades might be due to the increased frequency of extreme weather events, for which measures are to be taken to reduce flood vulnerability, through proper land use planning following a sustainable development strategy.

- Seasonal and extended range forecast of rainfall and improved forecast of extreme rain events at a longer lead can help in reservoir operations. Also, the water storage in dams should be kept at least one metre, can go up to 10 ft below the full reservoir level. Besides this, it is essential to review the rule curves of all the reservoirs in Kerala.

- Adopt proper flood risk management programme to reduce the residual risk through early warning systems coupled with emergency actions and measures which can be taken to mitigate the effect of a flood disaster. An important step in improving an existing flood protection system is the provision of better warning systems. Apparently, the basis for a warning system has to be an effective forecasting system, which permits the early identification and quantification of an imminent flood to which a population is exposed.

- Depth of the Vembanad backwater showed drastic decrease, one of the main reasons for increased flood occurrence in the Kuttanad region. Scientific dredging should be adopted for the removal of silt and deepening the backwater. In order to protect the existing benthic zone and to minimize the effect of dredging, it is suggested to avoid dredging activities during the sensitive breeding and recruitment periods of aquatic organisms. In addition, the frequency of dredging may be reduced in order to attain fast recovery of the benthic fauna.

- Strong regulations for management of sand mining and quarrying should be established. No new licenses to be given for quarry and sand mining in the identified Ecologically Sensitive Zones of Western Ghats.

- Adopt rapid management plans for early detection and identification of invasive alien species.

- As per WGEEP, new dams based on large scale storage should not be permitted in Ecologically Sensitive Zone of Western Ghats. Also, the assessment of downstream impacts of dams on river ecology, floodplains, fishing habitats and livelihoods should be carried out.

- Improve environmental flow and hydrology of rivers through proper scientific riparian management programmes involving community participation. Restructure original course of the rivers if they are modified and rejuvenate the aquifers. WGEEP strongly recommend, no further inter-basin river diversions are permitted in the Western Ghats region. Furthermore, improve and upgrade hydrological databases in rivers and consolidate the ecological database and information at river basin level. Based on this, declare high conservation value stretches of rivers as ESAs and keep them free from further development. In addition, declare overexploited regions of rivers in the Western Ghats as ecologically sensitive and origin of rivers should be declared as, ‘no go areas’.

- In the catchments of the rivers, intensive soil and water conservation plans and afforestation should be pursued, so that flood management, environmental flow preservation and drought proofing can be easily achieved. Major decentralized land, water and forestry projects implemented by local government bodies will also provide tremendous job opportunities and create a vibrant natural resource base for sustainable growth.

- Certain recognised best practices of construction or development such as topsoil conservation and tree conservation should be followed as per the guidelines of Green Building certifications of Eco Housing, GRIHA or any other appropriate codes to be promoted. Also, certain activities like filling of marshes or wetlands and introduction of alien invasive species are not permitted.

- Many of the canals and distribution channels are being blocked by filling mud or local materials for construction purposes, encroachments, unscientifically constructed roads, bridges and culverts and aggressive spread of waterweeds. Hence, the functions of major rivers and canals forming part of the Kuttanad wetland system and several canals and drains draining the paddy fields in many regions (e.g. Onattukara and Thuravoor-Pattanakkad) of Vembanad wetland system are seriously compromised with these problems. With the blockade in flow of water and decreasing use of waterways, the water stagnation and pollution is reported in many canals. Thus canals away from the main waterways are clogged with hyacinth and weeds. Apart from obstructing of navigation, it causes breaking of bunds, accumulation of wastes, increased growth of waterweeds, promotion of prolific breeding of predators, parasites and deadly pathogens, and degrading the water quality. Hence, the degradation of water quality leading to scarcity of potable water in vicinity. The blockade in free flow of water also leads to flood occurrence during higher water period. An example is the AC canal, one of the major canals in Vembanad wetland system. A number of canals and tributaries that links AC canal to the tributary of river Pamba. These narrow canals of width 4 to 5 m were once used for inland navigation. The decline in the inland water transport has led to the negligence of water resources and has led to depletion. Hence, these canals should be revived immediately, so that it can act as an outlet to improve the water quality and also helps to reducing flood risk. For this, scientific cleaning of waste choking canals (mainly AC canal), increasing width of the canals, deepening of canals after removing silt and waste, clearing of encroachments and unscientific constructions on the banks of the canals should be adopted.

- Large scale encroachment activities in various parts of the rivers reduce the depth, water holding capacity and carrying capacity of the Vembanad wetland system. This results in the overflowing of rivers during the flood and inundated the adjacent low lying areas. Hence, there is a need for proper and effective government oriented management programmes for mitigating the flood risk in future.

- In 2012, 39 locations covering Sanctuaries, National parks, etc. were listed under the world heritage site for protection and conservation. Therefore, the WGEEP reports of Gadgil (2011) and Kasthurirangan (2013) should be implemented without any dilution. Also the rehabilitation of local peoples living in the ecologically sensitive zones and finding new livelihood opportunities for them must be taken for consideration. Furthermore, the encroachment and construction activities in the identified ESZ zones in Western Ghats should be evicted.

- Considering many factors contributing to flood risk and constraining flood control, an integrated approach with structural and non-structural measures will be more suitable for flood management in the Vembanad wetland system. The possible structural flood protection schemes involving flood regulation, diversion, and embankment construction as proposed by the Indo-Dutch Mission have to be revised based on detailed feasibility study considering various factors contributing to flood risk, need to sustain the rice cultivation, decrease in the area under rice cultivation and economic, social and environmental effects of flood control.

- The Netherlands implemented such an integrated and programmed approach referred to as the “Room for the River” which is also proposed by the Govt. of Kerala as part of the flood control in Kuttanad. For effective flood control, new ways of managing rivers are required; i.e. through creating more space for rivers to discharge their flows. The main objectives of this programme are improving safety against flooding of riverine areas and the improvement of the spatial quality of the riverine areas. The concept of Room for the River falls under the more widely applied practice of “Integrated River Basin Management (IRBM)”. This typically refers to a comprehensive and coordinated approach to the management of river systems. The measures which are involved in the “Room for the River” programme are; lowering of floodplains, removal of obstacles, dyke relocation, water retention and storage, by-pass, height reduction of groynes, deepening of summer bed, heightening of dykes and dyke improvement. There is a need to exchange innovative concepts and best practices of holistic, integrated programmed approaches for flood risk management of river basins across the globe. The Room for the River Program is considered as an “exemplary project” in this respect both in the Netherlands as well as internationally.

- Regarding the “Room for the River” programme, transferring the Dutch concept and best practices to other countries is likely to be a major challenge as there is no blueprint and each river basin has its unique features requiring customized programmes for strategic institutional change. Coordination and implementation of these integrated multi-level programmes require discussion and interaction amongst all involved stakeholders. To address the complexity and dynamic nature associated with these governance processes new, institutional structures and arrangements are required.

- Efforts should be made to live with water in the long run where pragmatic policies and practices that are nature friendly should be adopted. Flood-prone areas should be identified and projects can be implemented to make room for the rivers for its smooth flow. Low risk areas like playground, agricultural fields can be marked to store excess rainwater where water can be stored from the drains in case of necessity. Such actions can ease the stress on our drainage infrastructure. Also, the drainage capacity of our rivers and canals has to be increased for creating room for the river for its smooth flow without any obstructions. Extreme climatic events that can lead to climate change and global warming also be confronted with at the times of such unpredictable flooding. The preparedness on the state disaster management authorities and its professionalism has also be taken in to consideration in the preparation and action for any such flood and other natural calamities of the government. Practice drill can be conducted in the flood-prone areas. The expertise of agencies in government of Netherlands and Germany etc. can also be availed for the proper and early scientific preparedness and management of any flood situations.

- In India, floods were once mainly limited to the southern part of the Himalayan region, but now they have begun to spread to many other areas of India, including the urban conglomerations. The 2018 August flood in Kerala is one such major disaster that caused huge damages to man, infrastructure and properties, estimated to the worth of 4.4 billion USD. The local authorities alone, as well as the State government, cannot control urban floods of this magnitude. They can be handled only by concerted and oriented energy and resource investments. Such investments can only be done in a mission mode organization with active participation of civil society organizations at the metropolitan scale. Hence, this can be done through a metropolitan planning committee. The main objective of the mission is to mitigate flood risk and provide a pathway to water security. The idea of "sponge cities" is much relevant in this context.

- The definition of a sponge city is to make cities more permeable in such a way that they can hold and use the water which falls upon it. The rain water is absorbed by sponge cities, which is then naturally filtered through the soil and allowed to enter urban aquifers. This enables for the extraction of water from the ground through urban or peri-urban wells. This water can be readily treated and used for the supply of city water. In built form, this implies contiguous open green spaces, interconnected streams, channels and ponds in the neighborhood that can naturally detain and filter water. All of these can be effectively delivered along the lines of the Atal Mission for Rejuvenation and Urban Transformation (AMRUT), National Heritage City Development and Augmentation Yojana (HRIDAY) and Smart Cities Mission through an urban mission. Also such a mission should address the following;
    - i) Wetland policy: The shallow ends which often lie beyond the full tank level in most of our lakes have vanished. The best way to describe these shallow ends is as wetlands, occasionally held by private people, existing as ecological commons at other times. Regardless of ownership, land use on even this small scale needs to be managed by development control.
    - ii) Watershed management and emergency drainage plan: In policy and law, this should be clearly enunciated. Urban watersheds are micro ecological drainage systems, formed by contours of terrain. Detailed documentation of these must be held by agencies such as The Metropolitan Development Authorities, National Disaster Management Authority, State revenue and irrigation departments along with municipal corporations.

iii) Ban against terrain alteration: By flattening land and changing drainage paths, immense damage has been done to the city by builders, property owners and public agencies. Hence, terrain modification should be strictly controlled and a moratorium on any further terrain alteration needs to be enforced.

Moreover, our cities are becoming increasingly impervious to water, not just because of increasing built-up but also because of the nature of materials used (i.e. Hard, non-porous construction material that makes the soil impervious). New porous materials and innovations must be promoted to boost the city's capacity to absorb water (e.g. bioswales and retention systems, permeable materials for roads and pavement, drainage systems which allow storm water to trickle into the ground, green roofs and harvesting systems in buildings). There is an urgent need for rebuilding our cities such that they have the sponginess to absorb and release water without causing so much damage. This will be an effective method for mitigating the future flood impacts.

In the context of the Kerala floods 2018, the overall rehabilitation and rescue works conducted by the Kerala govt. and other central agencies, private entrepreneurs, individuals, fishermen and several other unknown persons are all commendable and praiseworthy. Several precious human and animal lives were lost in this calamity of flood, which should not again occur and actions suggested above are to be taken for the overall sustenance and growth of the state.

Reports on this Kerala Flood Study Published in National Newspaper in September, 2019

മാതൃഭൂമി

പരിസ്ഥിതിക്കും പ്രളയാഘാതം

- പ്രളയശേഷം സന്തുലിതാവസ്ഥ മാറുന്നതായി പഠനം
- മണ്ണിന്റെയും വെള്ളത്തിന്റെയും ഘടന മാറി

സ്വന്തം ലേഖകർ
തിരുവനന്തപുരം

► പ്രളയത്തിനുശേഷം സംസ്ഥാനത്തുടനീളം വെള്ളത്തിന്റെയും മണ്ണിന്റെയും ഘടന മാറിയത് പാരിസ്ഥിതിക സന്തുലിതാവസ്ഥയെ ബാധിക്കുമെന്ന് പഠനം. പ്രളയശേഷം ഹരിതഗൃഹവാതകങ്ങളുടെ അളവ് കൂടിയിട്ടുണ്ട്. വെള്ളത്തിന്റെ ശുദ്ധി കുറഞ്ഞു. മണ്ണിൽ അമ്ലത കൂടി.

സംസ്ഥാന മലിനീകരണ നിയന്ത്രണബോർഡിന്റെ സഹകരണത്തോടെ കൊച്ചി ശാസ്ത്ര സാങ്കേതിക സർവകലാശാലയിലെ ഡിപ്പാർട്ട്മെന്റ് ഓഫ് മറൈൻ ബയോളജി തയ്യാറാക്കിയ പഠനത്തിലാണ് ഈ കണ്ടെത്തൽ.

വിശദപഠനം ആവശ്യപ്പെട്ട് ഈ റിപ്പോർട്ട് പരിസ്ഥിതി വകുപ്പിന് കൈമാറുമെന്ന് മലിനീകരണ നിയന്ത്രണ ബോർഡ് ചെയർമാൻ കെ. സജീവനും പഠനത്തിന് നേതൃത്വം നൽകിയ ഡോ. ബിജോയ് നന്ദനും പറഞ്ഞു.

ജലസ്രോതസ്സുകൾ വറ്റാൻ കാരണം വരൾച്ചയല്ല

മറ്റു കണ്ടെത്തലുകൾ

ആശങ്കാജനകം

മലപ്പുറത്ത് ഭക്ഷണത്തിൽ മയക്കുമരുന്ന് കലർത്തി കവർച്ച

കുട്ടികളുടെ അശ്ലീലചിത്രങ്ങൾ വിദേശ വെബ്സൈറ്റുകൾക്ക് വിൽക്കുന്നു

Various other press reports on implications of flood on the Vembanad backwater including river system related to the study

KOCHI THE HINDU
THURSDAY, JANUARY 3, 2019

Invasive mussel in Kochi backwaters

The fast-growing species can tolerate a wide variety of environmental conditions

AATHIRA PERINCHERY
KOCHI

From clambering lantana plants to *karimeen*-like red-bellied paku, invasive species come in all sizes. The latest addition to Kerala's invasives list is only around a centimetre or two long: scientists have confirmed the presence of the invasive black-striped mussel *Mytilopsis sallei* in Kochi's backwaters.

'Alien' mussel

In a study published on December 25 in the scientific journal *Current Science*, researchers at the Cochin University of Science and Technology (Cusat) used basic genetic methods to confirm the identity of mussels they collected from Cochin harbour and Ezhupunna in Alappuzha. They extracted DNA from these mussels. While running this through an international online database, they matched it to the DNA of mussels observed from the Lam Tsuen River in Hong Kong (China), confirming that it is the same species that is now found in Kochi's backwaters.

The black-striped mussell, native to the South and Central Americas, is an invasive species in most parts of the world. In India, it has been recorded from the ports of Mumbai and Vishakapatnam. It spreads primarily through the discharge of ballast waters of ships. The fast-growing species - which dwells in shallow water - can tolerate a wide variety of environmental conditions (salinity, water temperatures and oxygen levels), which helps them thrive in the new areas they colonise.

The black-striped mussel is an invasive species in many parts of the world.

The researchers estimate that one square metre near Fort Kochi (from where they collected some of the mussel samples) contains as many as 748 individuals. This is extremely high, said Bijoy Nandan, professor at Cusat's Department of Marine Biology and one of the scientists who conducted the study.

Several costs

Though tiny, these invasive mussels are 'biofoulers': organisms that accumulate on wet surfaces, causing huge ecological and economic losses. They can cause the deterioration of coastal infrastructure. The mussels can displace native species of clams from their coastal habitats and cause a reduction in native biodiversity. Now the mussels can be spotted along most of Kerala's coastline, said Dr. Nandan.

THE HINDU KOCHI
SATURDAY, MARCH 23, 2019

Tests show algal bloom caused discolouration of Periyar

Growth triggered by mineral effluents or water stagnation

STAFF REPORTER
KOCHI

It was an algal bloom - an excessive increase of algae - that turned the waters of the Periyar downstream of the Pathalam regulator-cum-bridge green last week, reveal laboratory tests.

Water samples collected by the Pollution Control Board (PCB) on March 15 when the green colour was first noticed, had been given to the Cochin University of Science and Technology's (Cusat) School of Marine Sciences for microbiological analyses. Its tests reveal that the green colour was caused by the presence of *Platymonas*, a marine genus, said Eloor Environmental Engineer Sreelekshmi P.B.

"This is a type of green algae that is usually seen in highly eutrophic (when a body of water becomes overly enriched with minerals and nutrients which induce excessive growth of plants and algae) lakes," said Dr. Bijoy Nandan, Professor in the Department of Marine Biology, Microbiology and Biochemistry at Cusat, who supervised the microbiological tests. "This was a particularly heavy bloom, for algae dominated the samples by almost 90 per cent."

The stretch of the Periyar downstream of the Pathalam regulator-cum-bridge that turned green recently.

Algae thrive on the existing dissolved oxygen contents in the water. Dissolved oxygen levels thereby drop, affecting other aquatic organisms such as fish that then need to come to the water surface trying to gulp in air. Apart from affecting water quality this way, algal blooms can also release toxins and metabolites that could put aquatic organisms in danger if the bloom sustains for long, said Dr. Nandan. The March 15 incident in the Periyar was observed for two days, said Ms. Sreelekshmi.

Such algal blooms are caused by several factors: the accumulation of nutrients (such as nitrates and phosphates) in the water which come through industrial effluents, water stagnation due to low water flow and increases in the ambient water temperatures that happen during summers.

"Since this was seen only in a localised area, this could be due to the leachates in the water," said Dr. Nandan.

SUNDAY TIMES OF INDIA, ERNAKULAM / KOCHI
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Invasive mussel threatens ecosystem

TIMES NEWS NETWORK

Kochi: A new invasive marine species has been detected in the Kochi backwaters which is affecting the natural ecology of the system, according to a study published in an internationally peer-reviewed journal BioInvasions Records.

According to the study done by researchers of the marine biology department of the Cochin University of Science and Technology (Cusat), the new species has been documented as Mytella strigata, a highly invasive alien American brackish water mussel. Invasive marine species can dominate their new environment, modify ecosystem structure, compete with native species, threaten local fisheries and aquaculture, introduce diseases and interfere with coastal facilities.

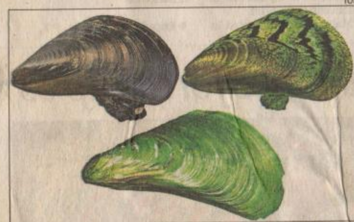
"From our preliminary study, it is assumed that the pathway of this species in Kochi may be through ballast water or by attaching itself to ships' hulls from its native range or from other Asian countries like Singapore, Thailand and Philippines where it has been established recently. They are competing with the native population of green mussel, Perna viridis," said S Bijoy Nandan, professor and head, department of marine biology, microbiology and biochemistry, School of Marine Sciences, Cusat.

He said that they grow faster than green mussel's and are adapted to live in a wide range of salinity between 5 to 35ppt (parts per thousand). This species attaches itself to floating plastic bottles, wooden pilings, walls of fish cages, hulls of boats and bottom sediment of Cochin backwaters. When the density of these mussels gets high, they die and sink, covering the bottom sediment resulting in depletion of dissolved oxygen. Globally, ballast water and fouling through the hull of ships have proved to be a major route for the spread of marine invasive species and, therefore, a precautionary approach is warranted while removal of ballast water along harbour area."

"The proliferation of this alien species poses a serious threat to the endemic species diversity of fragmented brackish water habitats of Kerala's coast, considered as one of the hot spots of endemic species," said P R Jayachandran, post-doctoral fellow, Cusat.

According to B P Aneesh, research associate, Cusat, the mitochondrial DNA sequences of mussels from this study are consistent with specimens in their native range, from Colombia, and from Singapore where it has recently been reported as invasive. "Locals started consuming this species and some of them believe it is green mussel, Perna viridis," said Philomina Joseph, professor, department of marine biology, Cusat.

TOI



Mytella strigata is a highly invasive American brackish water mussel

THE HINDU
KOCHI • Thursday • November 14, 2019

Decay of Vembanad ecosystem apace, says study

Reclamation, pollution choking waterbody, says report by School of Marine Sciences team

SPECIAL CORRESPONDENT
KOCHI

The ecological decay of Vembanad backwater system is on the rise owing to intense pollution and unauthorised construction, a study carried out by the School of Marine Sciences at the Cochin University of Science and Technology has revealed.

The study has established that the ecological decay of the wetland is on the rise due to intense pollution and unauthorised construction from the southern to the northern regions of the backwaters.

Violation and relaxation of the Coastal Regulation Zone (CRZ) norms have been recorded in many regions, it has found.

Strict enforcement of the CRZ norms for the backwaters has to be done, observes the study carried by a team led by Dr. S. Bijoy Nandan, Professor and Head, Department of Marine Biology, Microbiology & Biochemistry. The report has been submitted to the Kerala State Pollution Control Board for follow-up action.

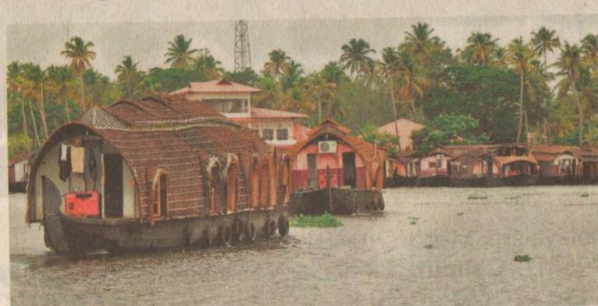
The research finding says reclamation of estuarine areas for agriculture has led to a drastic decline in the water holding capacity of the backwaters, which is recognised as a Ramsar site, from 2.4 km3 to 0.6 km3 during the past 50 years. The pollution load indices (PLI) were very high. The higher concentration of cadmium is the main reason for the increase in PLI. The main sources of cadmium pollution are industrial and municipal waste, it says.

The Vembanad backwaters has been continuously subjected to land reclamation for various purposes such as agriculture expansion, harbour development, and urban development. Untreated waste from houseboats is dumped into the waterbody, the report says.

Dr. Nandan suggests that a model based on the carrying capacity needs to be developed on the impact of tourism and related pressures on the wetland.

Action for protecting the Pathiramanal island should be implemented. Special attention should be paid by the Tourism Department to restrict nature tourism.

It must also ensure that no ecological modifications are made to the islands and should promote mangrove afforestation. Strengthening the water bird habitat assessment and monitoring network through training and participation programmes is to be carried out, he says.



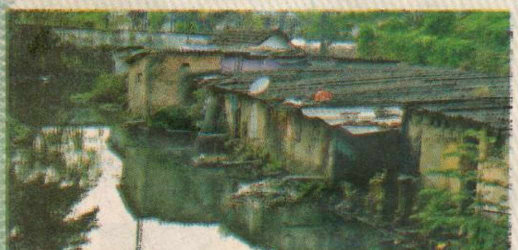
Untreated waste from houseboats is dumped into the Vembanad backwaters, adding to the pollution index of the waterbody. • FILE PHOTO

THE NEW INDIAN EXPRESS | KOCHI

02 KOCHI FRIDAY 15.11.2019

Toxic contamination of Vembanad lake poses major health hazard

Study flags massive presence of heavy metals, pesticides which can disrupt body processes



Sewage pipes from houses situated on the banks of Perandoor canal drain out into the water body, resulting in massive pollution | A SANESH

DEGRADING ECOSYSTEM

The lake is one of the most impacted zones – polluted by various organic and household waste, industrial activities and anthropogenic activities

217 wetlands in Kerala

- Vembanad, Ashtamudi and Sasthamkotta wetland ecosystems designated as Ramsar sites
- Detailed study on a monthly basis and eco-toxicological evaluation required to assess the environmental degradation
- More than **20,000 fishermen** are directly dependent on the aquatic resources of this wetland fetching over 7,000 tonnes of fish and shellfish annually
- Vembanad backwaters nourished by six major rivers -- the Achenkovil, Manimala, Meenachil, Muvattupuzha, Pampa and Periyar
- High geo accumulation index (Igeo) and contamination factor (CF) values were observed for cadmium and nickel
- High Pollution Load Index (PLI) indicates polluted sediments
- Concentration of metals like zinc, copper and nickel showing an increasing trend in organisms
- Study recommends bioremediation solutions to reduce the environment load

Detailed studies on hydrology, salinity, inorganic nutrient regime and patterns should be undertaken before implementing agrarian reforms

MANOJ VISWANATHAN @ Kochi

THE massive contamination of the Vembanad lake due to heavy metals and pesticide has reached alarming levels, posing a major health risk to humans through trophic transfer, it has emerged. It is a study by the Kerala State Pollution Control Board — to assess the lake's contamination caused by heavy metals and pesticide content in water, sediment and organisms — which threw up the disturbing findings.

According to the research by Cusat's Marine Biology and Microbiology Department, long-term intake of high levels of heavy metals could well lead to a disruption of the body's biological and biochemical processes. Vembanad Kol Wetland spread across 50,000 hectares is the largest wetland along the country's south-west coast. It is one of the most impacted zones —polluted by various organic and household waste, industrial activities and anthropogenic activities like agricultural disposal and land reclamation. The year-long study by Cusat researchers began in February 2017. And samples from 19 stations in the northern and southern parts of Thannermukkom barrage, Aroor in the north and Ranikayal on the southern side of the lake were analysed.

The study found there was drastic decline in the depth and transparency of Vembanad estuary. Higher alkalinity values were observed towards the northern stations. Southern stations recorded low dissolved oxygen level while the biochemical oxygen demand (BOD) was high.

Houseboat tourism, sewage discharge and spread of invasive plant species play a crucial role in the decline in dissolved oxygen level in the estuary's southern parts. The phosphate, silicate and ammonia content was higher in the southern parts while nitrite and nitrate content was higher in the northern parts. The highest sulphide concentration was detected at Punnamada, said S Bijoy Nandan, head of department, who coordinated the study.

There was high concentration of zinc in the southern stretch and the Nehru Trophy Boat Race finishing point recorded the highest value of of 442 micrograms(mcg). In sediment, nickel concentration was found to be high in the southern stretch and Chithirakayal was found to be extremely contaminated. The Marthandam region showed higher values of heavy metals.

The study indicates that the southern part of the Vembanad backwaters suffers massive contamination from heavy metals. Waste dumping, rusted boats along the canals of Alappuzha and developmental activities are the main reasons for anthropogenic enrichment of heavy metals in the estuary, said Bijoy Nandan.

THE NEW SUNDAY EXPRESS | KERALA
KOCHI | SUNDAY 25.11.2018 | newindianexpres

'Alarming presence of heavy metals in water bodies'

rts call for a study on heavy metal contamination of potable ter projects in view of the increase in renal diseases in Kerala

ORRYING STATS

.5 lakh
ey patients in Kerala

1,450
ts waiting for kidney transplantation

e volume of industrial s discharged from the alamassery industrial bout 260 million litres r day, much of which is I into the Periyar River

pal investigator and head the Cusat Marine Biology, biology and Biochemistry Department

MANOJ VISWANATHAN @Kochi

AT a time when the National Green Tribunal had directed the Central Pollution Control Board (CPCB) and the Kerala State Pollution Control Board to prepare an action plan to reduce the impact of industrial effluents in water bodies at Eloor and Edayar industrial area in Kochi, a study conducted by the School of Marine Sciences of Cusat has revealed increased heavy metal content in Kochi Estuarine system is adversely affecting the fish and aquatic organisms.

High level of heavy metals is damaging the kidney, liver, muscle, tissues and gills of fish. "The Kochi coastal zone is under increased industrial activity with over 250 large and medium industries causing heavy metal contamination leading to ecological decay in the region," principal investigator and head of the Cusat Marine Biology, Microbiology and Biochemistry Department S Bijoy Nandan told *Express*. "The volume of industrial effluents discharged from the Eloor-Kalamassery industrial belt is about 260 million litres per day, much of which is directly discharged into the Periyar River from where it enters the backwaters. There is a need to study the heavy metal contamination of drinking water projects in view of the increase in renal diseases in Kerala."

There have been frequent reports of Periyar turning red due to the release of industrial effluents. These effluents carry a huge quantity of copper, zinc, lead, iron, arsenic, cadmium and other heavy metals.

Though the Kerala Water Authority distributes water pumped from Periyar after clarification, filtration and disinfection, experts say the process is not sufficient to remove the heavy metals. So, the authorities have to improve the treatment process and ensure the tap water is safe to drink, said Nandan.

"It is true that heavy metal contamination of drinking water can cause renal diseases. There were reports blaming heavy metal contamination of drinking water for renal diseases in Japan and other countries in the past. However, we don't have any proof to relate the increase in renal diseases in India with heavy metal contamination," said senior nephrologist R Kasi Visweswaran. According to experts, increased presence of copper can lead to changes in haemoglobin and can be cancerous. Lead gets accumulated in the liver and kidney damaging the cells. It can affect the respiratory system and the brain cells. Zinc causes abdominal pain and vomiting.

The Cusat study found an alarmingly high concentration of metals like zinc, lead, cadmium and copper in the sediment samples collected from the Kochi Estuarine system, which would have deleterious effects on organisms and would impose serious health issues leading to bioaccumulation and biomagnification trends. The increased heavy metal content in water has led to an abnormality of the blood cells, structural changes in the gills, liver, kidney and spleen of the aquatic organisms, the report said.

The team studied the impact of contamination in pearlspot, mussels, black clam, shrimp, tiger prawn, jellyfish, copepods, and micro algae. The team prepared a definitive Water Quality Criteria for copper, zinc and lead adopting the guidelin United States Environ Protection Agency (U While the USEPA benc for permissible level o metals in water bodies micrograms per litre f per, 81 micrograms p for zinc and 8.1 micr per litre for lead, the c tration of these meta 5.08 micrograms, 54.96 grams and 25.40 micr respectively.

The results of the were published in the r environmental researc nal Elsevier. P R Jay dran, Anu P R, Don Xa D and Midhun A M w project fellows asso with the study.

The Central Water Co sion had conducted a st 2016 on the status of metals in Indian riv 2016, which reported 38 crograms of lead per l water in Achankovil and 13.58 micrograms o per litre in Kallada Riv report said Periyar w most polluted at six site high concentration of c arsenic, vanadium, sele chromium, magnesium um and nickel.

The Eloor industrial belt

HEAVY METALS IN KOCHI ESTUARY WATER	USEPA BENCH MARK
Copper: 5.08 micrograms per litre	Copper: 3.1 micrograms
Lead: 25.40	Lead: 8.1
Zinc: 54.96	Zinc: 81

SEDIMENT	SEA WATER QUALITY CRITERIA RECOMMENDED BY CUSAT
Copper: 18.16	Copper: 7.36 micrograms
Lead: 32.45	Lead: 2.81
Zinc: 135.87	Zinc: 13.53

EA CHN | 2019 ഡിസംബർ 19 • വ്യാഴാഴ്ച മാതൃഭൂമി
വാർത്തകൾ 05

വേമ്പനാട്ട് കായൽത്തടങ്ങളിൽ ലോഹ മാലിന്യം

കെ.പി. പ്രവിത
കൊച്ചി

▸ വേമ്പനാട്ട് കായൽത്തടങ്ങളിൽ അപകടകരമായ അളവിൽ ലോഹ മാലിന്യങ്ങളുടെ സാന്നിധ്യം. ഈ മേഖലയിലെ ആവാസ വ്യവസ്ഥയിൽ മാറ്റം വരുത്താനും മാലിന്യങ്ങൾ കാരണമായിട്ടുണ്ട്. സിങ്കിന്റെയും കാഡ്മിയത്തിന്റെയും ലെഡിന്റെയും ചെമ്പിന്റെയുമെല്ലാം സാന്നിധ്യം കായൽത്തടത്തിൽ കണ്ടെത്തി.

കൊച്ചി ശാസ്ത്ര സാങ്കേതിക സർവകലാശാലയിലെ (കുസാറ്റ്) മറൈൻ സയൻസസ് സ്കൂളിന്റെ നേതൃത്വത്തിൽ നടത്തിയ പഠനത്തിലാണ് ഈ വെളിപ്പെടുത്തലുള്ളത്.

കായലിലേക്ക് അനധികൃതമായി മാലിന്യങ്ങൾ തള്ളുന്നതും അനധികൃത നിർമാണവുമെല്ലാം ഇതിന് കാരണമായി ചൂണ്ടിക്കാണിക്കപ്പെടുന്നു.

ഈ മലിനീകരണം ജനങ്ങളുടെ ആരോഗ്യത്തിലുൾപ്പെടെ ദൂരവ്യാപകമായ പ്രത്യാഘാതങ്ങളുണ്ടാക്കുമെന്ന് മറൈൻ ബയോളജി, മൈക്രോ ബയോളജി ആൻഡ് ബയോ കെമിസ്ട്രി വകുപ്പ് മേധാവി ഡോ. എസ്. ബിജോയ് നന്ദൻ പറഞ്ഞു.

മാലിന്യം അപകടകരമായ അളവിൽ

ആവാസ വ്യവസ്ഥയിൽ മാറ്റം

എറണാകുളം, ആലപ്പുഴ, കോട്ടയം മേഖലകളെയാണ് മാലിന്യ പ്രശ്നം രൂക്ഷമായി ബാധിക്കുന്നത്. മാലിന്യങ്ങളുടെ അംശം മേഖലയിലെ മീൻപിടിത്തത്തെയും കാര്യമായി ബാധിച്ചിട്ടുണ്ട്. പഠന റിപ്പോർട്ട് തുടർ നടപടികൾക്കായി സംസ്ഥാന മലിനീകരണ നിയന്ത്രണ ബോർഡിന് സമർപ്പിച്ചു.

മാലിന്യം കായലിലേക്ക്

വ്യവസായ മാലിന്യങ്ങൾ ഉൾപ്പെടെയാണ് കായൽ മലിനീകരണത്തിന്റെ തോത് കൂട്ടുന്നത്. വിശാല കൊച്ചിയിലെ വ്യവസായ മേഖലയിൽനിന്ന് 260 എം.എൽ.ഡി. അവശിഷ്ടങ്ങൾ കായലിലേക്ക് എത്തുന്നു.

കായൽ കേന്ദ്രീകരിച്ചുള്ള വിനോദസഞ്ചാരവും മാലിന്യത്തിന്റെ തോത് കൂട്ടുന്നുണ്ട്. ഹൗസ്ബോട്ടുകൾ വഴി മാത്രം കായലിലേക്ക് ഓരോ ദിവസവും എത്തുന്നത് ഏകദേശം 4.25 ടൺ മാലിന്യങ്ങളാണെന്ന് റിപ്പോർട്ടിൽ ചൂണ്ടിക്കാണിക്കുന്നു.

ആലപ്പുഴയിലെ പോർട്ട് ഓഫീസിൽ നിന്നുള്ള കണക്കനുസരിച്ച് 1500-ലേറെ ഹൗസ്ബോട്ടുകൾ ആ മേഖലയിൽ മാത്രം സർവീസ് നടത്തുന്നുണ്ട്.

ഫാർമസ്യൂട്ടിക്കൽ മാലിന്യവും

ഫാർമസ്യൂട്ടിക്കൽ ഉത്പന്നങ്ങളിൽ ഉപയോഗിക്കുന്ന സംയുക്തങ്ങളുടെ സാന്നിധ്യം കായലിലെ പല മേഖലകളിലും കണ്ടെത്തി. ഇതിൽ മരുന്നിലും സൗന്ദര്യവർധക വസ്തുക്കളിലും ഉപയോഗിക്കുന്നവയുണ്ട്.

പാതിരാമണൽ, പുന്നമട, തണ്ണീർമുക്കം എന്നിവിടങ്ങളിലെല്ലാം ഇത്തരത്തിലുള്ള സാന്നിധ്യം ശ്രദ്ധേയമായ അളവിൽ കണ്ടെത്തി. ഇവ കായലിലേക്ക് എത്തിയത് എങ്ങനെയെന്നും ഇവയുണ്ടാക്കുന്ന പ്രത്യാഘാതം സംബന്ധിച്ചുമെല്ലാം കൂടുതൽ പഠനം നടത്തണം. പലയിടത്തും സീവേജ് മാലിന്യങ്ങൾ കായലിലേക്ക് ഒഴുക്കുന്നു.

ലോഹ മാലിന്യങ്ങളുടെ ഉൾപ്പെടെയുള്ള സാന്നിധ്യം ഓരോ വർഷവും വർധിക്കുകയാണെന്നും റിപ്പോർട്ടിൽ ചൂണ്ടിക്കാണിക്കുന്നു.

THE HINDU KOCHI
WEDNESDAY, JANUARY 22, 2020

'Cochin estuary turning into source of nitrogen emissions'

SPECIAL CORRESPONDENT
KOCHI

Human activities have accelerated nitrogen loading in the Cochin estuary, thereby turning it into a potential source of nitrous oxide (N2O) emissions, according to a study by researchers at the Department of Marine Biology, Microbiology & Biochemistry at the School of Marine Sciences at Cochin University of Science & Technology (Cusat).

"Our studies in Cochin estuary confirm higher anthropogenic nitrogen loading. It acts as a significant source of N2O emissions to the atmosphere," said S. Bijoy Nandan, Professor and Head of the Department.

> Our studies in Cochin estuary confirm higher anthropogenic nitrogen loading
>
> S. BIJOY NANDAN
> Head, Department of Marine Biology, Microbiology & Biochemistry

Prof. Nandan said that the rise in N2O emissions had critical role in creating climate emergency considering the global trend of N2O emissions from estuaries and coastal wetlands.

"Any ecosystem can act as sinks or sources of greenhouse gas emissions. It is the balance between the nitrification and de-nitrification rates that makes them sinks (converting the available N2O or produced N2O to other forms of nitrogen) or sources (producing higher concentrations of N2O)," he said.

A higher concentration of N2O in the water column above the atmospheric concentrations leads to N2O water to air fluxes (exchange), making them sources of nitrous oxide. Prof. Nandan said that increasing anthropogenic inputs (sewage, industrial, agricultural discharges, pollution problems) had accelerated the nitrous concentrations in estuaries worldwide, especially in tropical estuaries.

Cochin estuarine system (CES) is regarded as one of the world's polluted estuary.

2 REGION
THE HINDU KOCHI
SUNDAY, MAY 17, 2020

Despite lockdown, Periyar gasps for breath

Absence of industrial activity and reduced human interference fail to improve water quality

G. KRISHNAKUMAR
KOCHI

A field study by researchers at the Cochin University of Science and Technology (Cusat) has revealed that the lack of industrial activity and reduced human interference during the lockdown period have not contributed to improvement of water quality on the Pathalam-Eloor stretch of the Periyar.

Data collected by the team representing the department of marine biology, microbiology and biochemistry, Cusat, showed that the water quality had deteriorated despite expectations that the sanitary standards of the Periyar would improve during the lockdown period. The study was done on April 30 and May 1.

"The dissolved(DO) level was zero at the Pathalam bund, while the biological oxygen demand (BOD) went up to 40.59 mg/litre. At FACT, the corresponding figures were 1.63 mg/litre and 20.26 mg/litre. The primary productivity in the region also collapsed. The lockdown period has not improved the water quality of the river in the downstream zone," said Dr. S. Bijoy Nandan, professor and head of the department of marine biology, microbiology and biochemistry.

Unquiet it flows: Experts have sought immediate intervention by the government and the Pollution Control Board to restore the Periyar to its original state.

"The spike in BOD value recorded at the three stations is an indication of high organic pollution on the stretch from various sources, including sewage waste. The increase in organic load naturally reduces the DO content in the waterbody leading to fish kill and algae boom. An isotopic analysis can determine the source and age of industrial effluents already documented in the accumulated sludge," he observed.

Suggesting the immediate intervention of the government and the Pollution Control Board to restore the river to its original state, Dr. Nandan called for steps to de-silt and de-sludge waste and other settled matter from the upstream and downstream regions of the Pathalam bund. Bio-remediation measures can be taken up to check fish kills and depleting levels of oxygen, he said.

A study on fish kills on the Eloor-Edayar stretch conducted by the research team in 2015 had suggested the setting up of common treatment facilities for scientific disposal of industrial effluents and sewage generated at the level of local bodies.

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