ASSESSMENT OF NUTRIENT LOADING AND WATER QUALITY IN A TROPICAL WETLAND

A Thesis

Submitted in fulfillment of the

requirements for the award of the degree

of

DOCTOR OF PHILOSOPHY
In
ENVIRONMENTAL ENGINEERING

By

VANDANA SHAN

DEPARTMENT OF ENVIRONMENTAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

DELHI-110042, INDIA

August, 2019

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DECLARATION

I hereby declare that the research work presented in this thesis entitled "Assessment of Nutrient Loading and Water Quality in a Tropical Wetland " is original and carried out by me under the supervision of Dr. A. K. Haritash, Associate Professor, Department of Environmental Engineering, Delhi Technological University, Delhi, and under the co-supervision of Prof. S. K. Singh, Professor and Head, Department of Environmental Engineering, Delhi Technological University, Delhi, and being submitted for the award of Ph.D degree to Delhi Technological University, Delhi, India. The content of this thesis has not been submitted either in part or whole to any other university or institute for the award of any degree or diploma.

Date: Vandana Shan

Place:

DELHI TECHNOLOGICAL UNIVERSITY
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CERTIFICATE

Date:

This is to certify that the Ph.D. thesis entitled "Assessment of Nutrient Loading and Water Quality in a Tropical Wetland" being submitted by Ms. Vandana Shan for the award of the degree of Doctor of Philosophy in Environmental Engineering, to Delhi Technological University, Delhi, India, is a bonafide record of original research work carried out by her under our guidance and supervision. The results embodied in this thesis have not been submitted to any other university or institution for the award of any degree or diploma.

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ABSTRACT

Water resources have been associated with the development of human civilization from historical time period. Excessive and improper use of agrochemicals in crop fields and unscientific agricultural activities in catchment area can cause a serious threat in wetland ecosystem. The present study has been done to determine nutrient loading and water quality of surface water in a tropical wetland and suggested applicable management strategies for long term use of wetland. For this purpose, various physico-chemical parameters and heavy metal content in water and sediment samples were investigated spatially and seasonally during the time period of two years. Carlson Trophic status index and Gaardner and Gran method were used to determine trophic status and productivity of wetland respectively. Multivariate statistical techniques, principal component analysis (PCA) /Factor analysis (FA), cluster analysis (CA) were computed to determine relationship between parameters and their influence on water quality with possible contamination sources in wetland respectively. Area distribution within the study area was determined by using polygon feature in google earth map which revealed that permanent green belt persisted throughout the study period with varying water level and vegetation growth in different seasons. A significant variation among physico-chemical parameters, nutrients and heavy metals, was observed seasonally whereas minimum variations were investigated spatially in water and sediments of wetland. Seasonal trend for major pollutants in wetland observed with their decreasing concentration as pre-monsoon > monsoon > post-monsoon confirming that excessive evaporation from wetland surface will concentrate the water with inorganic salts and nutrients. Contamination from catchment area and backflow water of drain no 8 (in monsoon) notably influences various physico-chemical properties of sediments as well as water in wetland. Also agrochemicals like number of pesticides contribute different types of heavy metals in wetland systems which further declined quality of water and sediments and bioaccumulate in various biotic species within wetland. The growth of submerged vegetation helped in improving water quality by adding photosynthetically-produced oxygen to water and by filtering the suspended impurities. But, the addition of wastewater from adjoining villages and runoff from nearby fields has resulted in increased concentration of nutrients (phosphates and nitrates) and heavy metals in monsoon season. Since these chemical species cause eutrophication and impart toxicity, respectively, the health of ecosystem and aquatic life is affected adversely.

Besides preliminary investigation of physico-chemical parameters along with nutrient and heavy metal concentration, distinct approaches were implemented to assess the pollution status of wetland water and sediment in research area. For this purpose, various water quality indices, heavy metal pollution index (HPI); heavy metal evaluation index (HEI); degree of contamination (C_d); and water quality index (WQI) were incorporated to define suitability of water in irrigation and aquatic use. Results obtained during the analysis classified water appropriate for irrigation and aquatic life except the regions adjoined to rural habitation. Various metal pollution indices viz. enrichment factor (EF), contamination factor (CF); degree of contamination (DC), pollution load index (PLI), geo-accumulation index (I_{geo}), sediment pollution index (SPI) in sediments were analysed to determine degree of contamination along with their sources of origin either natural or anthropogenic. Sediments were found minimum to significantly enriched with Cd, Cr, Zn, Ni, Cu and Pb, heavy metals, indicate their anthropogenic source of origin wherein Cd possessed high geo-accumulation index except all other studied heavy metals. Degree of contamination below total number of studied heavy metals, confirms their decreased contamination in wetland sediments. Based on Sediment Pollution Index, sediments were found low to moderately contaminated with SPI in range between 0 to 2, indicating natural source of origin. Also well defined seasonal changes in primary productivity were observed with increased trend from monsoon to post-monsoon and then pre-monsoon. Carlson Trophic Status Index classified water of Bhindawas wetland in hypereutrophic category. In order to avoid further degradation and declining wetland water quality and to eventually restore the beneficial uses of the wetland, proper management strategies including reduced agro-chemicals (fertilizers and pesticides) use in catchments should be exercised or adopted. Also proper rules and guidelines should be prepared for the trophic status of freshwater bodies in the nation by making bottom-up-down discussion.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AP	Available Phosphate
APHA	American Public Health Association
BOD	Biological Oxygen Demand
CA	Cluster Analysis
Ca	Calcium
CaH	Calcium Hardness
CCME	Canadian Council of Ministers of Environment
Cd	Cadmium
C_d	Degree of Contamination
Cl	Chlorine
CF	Contamination Factor
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
Cr	Chromium
Cu	Copper
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EC	Electrical Conductivity
E.Coli	Escherichia coli
EF	Enrichment Factor
EPA	Environmental Protection Agency
Fe	Iron
HCO_3^-	Bicarbonate
HEI	Heavy Metal Evaluation Index
HNO_3^-	Nitric Acid
HPI	Heavy Metal Pollution Index
$H_2SO_4^-$	Sulphuric Acid
I_{geo}	Geo-accumulation Index
K	Potassium
MAC	Maximum Allowable Concentration
mCd	Modified Degree of Contamination
Mg^{2+}	Magnesium
mg/l	Milligram per Litre
Mn	Manganese
MoEF	Ministry of Environment and Forests
MPI	Metal Pollution Index
MSL	Mean Sea Level
N	Nitrogen
Na^+	Sodium
NH_3	Ammonia
Ni	Nickel
NO_3^-	Nitrate
OM	Organic Matter
ORP	Oxidation Reduction Potential
P	Phosphorus

Pb	Lead
PCA	Principal Component Analysis
PERI	Potential Ecological Risk Index
PI	Permeability Index
PLI	Pollution Load Index
PO_4^{3-}	Phosphate
RSC	Residual Sodium Carbonate
SAR	Sodium Absorption Ratio
SO_4^{2-}	Sulphate
SPI	Sediment Pollution Index
SQG	Sediment Quality Guidelines
TDS	Total Dissolved Solids
TH	Total Hardness
TKN	Total Kjeldhal Nitrogen
TLI	Trophic Level Index
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSI	Trophic State Index
TSS	Total Suspended Solids
WHO	World Health Organisation
WQI	Water Quality Index
Zn	Zinc

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CHAPTER 1

INTRODUCTION

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1.1 Background

Wetlands are part of our natural wealth. They are one of the highly productive and valuable ecosystems where productivity is highly dependent on nutrient input and transformation (Mitsch and Gosselink, 2000). According to Ramsar Convention, wetlands are defined as areas of marsh, fen, peatland 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 (Ramsar, 2016). The earth support a wide range of wetlands depending upon various regional and local variations with respect to soil type, climatic conditions, water chemistry, topography, hydrology, vegetation and human interferences. Wetlands are complex ecosystems which undergo various physical, chemical and biological changes. They are nature's scheme for performing ecological, economical and hydrological functions. They play an important and vital role for maintaining the equilibrium in the nature both physically and biologically and commonly wetlands are described an intermediate or transitional zone between land and water. They provide a number of ecological, economic, protective, cultural and recreational values. Globally, an estimated areal distribution of wetlands falls between an extent of 917 million hectares to more than 1275 million hectares (Finlayson and Spiers, 1999; Lehner and Doll, 2004), and around an area of 124 million hectares was occupied by 1421 sites as Wetlands of International Importance as stated by Wetlands International (2005). Cowardin in 1979 devised wetland classification based on their ecological, geological and hydrological characteristics and categorized wetlands into riverine (rivers and streams), lacustrarine (lakes), marine (coastal wetlands), estuarine (mangrove swamps, tidal marshes and deltaic region) and palustarine (marshy region, swamps and bogs).

1.2 Tropical Wetlands

Wetlands situated between the Tropic of Cancer (latitude 23½° north) and the Tropic of Capricorn (23½° south) are known as Tropical wetlands. Equator passes at the centre of the tropics. Wetlands occupy more than one third of the Earth's surface which may lie between 20° N and 30° S latitude, with large area occupied by wetlands, marshes, tropical rainforests and floodplain wetlands (Tiner, 2009). Wetlands occur from the tundra to tropics in all continents except Antarctica (USEPA, 2011). Areas with humid climates support a large number of wetlands due to high precipitation rate as compared to arid climates having excess evapo-transpiration. All the countries of South East Asia fall in tropics and India, being a part of Southeast Asian countries lies mostly in the tropics. Wetland functions are majorly affected by distinction in the environments of tropical and temperate zones. As tropical wetlands fall near the equator, the humidity is high throughout the year with high precipitation rate in tropical zone oscillating from northern to southern regions, causing alternative dry and wet seasons. Moreover in tropical regions ambient temperature does not change frequently as it is observed in temperate zone (Pearce and Smith, 1998). It rains heavily and regularly almost every day during the wet season. The day time temperature never fall below 25°C and nights are quite cooler with a few degrees. Climate in all the tropical countries is not the same whereas the annual temporal variations are very less as compared to other zones. Instead of large temperature gap, natural wetland's distribution in globe varies i.e. 1,200,000 Km^2 in South America, 350,000 Km^2 in Asia, 340,000 Km^2 in Africa, and 2,000 Km^2 in Australia.

Indian wetlands are attracting concerns of various researchers towards long term studies as it is situated in tropical zone having highly bio diverse wetland ecosystems. India due to its varying geographical and climatic conditions sustain a large number of biologically active wetland habitats (Prasad et al., 2002) with natural high altitude cold desert wetlands to hot, humid wetlands of coastal zones on this planet. As stated by National wetland Atlas, Indian wetlands occupy total area of around 15 million hectares with 757,000 numbers of wetlands which represent almost 4.7% of total geographical zone of the nation containing 69% inland wetlands, 27% coastal and 4% other wetlands (with area < 2.25 hectares) (SAC, 2011; Panigrahy et al., 2009).

Indian wetlands are mainly classified in two main categories, inland and coastal wetlands according to definition devised under the Ramsar Convention and these are further distributed into two forms as: natural and man-made. Ox-Bow lakes, high altitude wetlands, riverine wetlands, waterlogged area, river/stream are natural inland wetland and creeks, sand/beach, intertidal mud flats, salt marsh, mangroves and coral reefs come under the category of coastal natural wetlands. However Reservoir/barrages, tanks/ponds, salt pans and aquaculture ponds are examples of inland man made wetlands and coastal man made wetlands category respectively. Need for manmade wetlands have risen for water storage and conservation, flood control, field irrigation, electricity generation, fishery and urban water supply (Prasad et al., 2002). A large number of man-made wetlands coupled with various natural wetlands, also contribute to species diversities of flora and fauna. Also Indian wetlands are the home of native flora and fauna and also resting and nesting places for migratory birds.

1.3 Wetland Functions and Value

Tropical wetlands perform important ecosystem functions and contribute major role in the welfare of large part of human population (Junk, 2002). Wetlands in tropical, semiarid zone of Haryana are spread in around 14216 ha area of open water and 2245 ha area for aquatic flora (Panigrahy et al., 2010). Wetlands are invaluable assets of a country and responsible for making it economically prosperous with large number of their services like food, fodder, fuel, medicines, and raw materials. Turner and Jones (1991) and Farber and Costanza (1987) stated the economic benefits of temperate wetlands. Due to the lack of data and resource constraints, basic methodology for valuing and assessing of ecological and economic benefits of tropical wetlands are still ongoing. Very few studies regarding economic importance of tropical wetlands have been undertaken till now. Yet recent studies across the tropical developing countries justified the crucial economic importance of tropical wetland systems, including inland freshwater and coastal mangrove regions (Barbier, Adams and Kimmage, 1991; Barbier, Costanza and Twilley, 1991). Being ecologically unique and active, tropical wetland performs various vital functions like water purification, nutrient retention and removal, flood mitigation, pollution abatement, stream flow maintenance, carbon sequestration and ground water recharge and which comes under indirect values. According to economic point of view, wetlands have been stated as a low cost biological system in reduction of point source and nonpoint sources e.g. agricultural and urban landscapes (Bystrom et al., 2000). Wetlands act as an efficient sources, sinks, and transformers of nutrients (nitrogen and phosphorus) depending upon their type, hydrologic status, and the residence time of nutrients coming from various geologic, biologic, and hydrologic pathways; (Mitsch and Gosselink, 2000) which are further efficiently removed by different biological and physico-chemical activities.

Wetlands control harmful impacts of flood by absorbing excess rain water and reducing the water flow. Davis (2002) stated that an acre of wetland can reserve 1 million to 1.5 million gallons of water from flood. Besides this wetlands are characterize as “Kidney of the landscape” which filter nutrients, harmful chemicals dissolved in waste water, storm water, and municipal sewage passing through it and help in sustaining its water quality. This quality makes them natural filter. Wetlands are well known ground water recharging source, which depends upon soil, biota, location and gradient of water table (Carter and Novitzki, 1988; Weller, 1981). Mineral soil located nearby and at the edges of wetlands help in groundwater recharge (Verry and Timmons, 1982). Seasonally, ground water recharge of up to 20% of wetland volume is discovered by various researchers (Weller, 1981). Besides various direct and indirect benefits, they provide various non use attributes such as water storage during monsoon, wild life maintenance by providing natural habitats to a wide varieties of plant and animal species, water quality protection against nutrient enrichment, agricultural runoff and salinization (Whitehead and Blomquist, 1991). Wetlands are known "Biological Supermarkets" and Gene Banks of Species as they provide adequate amount of nutrients, primary productivity and shallow water (USEPA, 2011) in tropical and subtropical regions and make ideal conditions for feeding and breeding activities of various wildlife species. They also provide staging sites/ stopping place for waterfowl and various migratory birds during winter (Prasad et al., 2002). Tropical wetlands are known as hotspots for the enhancement and maintenance of biodiversity (Gopal et al., 2001). Dugan (1988) stated that a number of communities in rural regions derive a huge range of advantages from different wetland ecosystems.

1.4 Water and Sediment Quality in Wetlands

In recent years due to industrialisation, urbanisation and agricultural activities surface water and ground water is highly deteriorated. In last few decades, it was observed that various natural sources, subsidence, erosion, floods, drought along with manmade sources viz. encroachments, pollution, and unsustainable grazing and excessive exploitation, change in land use are highly responsible for posing danger to the wetlands. Besides this weed growth and siltation are major contributing factor in lowering the quality of water in wetlands. Water and sediments in wetlands collectively reflects the actual pollution pattern of aquatic ecosystem. The water quality parameters don't provide sufficient knowledge about the health status of water body. Sediments act as both carriers and sinks (Singh et al., 2005) for contamination and provide the history of pollution phenomenon by providing the record of waste and nutrients input by surrounding catchment areas (Mwamburi, 2003). Both Phosphorous and nitrogen are major nutrients causing eutrophication of the wetlands. Phosphorus can be removed through sedimentation, soil sorption, immobilization, accumulation by organic matter and plant uptake. Nitrogen is removed in wetlands by filtration, adsorption, sedimentation, nitrification, denitrification, uptake by plants and microorganisms, and volatilization (DeBusk, 1999; Bowden, 1987; Faulkner and Richardson, 1989). Besides major nutrients (P and N), physicochemical parameters, metals are also considered as a group of pollutants with high ecological significance. Due to their dissolution in water column and accumulation in suspended particles and sediments they influence the quality of water as well as sediments and need to be analysed periodically. Naturally sediments reach in aquatic ecosystems through weathering of rocks and soils and atmospheric fall out. Also some manmade activities like discharge from municipal, agricultural and residential area into various water bodies also contribute adequate concentration of metals in water ecosystems (Demirak et al., 2006). Concentration of limiting nutrient phosphorous, chlorophyll and transparency collectively determine the trophic status of a water body which varies spatially and seasonally in wetland areas and reflects the productivity. During last few years, the high nutrient containing water from surrounded agricultural fields and back flow from waste water drains have increased the inorganic as well as organic pollution.

1.5 Loss of Wetlands

Wetland ecosystem constitutes about 6 % of the land area all over the world (Mitsch and Gooselink, 2007). They are most sensitive and exploited ecosystems among all environmental resources and at higher risk of degradation and loss. Tropical wetlands being highly productive and dynamic ecosystem support a large number of populations through the services they provide (Finlayson and Moser, 1992). In wetland ecosystems exchange of materials among various multiple and linked components take place through energy flow, physicochemical transfer, water flow and moving biota. Wetlands help in regulating the water movement within the watershed along with global water cycle thus accomplishing the vital function of hydrologic flux and storage. A number of natural and anthropogenic factors have caused destruction, fragmentation of various wetland types affecting the water quality and quantity of water resources, resulting in biodiversity loss. Also a number of external forcing factors have sufficient magnitude to alter the proper functioning of ecosystem. Millennium Ecosystem Assessment enlisted demographic and economic transition (includes globalisation, policy framework, trade and market), technological and behavioural change as major primary drivers causing wetland degradation and its subsequent loss. Intense proximate drivers such as pollution, salinisation, eutrophication, overharvesting (fishing, hunting), drainage and infilling, infrastructure expansion (for urban, agriculture and industrial purposes), introduction of invasive species, land use and land cover changes, hydrological modification in streams and wetlands are major primary drivers, which ultimately affect the structural and functional aspects of tropical wetlands. These factors or drivers further affect the supporting, provisioning and enhancing values of wetlands to a large extent.

Land-use change exerts immense pressure on wetland structure. Agriculture, aquaculture, urban settlements are most prominent land uses and have a considerable impact on wetlands. Also small variations like reduced canopy and drainage for agricultural production of wetlands can cause large impacts on wetlands worldwide (Ramsar Convention, 1991). Major problems are in developed nations, Europe and North America where 55 to 65 % of available wetlands have been drained for agricultural use by 1985. Figures for tropical and subtropical regions of Asia; Africa and South America are 27 %, 2 % and 6 % respectively. Lack of water resources to meet agricultural demands in developing countries are also because of excessive extractions of water from wetlands, causing temporary and permanent wetland loss (Ramsar Convention, 1991) which includes drastic change in microclimate of wetlands. Apart from these, major driving factor of wetland loss and its degradation is pollution due to agricultural run-off, dumping of hazardous waste, discharge of industrial effluents, untreated sewage disposal in wetlands. Due to these manmade activities in delicate ecosystem, wetland suffers adverse impacts on water quality and productivity. Accumulation of fertilizers leads to enrichment of water bodies causing eutrophication, depletion of oxygen content which leads to obnoxious conditions and anaerobic oxidation causing release of methane, ammonia and hydrogen sulphide. Native vegetation is adversely affected by invasive species like *Eichhornia crassipes*, *Salvinia molesta* due to their excessive uptake of nutrients, which have created nuisance in water bodies. Wetlands have unique characteristics of retention and transformation of pollutants in water, such as nitrate, phosphorous and heavy metals through biogeochemical and sedimentation processes. Denudation of catchment areas results in soil erosion leading to siltation and disturbances of the hydrological regime.

After a survey conducted by the Wildlife Institute of India it was found that, in last five decades, about 70-80 % of fresh water lakes and marshes in gangetic flood plains have been lost. Presently, only 50 % of Indian wetlands are left undisturbed and they are also being lost at fast rate of 2 to 3 % yearly. The World Wide Fund for Nature published the Directory of Indian Wetlands consisting of 147 wetland sites under India and Asian Wetland Bureau, 1995 records. Hunting (32 %), drainage for agricultural use (23 %), human settlements (22 %), and fishing and associated disturbances (19 %) were major drivers responsible for loss of most of wetland sites. Also deforestation and vegetation loss in catchment areas caused soil erosion and siltation which accounts 15 % wetland loss.

1.6 Management and Restoration of Wetlands

Wetlands are vital natural water resource and are amongst the most threatened ecosystems on account of ecological, social and economic factors. These ecosystems cannot be treated in isolation. Due to ever increasing human population and various developmental activities, there is tremendous pressure on the limited water resources and consequently, their overexploitation has led to considerable deterioration in water quality. Even the water bodies which are integral part of protected area network, as well as those which have been assigned national and international status under various conventions such as Ramsar and World Heritage, have not been spared. As these wetland resources are invaluable and we must prevent their draining and degradation. They constitute an important component of community water security system. The root causes of the degradation and loss of wetlands are lack of conservation and poor management system. A large number of Indian wetlands are ignored in various policy programmes even after various national legislations on wetland regulation have been implemented. This is due to only a selected number of wetlands have received proper financial and technical assistance/attention from central government and remaining ones in a neglected state under wetland conservation programme. Wise uses of sustainable management of wetlands will lead to prosperity and benefits to mankind. The greed for land, multiple demands on various water resources along with their wasteful use and the treatment of wetlands as dustbins are main reasons for wetland loss and their deterioration. Also for effective water management programme it is highly required to understand the water quality problems which occur from natural as well as anthropogenic processes. Also the assessment of wetlands for their management is an applied side of wetland science requiring an understanding approach for ecological and scientific perspectives of wetlands equalized with legal, institutional and economic realities to protect beneficial and treasured ecosystem. Hence for productive and sustainable management of the valuable wetland ecosystems, the economics, environment and society need to be integrated. And also people should be aware about the significance of wetlands as a major source base. As preservation of water quality is an important factor for planning projects and development of various sectors, a multidisciplinary approach is required to plan strategy for periodic review of quality and quantity aspects.

In the last few years, tropical wetlands have attained huge attention towards their sustainable use and adaptive management strategies. Based on the available information wetlands are facing problems like inadequate information and uneven management of these valuable systems. On behalf of the Ramsar Convention, Wetland International had assembled the information related to wetlands in Global View of Wetland Resources and Priorities (Finlayson and Spiers, 1999, Finlayson et al., 1999). Even then it was difficult to utilize much of this to evaluate the situation of world wetland resource or to set up priorities for sustainable management of wetland (Finlayson and Spiers, 1999). Only 7% of contracting Parties to the Ramsar Wetland Convention had an appropriate national inventory whereas 25 % did not have an inventory.

A greater understanding of the long-term outcomes of land-use and land cover variations and alteration and degradation of ecosystem is also required to maintain structural and functional aspects of tropical wetland ecosystems. A conceptual framework is highly required for wetland management which should include all the major issues affecting the wetland status, trends, primary and contiguous drivers change, conservation framework and associated responses, scientific input and data organisation and management respectively. Further a better understanding is required to address social vulnerability, change of perceptions, behavioural and institutional aspects for wetlands land use.

1.7 Novelity of the present Research Work

A number of missing links are identified as a part of this study and the main issues are nutrient loading, productivity, narrative and numeric criteria for aquatic life and irrigation use that have not been done earlier. Apart from this sources of pollution in wetland need to be advanced thoroughly. A large number of studies related to seasonal variations in water quality parameters, in water and sediments in Bhindawas wetland area has been reported earlier. Also there is no record of the study related to heavy metals contamination of water and sediments seasonally and spatially. So the present study will be helpful in determination of water and sediment pollution indices with respect to varying concentration of heavy metals in water column as well as in sediments to determine possible contamination sources of heavy metals in wetland.

1.8 Objectives of the Study

Following are the objectives of the study:

(1) To characterize the quality of water and sediments in Bhindawas bird sanctuary and assessment of nutrient loading spatially and seasonally.

(2) To determine the trophic state, primary productivity and nutrient cycling in the wetland during the study period and establish the trend towards change.

(3) To identify the probable sources of nutrients/pollutants and variables causing changes to Bhindawas wetland.

(4) To suggest corrective/restoration options for improvement in lake water quality and to study the response of wetland towards the corrective option.

CHAPTER 2

REVIEW OF LITERATURE

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REVIEW OF LITERATURE

Historically, water resources has been associated with development of human civilization. Amongst them, wetlands are known most fertile ecosystems after tropical rain forests throughout the world and known most vital factor for existence of living creatures (Ramachandran et al., 2006). Wetlands are transition zone between various terrestrial ecosystems (upland forests and grasslands) and aquatic ecosystems (lakes, rivers). In, general these water resources are highly essential for various agricultural, industrial, developmental and socioeconomic activities which indirectly imparts progress of a nation. Wetlands perform a large number of ecological functions and are valuable landscape of environment, having various aesthetic, recreational and socioeconomic values. Water pollution by agrochemicals has become an increasing threat to mankind and natural ecosystems in past few decades. Not only natural processes like, precipitation rate, climate changes, rock weathering and siltation in shallow water bodies can affect water quality (DWAF, 1995) but also various anthropogenic activities have drastically change water quality of lentic as well as lotic ecosystems along with their major ecological functioning (Beman et al., 2005; Binhe and Thomas, 2008; Nouri et al., 2009; Giridharan et al., 2009; Chan, 2011) physical habitat, and biological integrity (Varol and Sen, 2009).

2.1 Water quality

The major human activities responsible for degradation and contamination of these water bodies are disposal of municipal waste, industrial effluent and huge varieties of synthetic chemicals (Asrari et al., 2008; Bozelli et al., 2009; Sawant et al., 2010; Niu et al., 2015; Nyairo et al., 2015). The biological health of aquatic ecosystems is mainly influenced by presence of an adequate amount of nutrients and organic and inorganic impurities. Succession of major nutrients in the water as well as in sediment is prerequisite demand of aquatic ecosystem for proper functioning and maintaining balance between various biotic and abiotic components (Venkatesharaju et al., 2010). Presence of appropriate amount of nutrients in water bodies imparts crucial information regarding available resources for supporting aquatic life and water quality status (Medudhula et al., 2012; Ramesh et al., 2007). Water quality is generally determined by various physicochemical and biological water quality parameters (Medudhula et al., 2012; Upadhyay et al., 2013). Engineers, Ecologists and Hydrologists have defined water quality in different terms. According to Farrell-Poe (2000) the term "water quality" is used to indicate the water suitability for particular use based on the chemical, physical or biological characteristics of water (Westbrook et al., 2011). Water quality is defined as "chemical, physical and biological descriptors that affect the structure and function of ecosystems as well as those that negatively impact human and livestock health if in elevated concentrations". Climate, landscape, and geomorphologic processes are major factors which affect both quantity and quality of water entering the wetlands (Tuladhar, 2013). Chowdhury et al. (2012) and McKenzie et al. (2012) stated that physico-chemical parameters like, electrical conductivity (EC); pH; biological oxygen demand (BOD) and chemical oxygen demand (COD) along with some major elements, nitrogen (N) and phosphorus (P) play an important role in wetland ecosystem and known indicators of water quality. Water quality of wetlands has recently become a matter of great concern due to excessive degradation of various freshwater resources and its adverse impacts on human health and aquatic life. A number of threats which mainly affect water quality of wetlands are accumulation of suspended impurities, organic components, nutrients, trace metals and pathogens (Yu et al., 2015) which ultimately imparts change in physical, chemical and biological characteristics of water system. A minimum amount of heavy metals such as Cu, Ni, Fe, Zn and Cr in water system is essential for biochemical processes of aquatic flora and fauna (Karpagavalli et al., 2012). The natural source of heavy metals in wetlands is geologic deposits or soil parent materials (Langner et al., 2011). But combined with various anthropogenic activities like dumping of domestic waste, industrial effluent in water, landfills, mining and use of synthetic chemicals such as fertilizers, paints, pesticides, batteries have caused nuisance in environment and created ecological imbalance. Heavy metals being persistence, toxic and non-biodegradable, bio accumulated at higher trophic levels in ecological food chain creating imbalance and affecting natural functioning of water ecosystem (Aderinola et al., 2012). A large number of studies have been done to investigate the physicochemical parameters of water quality in India (Ramachandran et al., 2006; Rai et al., 2011; Azmi et al., 2015; Mishra et al., 2008). Potential pollution sources and long term monitoring assessment of physicochemical parameters are essential for water quality evaluation as they significantly contribute to temporal as well as spatial variations in water quality. Kumar et al. (2006) studied variations in physico-chemical parameters of lake with depth and season.

Kumar and Dhankhar (2015) studied the spatial and temporal changes in water quality of

Bhindawas wetland and stated hypereutrophic status of lake along with high concentration of physicochemical parameters like, TDS, turbidity, total phosphorus and nitrate during study period. Also Garg et al. (2010) determined the physico-chemical characteristics, pollution and trophic status of Ramsagar reservoir and indicated mesotrophic status of Ramsagar reservoir with moderate range of nutrients concentration. Hussain Sagar lake, were analyzed by Kora et al. (2017) with respect to various physico- chemical (pH, TDS, COD, EC, and chlorophyll-a) and biological parameters (E.Coli) and found hypereutrophic status of lake with presence of huge amount of coliforms and E. coli growth indicating severe organic contamination of the lake with human excreta and domestic sewage by various drainage canals due to residential and industrial growth in its vicinity. Research related to spatial as well as seasonal changes in physico-chemical characteristics in different water bodies have been conducted by a number of researchers (Panigrahy et al., 2009; Nazar et al., 2012; Sheela et al., 2011; Sahoo et al., 2015; Tuboi et al., 2018) by applying different statistical phenomenon like hierarchical cluster analysis, Cluster Analysis, Principal Component Analysis, ANOVA, in Chilika Lagoon; Anchar Lake, Khushalsar Lake and Dal Lake; Akkulam–Veli Lake; Loktak Lake and Keibul Lamjao National Park and Chilka lagoon and the study determined the useful application of these environmetric techniques for the analysis and interpretation of lake water. Nazar et al. (2017) conducted a research related to physicochemical parameters of water spatially and seasonally in Harike wetland (a Ramsar site in Punjab). He concluded that wetland had medium water quality with respect to CPCB and WHO standards alongwith increased concentration of a significant parameters during the pre-monsoon and monsoon probably by mixing of pollutants.

Previous research on water quality status of Bhindawas wetland have also been done by Saluja and Garg (2015) by computing various multivariate statistical analysis viz. Principal Component Analysis (PCA) and Cluster Analysis (CA) during pre-monsoon as well as monsoon season and stated various reasons for the pollution inside the lake. Also various study related to water quality determination of fresh water bodies were incorporated all over the world. Ndungu et al. (2015) determined information on water quality and sources of pollution in Lake Naivasha, Kenya. The study was done by using Cluster analysis (CA) and Principal component analysis (PCA). These tools are important for statistical analysis as they provide useful observations related to water quality in lake Naivasha. Water quality parameters associated with the study revealed that the major factors which influence the lake water quality were, agricultural activities (in northern region) and domestic discharge and natural mineral deposition associated with volcanic activity (in Crescent Lake). Shadrack et al. (2015) studied the physical characteristics of tropical wetlands in eastern direction of lake Victoria Basin and measured rainfall, flow rate, turbidity, and pH. The research concluded that almost 78 to 89 % retention of recharge water occurred with the largest contribution to water budget from Nzoia wetland during rainy season, afterwards Nyando and Kigwal/Kimondi. High levels of turbidity, pH was observed in rainy season and variations in flow rate were noticed as compared to dry season. All the three wetlands were found to have turbidity values above the recommended EPA value at the inlets during monsoon but declined values at the outlet of the wetlands within 1 to 5 NTUs as recommended by EPA. A significant correlation was found between rainfall amounts, flow rate and turbidity. Inlets have slightly acidic pH values (6.79 ± 0.55) to basic value (8.44 ± 0.17) mainly at the exit of the wetland. Olanrewaju et al. (2017) evaluated the variations in the spatio-temporal patterns of physico-chemical parameters of Eleyele reservoir. Samples were collected bi-monthly during dry (December-April) and wet (May-November) seasons. A distinct, seasonal variation in water quality parameters with higher values were noticed during wet season. Some physicochemical parameters such as COD and nutrients were found in excess amount at some sites stating their contaminated nature. Water at Eleyele reservoir is classified as moderately hard and eutrophic based on total hardness and secchi disc depth respectively. Idowu et al. (2013) inspected Ado-Ekiti Reservoir for its physico-chemical parameters in Southwest region of Nigeria between May 2002 to July 2004 with every month. Positive correlation was observed among transparency, pH and Dissolved Oxygen negative alkalinity negative correlation was observed between DO and free carbon dioxide. Also, positive correlation between plenty of Hepsetusodoe with DO and free CO_2 and negatively with temperature, pH and BOD were observed. Since all these correlations were significant therefore all the values support wide range of fish production. Besides this a number of other techniques were practiced to determine the water quality for different water bodies. Wang et al. (2014) suggested that surface water quality monitoring can be done through coupled method based on numerical simulation tests, mathematical analysis and field investigations in Poyang lake.

A number of studies in past few years revealed that a variety of techniques and methods have been adopted to determine the water quality status of lakes and rivers, all over the world. For better understanding of water quality in research area, various indices were incorporated to define the real status of water. Among them WQI is simplest one. Horton (1965) developed

WQI in US. Later it was widely utilized and implemented by European, Asian and African nations. WQI is one of the standard methods which summarize overall water quality information of water body into a single number which is simple and understandable for public (Pathak et al., 2015). Water Quality Index (WQI) is a 100 point scale that categorizes the water quality as excellent, good, very poor, poor, and unsuitable. It expresses overall water quality considering certain physicochemical and biological parameters. Khan et al. (2003) examined the quality of water in three watersheds by using WQI recommended by the CCME. Fathi et al. (2016) calculated the Water Quality Index of Choghakhor International Wetland by using eleven parameters consisting Alkalinity, Ammonium, BOD, conductivity, DO, hardness, nitrate, nitrite, pH, turbidity and TDS. Each parameter was assigned a relative weightage from 1 to 4 on the basis of their significance for human health and aquatic life. Duncan test and one-way ANOVA analysis were carried out to observe variations between sampling stations and various stages. And for interpretation of temporal and spatial changes in water quality parameters and water quality index, box and whisker plot and linear diagrams were exercised, respectively. The results from water quality index revealed the unsuitability of wetland water for human consumption and health due to addition of organic waste. Kangabam et al. (2017) performed a study to determine the WQI of the Loktak Lake by selecting a number of physicochemical parameters. WQI was calculated with the help of eleven selected parameters for five sampling locations. Values of WQI was found in range from 64 to 77 which revealed that Loktak Lake water is not good for drinking for human as well as animals. High values of subindices, DO, EC, COD and nitrite are responsible for high value of WQI. Water quality index (WQI) and physico-chemical analysis of surface water quality of Mallathahalli lake and Sankey tank, Bangalore was determined by Ravikumar et al. (2013). Result revealed that Water Quality Index values of Sankey tank water ranged from 50.34 to 63.38 and fell in good water class whereas in Mallathahalli lake WQI value varied in between 111.69 and 137.09 and the water fell under poor water category due to higher value of electrical conductivity, total alkalinity, total hardness, TDS, chloride, potassium and calcium in the surface water. Both the water bodies were found suitable for irrigation based on SAR values which belong to excellent (S1) class. Hydro geochemical investigations were done by Prasanna et al. (2011) determined the suitability and applicability of Perumal lake (Cuddalore) water for domestic and agricultural by investigating various physicochemical parameters. Piper trilinear diagram was used to identify major hydrochemical facies. The study also revealed that many samples were found suitable for irrigation based on % Na, PI, RSC and SAR values.

Table 2.1 Water quality with respect to various physicochemical parameters of Indian Lakes.

Lakes	pH	EC	Temp.	DO	TDS	BOD	TN	TP	References
				PARAMETERS					
Bhattrahalli Lake	8.51	1707	-	4.7	584	12	-	-	Veena et al. (2016)
Bhilai	6.5	807.6	25	5.14	452.3	-	0.26	-	Jena et al. (2013)
Chillka lake	8.03	-	33.5	7.56	26.66	3.5	16.74	0.17	Patra et al. (2010)
FutalaLake	7.8	-	26	7.8	263	2.4	3.5	1.4	Kazmi et al. (2013)
Harike lake	8.37	-	-	9.35	445.6	4.5	4.74	-	Parmar and Bhardwaj (2013)
Hussain saga	7.78	-	30	2.26	680	2.69	5.4	7.2	Sailaja and Reddy (2015)
Kargil lake	7.8	258	24.5	15.8	213	3.9	9.2	4.8	Bondugula and Rao(2015)
Keerat Sagar	8.3	778.2	25.4	6.34	502	3.48	10	-	Pal et al. (2013)
Kolavai lake	7.38	811	30.8	7.8	576	11.2	-	0.08	Babu and Selvanayagam (2013)
Lokhtak lake	7.31	-	-	8.58	71.33	5.07	-	-	Laishram and Dey (2014)
Mansagar lake	8	-	21.8	15.4	1840	2.1	11.3	0.2	Kazmi et al. (2013)
Naini lake	8	-	18.8	9.9	440	2	4.6	0.2	Kazmi et al. (2013)
Palakdil	8	70	32	5.8	51.03	3.4	47	0.42	Lalmuansangi and Lalramnghinglova (2014)
Renuka lake	7.3	-	-	6.66	363.8	1.81	4.29	0.16	Singh and Sharma(2012)
Roop Sagar	7.4	-	26	4.2	-	4.2	0.19	0.24	Vaheedunnisha and Shukla (2013)
Rudrasagarlake	9	115	-	8.6	-	4.1	7	-	Pal et al. (2016)
Sanhit Sarovar	8.8	-	31	-	-	14.5	1.5	0.6	Kazmi et al. (2013)
Sarkhej Lake	8.7	489	20	3.36	184.2	1.21	8.22	0.77	Umerfaruq et al. (2015)
Sukhna Lake	8.1	-	25	6.8	-	3	0.16	0.6	Chaudhry et al. (2013)
Wular Lake	7.8	232.3	14.1	9.3	143.5	-	0.8	-	Yaseen et al. (2015)

Note: Except pH, EC (µS/cm) and Temp (°C), all parameters have unit in mg/l.

2.2 Sediment Quality

Aquatic sediments are dynamic and heterogeneous system consisting of soil particles whether silt or sand and mixture of both particles that settle down at the base of water body (USEPA, 2002). These particles are generally brought through various natural sources (soil erosion, decaying of flora and fauna, wind flow, precipitation and atmospheric fall out). Major part of these sediments are found along with organic and inorganic materials at bottom and derived mainly from lakes and its catchment areas (Chapman, 1996; Rangel-Peraza et al., 2015). Being an integral part of water ecosystem, they provide area for feeding, rearing, spawing and habitat for variety of aquatic species. Sediments help in maintaining water quality by removing pollutants in overlying water column. Due to increased civilisation and various developmental activities, heavy metals are continuously added into various aquatic ecosystems and posing dramatic effects on water status and biological health of water ecosystems (Jha et al., 2003; Xia et al., 2011; Shang et al., 2015). Sediments act sink as well as source in water ecosystems as in one hand, they adsorb pollutants on its surface from water column and on the other hand it become potential pollution source by remobilization of contaminants in water ecosystems (Doong et al., 2002; Malferrari et al., 2009; Khadka, 2011). Jhingran and Sugunan (1990) and Stronkhorst et al. (2004) stated that sediments of water ecosystem have direct relationship with water quality and productivity as they release nutrients for growth of planktons and organisms living at bottom of water ecosystem. Assessment of water quality alone provides insufficient information regarding health status of a water system. Sediments along with water reflect overall water quality of aquatic ecosystem. Sediments are known major indicators of water quality and aquatic pollution. Previously they were known as record of past historical events of lake but in recent years they play major role in lake dynamics. They are highly efficient in determining of pollution sources, its extent and monitor trace contaminants (Forstner and Wittmann, 1983; Dassenakis et al., 1996).

In aquatic ecosystems, geochemical variations and sediment fluxes are greatly influenced by increased anthropogenic activities. The physicochemical characteristics of sediments are majorly dependent on precipitation rate and temperature (Millman and Meade, 1983; Sondergaard et al., 2003; Jeppesen et al., 2005). Proper functioning of nutrient cycling in water ecosystem is maintained by microorganisms present in water sediments (Mishra and Dhar, 2004).

Several studies by various scientists have been done related to sediments in Indian water bodies. Vetharoy (2002) studied the geochemistry of Tambraparani estuary sediments and found that estuarine sediments have high amount of organic matter and composition of sediments greatly influenced the abundance of a huge number of flora and fauna. Saravanakumar et al. (2008) investigated various physicochemical characteristics like temperature, pH, nitrogen, phosphorous, potassium and organic carbon in sediments of mangrove in Kachh Gujrat. Niraula (2012) determined the limnological status of Beeshazar lake, Nepal by studying water and sediment quality and found high concentration of nutrients and organic matter in sediments and water quality unfavourable for aquatic species. Kaushal and Sharma (2001) studied sediments characteristics of Badhkal Lake, Haryana and found the moderate amount of available phosphorus (4.6 to 7.0 mg/100g of soil), organic carbon content (0.32 % to 0.75 %), and available nitrogen (11.2 to 51.5 mg/100g of soil). Fore and Grafe (2002) in their study revealed that change in pH, specific conductivity and nutrients of wetland is mainly due to addition of agricultural fertilizers and cattle waste. Siddique et al. (2012) investigated soil's physicochemical characteristics on the basis of aquaculture pond age (Bangladesh) and determined slight variations in pH and organic matter content from three ponds ranged from 6.2 to 6.3 , 6.0 to 6.2 and 4.42 to 4.53 %, 5.58 to 5.74 %, 7.53 to 8.58 % respectively. Pathak et al. (2004) conducted research on eighteen wetlands of Uttar Pradesh by studying their hydrological features and indicated their high productive nature due to their notable increase in organic content by microbial degradation of dead and decaying macrophytes at bottom layer. Also the nutrient and organic carbon content were found high in soil as compare to water column. Haggard et al. (2004) investigated the internal as well as external phosphorus loading of Lake Oklahoma.The physical disturbances in bottom sediments decrease or increase the available nutrient of the sediment (Gabet et al., 2003).

2.3 Heavy Metals in Wetlands

Metals are generally known as natural constituents of rocks, soils, sediments, and water. Three principal reservoir of metals in major aquatic ecosystems are, water, sediment, and biota. The metals must be both abundant in nature and readily available as soluble species. Some of the metals with atomic number below 40 restrict their availability or unavailable due to the less solubility of their hydroxides. Wood (1974) categorised metals into three major parts based on their harmful and irreversible effects of environmental pollution; Noncritical (Al, Ca, Fe, K, Li, Mg, Na, Rb, Sr); Toxic , highly insoluble or very rare (Hf, Ba , Ir, Ga , La, Ru, Os, Rh, Ta, Zr, W, Ti) and Very toxic and relatively accessible (Be, As, Ag, Be, Bi, Hg, Zn, Cd, Pb, Cr, Ni, Sb,Cu , Sn, Se, Tl, Co, Te). Heavy metals in water and soil are available in varying degree at various trophic levels in food web depending on various environmental, physical, chemical, and biological conditions (Siegel, 2004). Heavy metals beyond their permissible limit in water bodies have caused various irreversible effects viz. water pollution, negative impacts on aquatic life, including their growth reduction, genetic and behaviour changes. They can be lethal to them if exposed to high level of concentration (Pillay, 2004). A large number researchers have studied heavy metal contamination in lakes and wetlands in india and all over the world. Table 2.2 and Table 2.3 represent surface water and sediment pollution in various lakes /wetlands in India and Table 2.4 and 2.5 represent surface and sediment contamination of lakes/wetlands located in different countries all over the world.

Table 2.2 Heavy metals concentration (mg/l) in surface water of Indian lakes /wetlands.

				Heavy Metal Concentration			
Lakes	**Pb**	**Fe**	**Mn**	**Cu**	**Cr**	**Zn**	**References**
Ashtamudi lake	0.001	8.41	-	0.02	0.01	0.03	Karim and Williams (2015)
Bhattrahalli lake	0.002	0.283	0.059	0.003	0.003	0.009	Veena et al. (2016)
Bhilai	0.26	0.822	-	0.002	0.326	0.0533	Tiwari et al. (2015)
Chemberambakkam Lake	0.29	0.284	0.052	0.019	0.035	0.026	Batvari and Surendran (2015)
Cherlapally Lake	-	0.5	8.2	0.5	-	0.22	Amruthakalyani and Gangadhar (2014)
Chillka lake	0.385	1.1	-	0.29	0.07	0.247	Nayak et al. (2010)
FutalaLake	0.026	0.035	-	-	0.042	0.048	Puri et al. (2011)
Harike lake	0.53	1.3	0.02	0.26	0.12	0.69	Brraich and Jangu (2015)
Hussain saga	0.84	-	-	-	-	-	Suneela et al. (2008)
Keerat Sagar	-	0.011	0.007	0.024	-	0.216	Gupta et al. (2010)
Kolavai lake	0.138	7.82	-	0.126	0.008	0.232	Babu et al (2013)
Lake Anasagar	0.122	0.66	-	0.072	-	0.963	Dutta et al. (2009)
Lokhtak lake	0.7	-	-	-	1.3	3.6	Singh et al. (2015)
Naini lake	1.52	1.49	1.64	0.07	0.33	0.02	Sharma et al. (2014)
Sarkhej Lake	0.06	-	0.63	-	-	-	Patel and Vediya (2012)
Shahpura lake	0.06	-	-	0.39	-	-	Anu et al. (2011)
Renuka lake	0.35	1.49	0.87	0	-	0.15	Singh and Sharma (2012)
Wular Lake	0.9	-	0.9	0.6	-	2	Sheikh et al. (2014)

Increased concentration of heavy metals in water bodies has surpassed the concentration released by natural weathering (Villaescusa et al., 2000). Each and every segment of environment is highly affected by heavy metals due to their toxic and persistence nature. Beside this, they also accumulate at higher trophic level in ecosystem causing biomagnification (Loska and Wiechula, 2003; Pekey, 2006; Nouri et al., 2006). Being natural components of water, some heavy metals like Fe, Se, Zn, Mo, Co and Mn are needed in very less amount for the biological functioning of living organisms in water ecosystems. But beyond their permissible level they can affect bio-physiochemical activities of aquatic organisms along with water toxicity (Ochieng et al., 2007). Adsorption of various nutrients and trace metals at sediment surface containing inorganic and organic matter, further increased their concentration in bottom sediments (Jeon et al., 2003; Schmitt et al., 2003; Ochieng et al., 2007). Natural and anthropogenic sources added heavy metals in to aquatic system and with passage of time, they distributed themselves between aqueous and sediment phase by various physicochemical (adsorption, hydrolysis and co-precipitation) and biological activities.

Table 2.3 Heavy metals concentration (mg/kg) in sediments of Indian lakes /wetlands.

				Metal concentrations (mg/kg)			
Lake/Wetland	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	**References**
Hussainsagar lake	ND	40-60	ND	170-210	40-60	ND	Rao et al. (2008)
Veeranam lake	0.2-3.9	40-150	65-125	34-95	20-41	69-599	Suresh et al. (2012)
Jannapura lake	1.9	ND	89.75	40.05	0.2	0.034	Puttaiah and Kiran (2008)
Vembanad Lake	1 - 4	ND	47	64	ND	259	Prinju and Narayana (2006)
Bellandur wetlands	1.6-55.3	33.9-199.4	105-1147.8	15.1-138.4	31.2-308.2	125.7-2001	Ramachandra et al. (2018)
Akkulam Veli lake	0.27	183.17	53.8	83.77	59.05	123.4	Swarnalatha et al. (2013)
Chilka Lagoon	2.87	77.6	30.94	45.46	17.73	77.02	Banerjee et al. (2017)
Pulicat lake	-	0.996 - 5.016	4.22-8.97	ND	18.13-57.08	25.9-78.64	Porhajasova et al. (2011)
Ramgarh Lake (UP)	0.77	ND	32.47	ND	22.07	188.83	Singh and Upadhyay (2012)
ICRISATLake, Patancheru	0.01	35.02	20.05	21.98	10.56	27.33	Shirisha et al. (2016)
Kavvayi Wetland	2.54	ND	21.93	34.66	74.7	52.15	Shiji et al. (2015)

Large amount of heavy metals get deposited at bottom sediments and a very small amount of free metal ions remain dissolved in water. Metals settled on outer surface of bottom sediments may be resuspended at upper water sediment interphase causing secondary pollution (Beutel et al., 2008). Likens and Davis (1975) investigated that resuspension of sediments in shallow water bodies caused by waves and currents and subsequent transport and settling of suspended impurities or sediments to deeper zone of lakes. Some metals like, copper, cadmium, lead, and zinc can be released through sediments by oxidation of their sulphide phases (Kerner and Wallmann, 1992) at low pH and oxidation of organic matter (Forstner and Patchineelam, 1980). In sediment system, EC and pH are major controlling factor which affect the process of heavy metal release from sediments (Peters et al., 1997). Further based on differences in pattern of resuspension and sediment movement, Håkanson and Jansson (1983) divided lake bottoms into three zones such as erosional zone, transportation zone and an accumulation zone. Heavy metals not only have toxic effects on the aquatic and terrestrial biota but also can affect the availability of chemicals and nutrients in the aquatic ecosystem. Cadmium, Chromium, Copper, Iron, Lead, Nickel, Zinc). Sediment containing heavy metals are sensitive indicator of water pollution and had the significance of reflection the status of water system (Yang et al., 2005).

Table 2.4 Concentration of heavy metals (mg/l) in lake /wetland water samples from different countries

		Metal Concentration (mg/l)						
Country	**Wetland/Lake**	**Cd**	**Cu**	**Cr**	**Ni**	**Pb**	**Zn**	**Reference**
Bangladesh	Dhalai Beel Lake	0.007	1.053	0.093	0.035	0.108	3.318	Rahman et al. (2014)
Southeastern USA	Tuskegee Lake	ND-0.000001	0.0005-0.00121	0.00003 – 0.00205	ND-0.0066	0.0001 – 0.00071	0.0055-0.006	Ikem et al. (2003)
Nigeria	Asejire Lake	ND	-	ND	ND	0.015	-	Jenyo and Oladele (2016)
Malaysia	Curtin Lake	-	0.002	-	0.001	0.002	0.004	Prasanna et al. (2012)
Iran	Algol Wetland	ND	0.002	-	-	0.0036	0.076	Zafarzadeh et al. (2018)
Turkey	Hazar Lake	ND	0.02	-	0.01	-	0.05	Ozmen et al. (2004)
Tunisia	Ichkeul Lake	-	0.024	-	0.04	0.14	0.14	Yazidi et al. (2017)
Northern Bangladesh	Barapukuria Flood plain	-	0.21	-	0.18	0.23	0.43	Bhuiyan et al. (2010)
China	Chaohu lake	0.00089	0.00155	0.00073	0.00109	-	0.00759	Li et al. (2011)
East central China	Honghu lake	0.0000036	0.00193	0.00171	0.0012	0.00128	0.00213	Hu et al. (2012)

Table 2.5 Concentration of heavy metals(mg/kg) in lake /wetland sediment samples from different countries

		Heavy Metal Concentration (mg/kg)						
Country	**Wetland/Lake**	**Cd**	**Cu**	**Cr**	**Ni**	**Pb**	**Zn**	**Reference**
Egpt	El- Manzala	0.001-0.004	0.006-0.019	-	-	0.006-0.063	0.015-0.1	Goher et al. (2017)
Nigeria	Asejire Lake	0.0834	-	0.0154	0.0174	0.074	-	Jenyo and Oladele (2016)
Greece	Karla Lake	-	38.3	298.4	182.8	34.3	31.2	Skordas et al. (2015)
USA	Nicaragua Lake	-	59.5	23.1	40	3.7	58.7	Scheibye et al. (2014)
Greece	Koumoundourou Lake	-	22.6	57	48.1	110.5	118	Hahladakis et al. (2013)
Bangladesh	Dhalai Beel	0.61	31.01	98.1	25.67	59.99	117.15	Rahman et al. (2014)
Ethiopia	Awassa Lake	-	8.69	8.27	20.2	15.7	93.8	Yohannes et al. (2013)
China	Yilong Lake	-	31.4	86.73	35.99	53.19	86.82	Bai et al. (2011)
China	Chaohu Lake	0.92	38.6	80.1	44.7	94.9	-	Zheng et al. (2010)
Thailand	Songkhla Lake	-	1.8-126	-	2.5-21.9	8.2-131	5.4-562	Pradit et al. (2010)
Tanzania, Africa	Victoria Lake	2.5	21.6	11	-	29.6	36.4	Kishe and Machiwa (2003)

A large number of studies have been done all over the world on varieties of wetlands like marsh (Zhang and Lu, 2001) along with other water bodies like, (Qian et al., 2005; Ji et al., 2007; Xue et al., 2007), river (Lin et al., 2008), and coastal area (Huang et al., 2007). Vertical and horizontal distribution of heavy metals, with regard to their chemical forms was studied in water as well as sediments and their ecological risks in various biota (Samecka and Kempers, 2001; Demirak et al., 2006) was also determined. Numerous studies on heavy metals in the aquatic systems have been carried out in India including wetlands (Unni and Philip, 1990; Prusty, 2007; Rai and Thripathi, 2007; Rai, 2008), estuary and lake (Padmalal et al., 1997; Vardanyan and Ingole, 2006; Balachandran et al., 2006), rivers (Mehra et al., 2000; Kaushik et al., 2001; Singh et al., 2005; Purushothaman and Chakrapani, 2007), mangroves (Shyamalendu et al., 2001) and coastal areas (Balachandran et al., 2008).

2.4 Water and Sediment Quality Indices

In last few decades, a number of significant studies have been done with respect to heavy metal pollution in water bodies by a number of researchers and different methods have been developed for better understanding of water and sediment quality. The high degree of concentration level of metal pollution in the various aquatic ecosystem is of major concern . Depending upon proximity to point sources and large volume flow, water in rivers, streams and lakes became heavily polluted with elevated contents of Cd, Cr, Pb, Hg, and Zn, Cr. Based on observation of various researchers, Edet and Ntekim (1996), Yang et al. (1996), and Zhongyi (1996), it was concluded that there is prime need to monitor the water quality of various water resources to check and control of their futher deterioration from metal pollutants. Sediment quality has gained an increased attention for environmentalists, biologists and geologists as their deceisive nature because sediment are major hotspots of accumulation and regeneration of nutrients and heavy metals. With respect to water, a well known indices like Heavy metal pollution index (HPI), heavy metal evaluation index (HEI) and degree of contamination (C_d), have been used by a number of researchers (Mohan et al., 1996; Prasad and Jaiprakas, 1999; Prasad and Bose, 2001; Teng et al., 2004; Prasad and Mondal, 2008; Offiong and Edet, 1998 a, b; Edet and Offiong, 2002; Rapant et al., 1999) in different water bodies. In case of sediment, various sediment quality and pollution indices were applied to determine degree of pollution, natural and anthropogenic source of metal pollution, risk assessment; i.e., contamination factor (CF) (Turekian and Wedephol, 1961, Tomlinson et al., 1980; Fujita et al., 2014), degree of contamination (Tomlinson et al., 1980 and Seshan et al., 2010), modified degree of contamination (mC_d) (Jamshidi-Zanjani and Saeedi, 2013), geoaccumulation index (I_{geo}) (Muller, 1969; Chakravartyband Patgiri, 2009; Buccolieri et al., 2006; Davutluoglu et al., 2011; Fu et al., 2013; Ma et al., 2016), enrichment factor (EF) (Davutluoglu et al., 2011; Fransco –Uria et al., 2009; Liaghati et al., 2003; Wang et al., 2007; Zang et al., 2016), metal pollution index (MPI) (Hortellani et al., 2013), sediment quality guidelines (SQGs) (Davutluoglu et al., 2011; Fu et al., 2013), pollution load index (PLI) (Fujita et al., 2014; Wazne and Korfali, 2016), and potential ecological risk index (PERI) (Fu et al., 2013; Zang et al., 2016; Zhang and Shao, 2013).

2.5 Trophic state, Productivity, and Nutrient loading

Trophic state is the condition of a water body which determine its biological status in a given time period by considering biological, chemical, or composite indicators and describe its eutrophic conditions. Increase in composite indicators refer to trophic state index (TSI) where TP, Secchi depth and Chlorophyll a are major key factors to determine the TSI index. Chlorophyll-a, indirectly determine the algal biomass in water body. Increased Chl a value in water ecosystem is directly proportional to higher phytoplanktonic biomass which reflects higher productivity and eutrophic status. Secchi Disc depth determines the transparency in water body which majorly depends on inorganic suspended solids and algal density in water (Heiskary, 1985). Total phosphorous in water from various point and nonpoint sources, causes algal nuisance being a limiting nutrient and speeds up cultural eutrophication induced by man-made activities (Harper, 1992). Lakes and reservoirs naturally accumulate sediments and organic debris, thereby obtaining nutrients from their watersheds and increasing biological productivity (Dodds, 2002; Masters and Ela, 2008). Steffanson et. al. (2001) stated that eutrophication is a natural process, but accelerated by various anthropogenic activities to cause cultural eutrophication over a period of time. Measurement of biomass and productivity, various biotic indices like diversity, species richness fall under the category of biological indicators whereas chemical indicators include phosphorous and nitrogen concentration. Phosphorus in fresh water bodies may come from different sources, *e.g.*, point-source discharges, terrestrial runoff, faeces from waterfowl, decaying organisms, and rocks containing phosphorus. Natural as well as anthropogenic sources add phosphorus into lakes and reservoirs by waste produced from aquatic species and wildlife, and decaying parts of plants and animals, soluble salts or minerals having phosphorus and atmospheric fall out of particulate-bound phosphorus (*e.g.*, windblown soils containing phosphorus). Phosphorus found in the water column of the aquatic ecosystem, either within the bodies of aquatic organisms, or attached to sediment particles. Lee et al. (1981) on the basis of phosphorus contents have classified the water bodies into five categories, viz., oligotrophic (less than 0.007 mg/l), oligo-mesotrophic (between 0.008 and 0.011 mg/l), mesotrophic between (0.012 and 0.027 mg/l), meso-eutrophic (between 0.028 and 0.039 mg/l) and eutrophic (more than 0.040 mg/l). Later Nurnberg (1996), on the basis of phosphorus contents, have classified the lake ecosystems into four categories, viz., oligotrophic less than 0.01 mg/l, mesotrophic between 0.01 and 0.03 mg/l, eutrophic more than 0.03-1.0 mg/l and greater than 1.0 mg/l hypertrophic. Nitrogen is a main constituent of organic matter of both the plant and animals. Some of the bacteria fix atmospheric nitrogen into usable form (nitrate and ammonium ions) for plants by nitrification, ammonification reactions. Plants mainly utilize nitrogen mainly in form of nitrate and ammonium ion (Millero, 2001). Some bacteria convert nitrate back to nitrogen gas under anaerobic conditions when soluble organic matter is present. Denitrification is one of the main ways by which nitrogen is lost from water and soil.

Nitrogen is also known as limiting factor similar to phosphorous in a number of water bodies and play major role in some lake ecosystems (Moss, 2001; Maberly et al., 2003). Nitrogen in water ecosystem enters from a number of natural sources, such as dissolution of minerals from rocks (in very small amount), the dead decaying parts of flora and fauna, waste products from aquatic life within the water, urine and faeces of wild life in the catchment. Anthropogenic sources of nitrogen into lakes and reservoirs are mainly discharge of untreated sewage waste (Sylvester, 1961) and industrial effluents, leachate from septic systems. Other sources may be wastes from poultry and livestock or oxides from fuel combustion. Similarly nitrogen can enter in to water reservoirs through atmospheric deposition by pecipitation, runoff, or groundwater (Wetzel, 2001). Nurnberg (1996) on the basis of nitrogen contents have classified the lake ecosystems into four categories, viz., oligotrophic less than 0.35 mg/l, mesotrophic between 0.35 and 0.65 mg/l, eutrophic more than 0.65-1.20 mg/l and >1.20 mg/l hypertrophic. Lentic and lotic water ecosystems are highly interrelated with respect to nitrogen and phosphorous cycling. Abdallah (2011) and Golterman (2004) have also studied the major role of phosphorous in biogeochemical cycles of an ecosystem. Nitrogen and Phosphorous are major nutrients, essential for growth of various macrophytes which keep on interchanging between sediment and overlying water column in shallow water bodies (Abowei and Sikoki, 2005).

Nutrients, mainly phosphorous and nitrogen emitting from various point and nonpoint sources are major contributors of eutrophication and degradation of water ecosystems (Ansari and Khan, 2006; Zhang et al., 2008). Increased concentrations of nutrients, over stimulate the growth of algae and aquatic plant (Glibert et al., 2001) which in turn cause change in physiochemical characteristics of water (increase odour, pH, turbidity and sometimes generation of toxins) (Gopalkrusna, 2011). Later on degradation of organic matter by various biological and chemical activities reduced the amount of dissolved oxygen in water body affecting normal functioning and survivality of aquatic life. Among phosphorous and nitrogen, phosphorus is the main reason for eutrophication as different forms of nitrogen are utilized by various biochemical process (Scarlatos, 1997). Small concentrations of nutrients (P and N) are generally acceptable but their increased concentration beyond normal inputs, however, can affect the species composition of wetland vegetation and cause other biological effects (Guntenspergen et al., 1985). Internal as well as external loading of nutrients in water ecosystem are major contributing factor in assessment of water quality of aquatic water bodies. Phosphorus accumulation in lake is mainly governed by sedimentation (Brzáková, 2003). Excessive and unsustainable use of catchment for various urban and agriculture activities was identified main factor that trigger the eutrophication process and sedimentation in lake (Soeprobowatet et al., 2012). The inflow of sewage with high organic matter from lake surroundings and nutrients from agricultural runoff causes significant degradation of water quality (Misra et al., 2001). Dumping of religious offerings into the lake during festive seasons cause an additional impact of water quality (Dhote et al., 2001). Also nutrient status of the water ecosystem is highly dependent on sediment and water interaction which ultimately affect the productivity (Sharma and Sarang, 2004). Sediment chemical properties and microbial activities, likely play an important role in phosphorus release rates in the sediment–water interface.

Excess input of nutrients in surface water bodies (lakes, rivers and ponds) deteriorate the quality of water and interfere with recreational uses of lakes and adversely affect the biodiversity of that region. Nutrient loading of Bhindawas wetland is mainly due to nitrates and phosphate, two major nutrients which are responsible for choking several lakes to death due to excess growth of algal blooms and consequently depleting dissolved oxygen level (Upadhyay et al., 2013). The major nutrient inputs to a water body generally are wastewater discharges, land runoff, the atmosphere (precipitation and dry fallout), and ground water (principally nitrogen) (Rast and Lee, 1983).

Internal and external nutrient loading both contribute in significant amount of nutrients by wetland itself and various point and nonpoint sources near or in vicinity of wetland. Internal nutrient loading may be due to release of nutrients back into circulation from sediments of wetland especially phosphorous which may be due to decreased level of dissolved oxygen at bottom. Phosphorous can also be released from wetland sediments at high pH without oxygen depletion. Faecal contamination and secretion by some fish species (Black clam-intensive fish population in Finland shallow lakes) are also responsible for internal loading.

External nutrient loading may be due to release of nutrients from specific (point) and nonspecific (non-point) sources. Point source may be some urban community, factory, fish farm which can be measured and controlled easily. Whereas nonpoint source being wide and highly unspecific eg. large cultivated areas and forests, are highly difficult to measure, control, and manage. Results based on non-point sources can, however, be regarded only as suggestive, because quantity of Phosphorous and nitrogen received from the agricultural land (non-point source) differs greatly by year depending on frequency, duration and intensity of rainfall in watershed. The most significant source of nutrient loading to the surface water is observed non-point source loading from the agricultural areas (Helminen et al., 1998). Due to bidirectional movement of material between sediment and the wetland water, determining in internal nutrient loading is more difficult than external nutrient loading. Another sign of internal loading is if the phosphorus content in the water increases during the growing season and low inflow. Other mechanism causing internal loading of phosphorous in water body may be wind induced resuspension, bioturbation (microbial activity) and gas convection. The results indicate that of the human activities especially scattered settlement contributes significantly to the phosphorus loading, whereas forestry has only a minor impact on the loading.

Sediments having physical, chemical and biological components are usually subjected to changes by various environment factor. Pollution due to Phosphorous is considered to be the main reason for Lake Eutrophication as phosphorus input into the water system continues even after decreasing the external load (Song et al., 2006; Sondergaard et al., 2003). Nutrient enrichment (Eutrophic condition) in fresh water with abundance macrophytes growth usually resulted by internal loading of phosphorus released from sediments, rich in organic materials (Wetzel, 2001). Jeppessenger et al. (2001) also stated that re-suspension of sediments in water bodies doubles the process of phosphorous release in water column. A number of researchers (Marsden, 1989; Søndergaard et al., 2003; Jeppesen et al., 2005; Gao et al., 2005) documented that internal nutrient loading may delay lake recovery for long time periods even after reduction in external inputs of phosphorous and also affect lake trophic status. Phosphorus released from the sediment during anaerobic conditions along with H_2S and NH_4, whereas NO_3 is denitrified into N_2. Nitrogen to phosphorus ratio, greater than 14:1 determined phosphorus limiting condition (Perrone et al., 2008). Carlson (1977) developed a unique numerical classification method for classification of trophic status of the lakes. El-Serehy et al. (2018) performed quantitative assessment of trophic status index, trophic level index and WQI of lake Timsah and confirmed eutrophic conditions and bad or unsuitable water quality of lake with respect to TSI, TLI and WQI respectively. Harikrishnan and Aziz (1989) investigated ecological status of Neyyar reservoir in Kerala and found maximum concentration of phosphate during monsoon. Romero et al. (2002) during his study revealed that phosphorus is major limiting nutrient which affect the algal growth. Ecological study of the largest tropical lake, Chapala in Mexico was done by Lind and Lind (2002) and observed high turbidity and nutrient content in lakes resulting stable state of large phytoplankton biomass. Eutrophication and climate change have been known leading causes of the ecological transformations in Lake Victoria (Johnson et al., 2000; Verschuren et al., 2002).

Although various methods are used to classify lake but trophic state is one of the best method which determine the nutritional status of a water system. In past various trophic status indices were identified by researchers Carlson, 1977; Shannon and Brezonik, 1972 and Reckhow, 1980. Among them Carlson (1977) Index is widely used and higly reliable method based on three simple water quality parameters, TP, Chl-a and transparency. Also various studies related to trophic status of Indian aquatic system was done by (Sheela et al., 2011); Upadhyay et al. (2012) and Zbierska et al. (2015) evaluated the trophic status of the lake Niepruszewskie based on the nutrients concentration (nitrogen and phosphorus) and various eutrophication indicators viz. chlorophyll-*a*, water transparency secchi disk and found eutrophic or hypertrophic state of the lake due to increased concentrations of the nutrients. Cunha et al. (2013) studied the trophic state index for tropical/subtropical reservoirs (TSItsr) as well as limits for TP and Chl-a concentrations for six trophic levels: ultraoligotrophic, oligotrophic, mesotrophic, eutrophic, supereutrophic and hypereutrophic.Use of the TSItsr in other studies is encouraged to confirm its suitability for tropical/subtropical freshwaters. Salas and Martino(1991) proposed a simplified model for total phosphorus and a classification criteria for t rophic state of warm-water tropical lakes and reported upper limits for various trophic states (oligotrophic, mesotrophic and eutrophic status) with respect to the geometric means of TP and Chl a values and revealed that their classification method was more appropriate to determine the trophic status of seven lakes in Southeastern Brazil in comparison to that derived from the Carlson index (Petrucio et al., 2006). For controlling the eutrophication in lakes, extent of sediment phosphorus recycle is critical (Mayer et al., 2006). Elmaci et al. (2009) evaluated the trophic status of lake Uluabat, Turkey based on nutrient ratios and Carlson's trophic state index values with respect to TP, SD and Chl-a and found lake Uluabat an eutrophic system. Previous study related to trophic status assessment of Bhindawas Lake, Haryana, India has also been conducted by Saluja and Garg (2017) and stated hypereutrophic status of lake due to high concentration of phosphorous. Rahmati et al., 2011 carried out study on Marzanabad, a shallow wetland located in southwest (SW) of Babol city in north of Iran by using Carlson Trophic State Index (TSI) for determining trophic status. Various environmental variables were determined and compared with the TSI in order to determine the the water quality based on the studied parameters, it was found that lake has high tropic level. Population densities of human, livestock and land use pattern have strongly influenced the nutrient loading (N and P) to the various water resources viz. rivers, lakes, and oceans throughout the world (Omernik, 1977; Reckhow et al., 1980; Jones et al., 1984; Cole et al., 1993; Howarth et al., 1995, 1996; Smith et al., 1997). Brodersen et al. (2001) and Jonasson (2003) stated that during growth seasons, lake Esrom remained nitrogen limited for long time period and nitrogen and phosphorous was strongly correlated with each other. Sagrario et al. (2005) in his studies, demonstrated that value of nitrogen above 1.2-2 mg NL^{-1} and phosphorus value above 0.1 - 0.2 mg PL^{-1} cause turbidity and growth of submerged macrophytes, supported with increased phosphorous concentration but decreased nitrogen values (below 1.2 mg NL^{-1}) whereas Nitrogen concentration beyond 1-2 mg NL^{-1} limited the growth of submerged macrophytes.

Aquatic plants (macrophytes) are known significant primary producers in wetlands and have important link between the sediment, water in wetlands, lakes and rivers (Wetzel et al., 1994). Being primary producers, they also perform various ecosystem processes such as element cycling, biomineralization, material transformation, transpiration and sedimentation, release of biogenic trace gases into the atmospheres (Carpenter and Lodge, 1986). The rate at which the sun's radiant energy is converted into organic food by various photosynthetic and chemosynthetic activities of producers (phytoplankton, algae and macrophytes in water) is known primary productivity (Odum, 1959). Increased production rate provide appropriate raw matter for formation of other life forms. Primary productivity is known potential index of productivity for a number of diverse ecosystem throughout the world (Wetzel, 2001). Phosphorous and nitrogen, both are known primary limiting nutrients, affecting productivity (Bridgham et al., 1996) and responsible for variation in structural and functional attributes of wetland during their increased assimilative capacity (Carpenter et al., 1998). Study related to productivity, biological factors of the wetlands, their exploitation, physiochemical and productivity status was done by Vass (1989). Some bogs, Cypress domes are wetland having less nutrients usually support rare plant species (Keddy, 2000) and species of plants incompetent to plants of higher nutrient wetland (flood-plain wetland, tidal marshes). Brylinsky (1980) reported higher productivity rate in tropical waters than temperate waters. In tropics, Upper limit was observed around 11gC/M2/day, which is three times as compared to rate of primary production ion temperate lake, which rarely increased by 3gC/m2/day (Talling, 1965). Most lakes in the world are shallow with plenty of light and nutrients – and should therefore be among the most productive aquatic systems on earth (Tranvik et al., 2009). Seasonal variations in nutrients availability and transparency in in context of primary productivity of high altitude tropical lake, Tana, Ethiopia was observed by Ayalew et al. (2007).

Productivity of a water bodies showed seasonal and geographical variations and influenced mainly by availability of nutrients and various physiological factors, temperature, transparency and available sunlight (Khatri, 1984; Vijaykumar, 1994).

Plants distribution, species composition (submerged plants) and their productivity are influenced mainly by various factors viz. lattitude, availability of sun radiations, season, temperature varying water depth (Barko et al., 1986; Jylha et al., 2004; Dar et al., 2014). Sultan et al. (2003) during his study stated that physico-chemical factors induced high rate of productivity in natural and cultural ecosystems. Temperature is known as other major factor affecting productivity in water bodies. Sreenivasan (1964) also reported the increased production rate during high temperature. Also nutrients availability help in controlling primary production of water ecosystem (Qasim, 1972; and Nair and Thampy, 1980). Harikrishnan (1993) determined availability of higher amount of sun radiations during pre-monsoon and post-monsoon are favourable for high primary productivity in Edava-Nadayara estuary.

The need for primary productivity of an aquatic ecosystem is required to provide useful information related to productive nature and pollution status of water body (Thosar and Das, 1984). Vashistha and Paulose (2016) studied the trend in seasonal variations in primary productivity of Siliserh lake India and validated the fact that lake during winter and summer season show oligotrophic status but in monsoon due to excessive runoff of nutrients from surrounding agricultural fields reached eutrophic conditions. Last few decades, a number of Indian researchers, Sreenivassan, 1996; Pathak, 1979; Singh, 1998; Harikrishnan and Abdul, 2000; Shukla and Pawar, 2000; Mandal, 2002; Synudeen Sahib, 2002; Kumar and Singh, 2006; Hujare and Mule, 2007; Patil and Chavan, 2010; Koli and Ranga, 2011; Mishra et al., 2012; Barupal and Gehlot, 2014 have studied primary productivity of different water bodies. Mandal et al. (2005) determined the increase fluctuations in gross and net productivity of Karwar lake, Bihar from late winter to late summer with reaching peak values.

Wetlands generally known as Kidney of Catchment (Mitchell, 1994, and Mitsch and Gooselink, 1986) worldwide, and help in improving water quality by effective reduction of nutrient loads coming through various point and nonpoint sources. This property of wetlands makes them to use for treatment of domestic or industrial waste (Allinson et al., 2000). Last few decades, an intensive study was going on to determine the release of phosphorus and nitrogen load from lake sediments. Historically, more attention has received from researchers in context of phosphorus input due to its limiting nutrient status for productivity of plant species than nitrogen due to occurring of highly complex nature of various nitrogen transformation processes (Nowlin et al., 2005).

Shimizu et al. (2015) determined the nutrient loading (total nitrogen (TN) and total phosphorus (TP) by using the SWAT model into a hyper-eutrophic lake located in western Japan for 60 years with considering changes in land use pattern and the amount of domestic wastewater in the watersheds.

Large amount of nutrient load get their way into various lotic and lentic water bodies through catchment and tributaries. Surface run off from sub-basin having varying soil type, vegetation, slope, moisture is mainly responsible for phosphorous loading into the various water systems like streams and lakes. Sewage treatment plants and agricultural runoff also increase external nutrient load into water bodies from the catchment.

Fore and Grafe (2002) stated the alterations in soil pH, specific conductivity and available nutrients among other changes, may be indicative of wetland loading from agrochemical fertilizers and cattle wastes. A very few studies have been done on nutrient loading of lakes and wetlands. Tibebe (2017) studied the internal and external agrochemical load, dynamics and impact on the freshwater lake Ziway, Ethiopia and stated that the distribution of values of SRP, NO_3-N, NO_2-N and TN values in most of sampling sites and season were observed higher at top surface of sediments and successively decrease with depth of the sediment profiles. Also Carlson trophic state and Vollenweider models stated eutrophic status of lake Ziway. Water quality is highly influenced by internal nutrient loading in addition to external nutrient loading. Haggard et al. (2004) studied the trend of phosphorus flux in Lake Oklahoma and found that internal and external loading in lake from reservoir occur from bottom sediments and various external sources respectively. Phosphorous retention capacity in wetlands is governed by both biotic and abiotic processes (Nair et al., 2015). Biotic processes include phosphorous uptake by vegetation, plankton and microorganisms and abiotic processes incorporate sedimentation, adsorption on to soil surface, precipitation and exchange of P between soil and water column. As phosphorous is present in both organic and inorganic form in water bodies whereby process of mineralisation, organic P transfer into inorganic P, which is easily uptake by vegetation and assimilated into microbial biomass. Inorganic phosphorous is mainly bounded with sediment surface. Microbial and plant assimilation help in short term retention of phosphorous as well as removal of same from nutrient pool temporarily (Reddy et al., 1999).

But in last few decades it was observed that wetlands, used to abatement of nutrients load have become degraded and inefficient in nutrient management (Osborne and Totome, 1994; Chague-Goff et al., 1999) and source of water and air pollution (produce incomplete nitrogen transformation and release ozone depleting green house gas, N_2O (Machefert et al., 2002). Vollenweider (1968) found that increased anthropogenic pressures is responsible for high nutrient loading in most of the lake systems. Excessive amount of phosphorus (P) and nitrogen (N) to shallow lakes are mainly responsible for high macrophyte production, which after senescence increased nutrient concentration to both sediments as well as water column (Solim and Wanganeo, 2008). Generally nitrogen is found bounded with organic matter of sediments and high concentration of nitrate-nitrogen from water column is removed by macrophytes consumption and by denitrification as (Hunt et al., 2003) and A number of researchers also stated that successive addition of phosphorous by manmade sources not only cause enrichment of lake by external loading but over a long time period, release phosphorous into overlying water due to internal loading which is equally a matter of great concern for nutrient pollution in water bodies (Nurnberg, 2005).

Quality and quantity of water, both, highly depend upon the ecological integrity of water ecosystems viz. lakes, rivers and wetlands that must be protected and restored. Wetlands jurisdiction is diffused and falls under various departments like agriculture, fisheries, irrigation, revenue, tourism, water resources and local bodies with each department having its own developmental priorities. There is no separate policy or act for wetland management. In developing nations like India, fast growing population and unplanned urbanisation and developmental activities have taken their trolls on wetlands.

Now a days, wetlands have transformed into wasteland for short term economic gains at the cost of long term economic losses. On account of social and economic factors, wetlands are amongst the most threatened ecosystems with intensive exploitation of resources and high magnitude of degradation. Major causes for loss and degradation of wetlands are treatment of wetlands as dustbins, multiple demands on water resources by various sectors (agricultural, industrial, domestic and thermal power plants) and greed for land. To overcome unavoidable impacts to wetlands, periodic monitoring of wetland ecosystem is prime requirement. Monitoring plan needed for wetlands should include vegetation, water regime, and sediment and water quality. Proper management of wetlands require an understanding of ecological and scientific aspects of wetlands balanced with legal, institutional and economic realities. Advanced techniques along with effective conservation strategies by trained academicians and professionals including hydrologists, ecologists, geologists, economist watershed management expertise, planners and decision makers linked with local expertise is mainly required for proper and overall management of wetlands. For sustainable management of wetlands, environment, society and economics need to be integrated and above all public awareness about the significance of wetlands as major source base which would increase knowledge and understanding of wetlands and evolve more comprehensive and long term conservation and management strategies.

CHAPTER 3

MATERIALS AND METHODS

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3.1 Study Area

There is no wetland of International importance listed in the Ramsar Convention in the State of Haryana but some of them are of great value and of major ecological importance. Two wetlands namely, Bhindawas (Jhajjar) with wetland area 412 hectares and Sultanpur (Gurgaon) having area of 145 hectares are of national importance amongst many other small wetlands. Bhindawas wetland is a man made wetland of the gangetic plains and located at 28°32' North latitude and 76°32' East longitude in Jhajjar district of Haryana. It is a natural depression with manmade earthen impoundments around to store the stormwater and agricultural runoff. It gets water from rainfall (during monsoon) and mostly from excess spilling over from JLN Canal and drains its water into drain no. 8. Bhindawas wetland also collects water from the vast stretches of agricultural field of twelve villages namely a few Bhindawas, Redhuwas, Chhadwana, Nawada, Bilochpura etc. The water depth in lake actually ranges from 1 foot to 6 feet, and its water holding capacity has been enhanced with construction of earthen embankment all along its boundary. The lake serves as a buffer during floods and lean season/drought. Being a large wetland in Haryana and protected area it has emerged as a major habitat for native and migratory birds of about 250 species in the country. Due to reduced levels of water in Bharatpur bird sanctuary (Rajasthan) in last few years, Bhindawas wetland has gained increasing interest by migratory birds. After realizing environmental significance and ecological services, Bhindawas wetland was declared as a bird sanctuary in 1986 by MoEF, Government of India. Since then the wetland has emerged as an important ecological habitat and place of recreation, attracting a good number of tourists. At present Bhindawas Bird Sanctuary is facing a tremendous pressure of silting, excessive grazing, excess nutrients pollution and excessive growth of weeds.

In the current study Bhindawas wetland as a tropical wetland has been chosen as the study area. Seasonal and spatial variations in water and sediment quality at twenty locations within the wetland along with inlet and outlet have been selected for the study of various parameters.

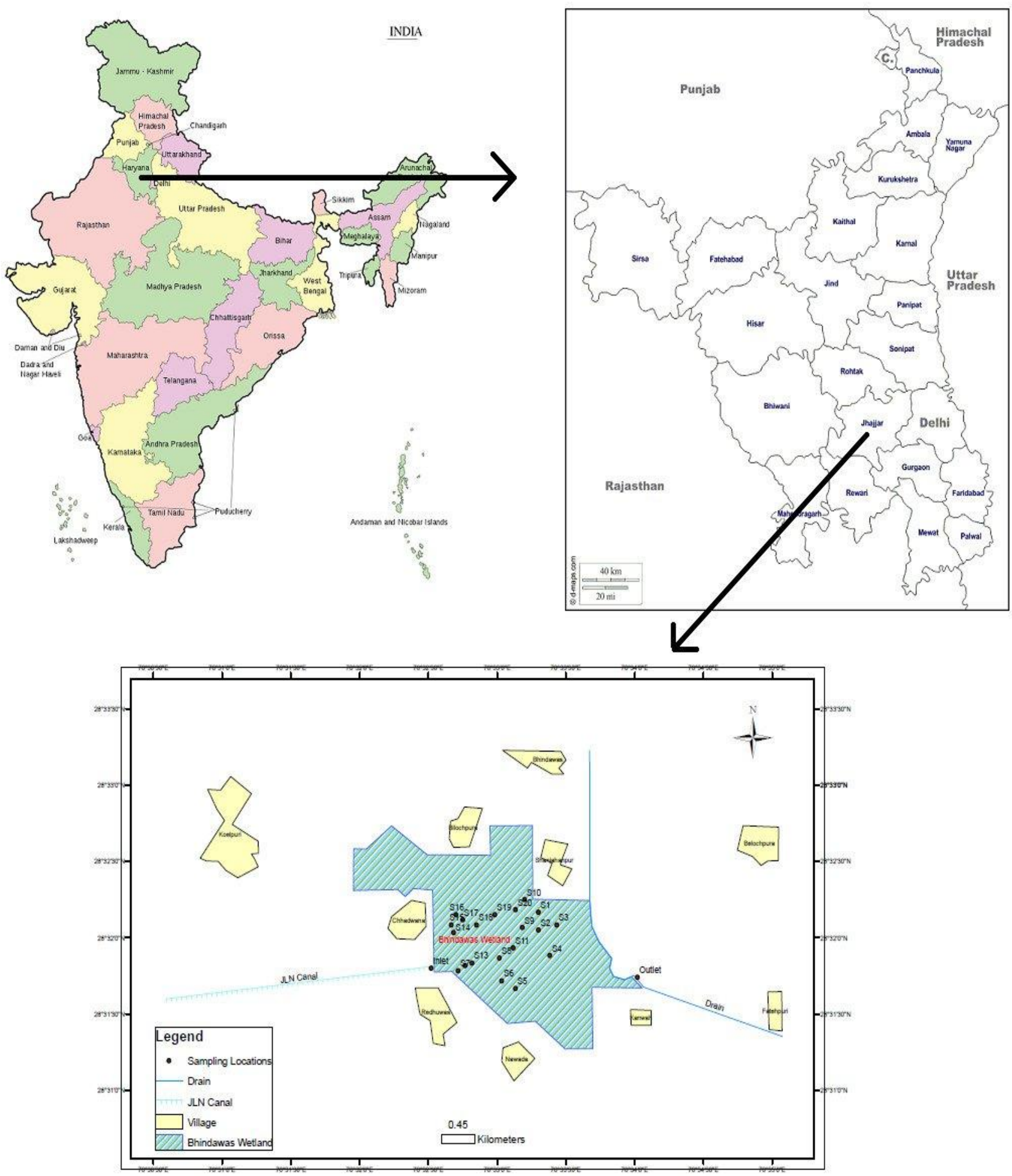

Figure 3.1. Sampling locations in Bhindawas Wetland

3.1.1 Climate and Rainfall

The climate of the Jhajjar district can be described as tropical steppe, semi-arid and hot which is characterized by extreme dryness of the air except during monsoon months. Hot summers, cold winters and scanty rainfall are major climatic characteristics of Jhajjar. The area experiences climate extremes from hot summer (March-June) to cold winters (January-March) with short monsoon period (June-September) and post-monsoon (October-December). The minimum and maximum temperature recorded is 7°C (January) and 43°C (May and June) respectively. Mean annual rainfall received is 444 mm (Department of Agriculture, Haryana).

Rainfall	
Mean Annual Rainfall	444 mm
Normal monsoon Rainfall	379.3 mm
Normal Rainy days	23
Temperature	
Mean Maximum	43^0C (May & June)
Mean Minimum	7 ^{0}C (January)

Mean minimum and maximum temperature are 9℃ (January) and 42℃ (May & June), whereas mean annual rainfall is 444 mm in the study area.

3.1.2 Geomorphology and Soil

The study area lies in the ndo-Gangatic alluvial plain ranging from Pleistocene to recent age Aeolian deposits. The district area in south western part possesses a very small hill and rest of the area is alluvial plain. Jhajjar district have elevation ranges from 212 to 222 m above mean sea level (MSL) with increased elevation (upto 276m above MSL) in the south-western region as compared to north zone by 0.48 m/km of slope. Natural drainage system is absent and generally the area is drained by main drain No.8 of the district.

The soils of the district are classified as arid brown (solonized) and sierozem. In north eastern part Jhajjar district, soil is observed fine to medium textured consisting sand to sandy loam covering areas of Bahadurgarh and nearby Jhajjar. And in southern eastern parts of district, pale reddish brown coloured clay was found.

3.1.3 Agricultural Activities

Bhindawas wetland is situated at the centre of a number of villages. Water of this wetand is mainly utilized for irrigation of agricultural fields and domestic purposes in these villages. Agriculture is main occupation for the people of this area. Due to surrounded by large vegetation and agricultural fields, Bhindawas wetland gained excess water during floods and water contaminated from agricultural fields with large number of pesticides, fertilizers and nutrients. All these compounds are responsible for degradation of water quality of Bhindawas wetland. Excessive nutrients input in wetland water from agricultural runoff have made the ater quality questionable.

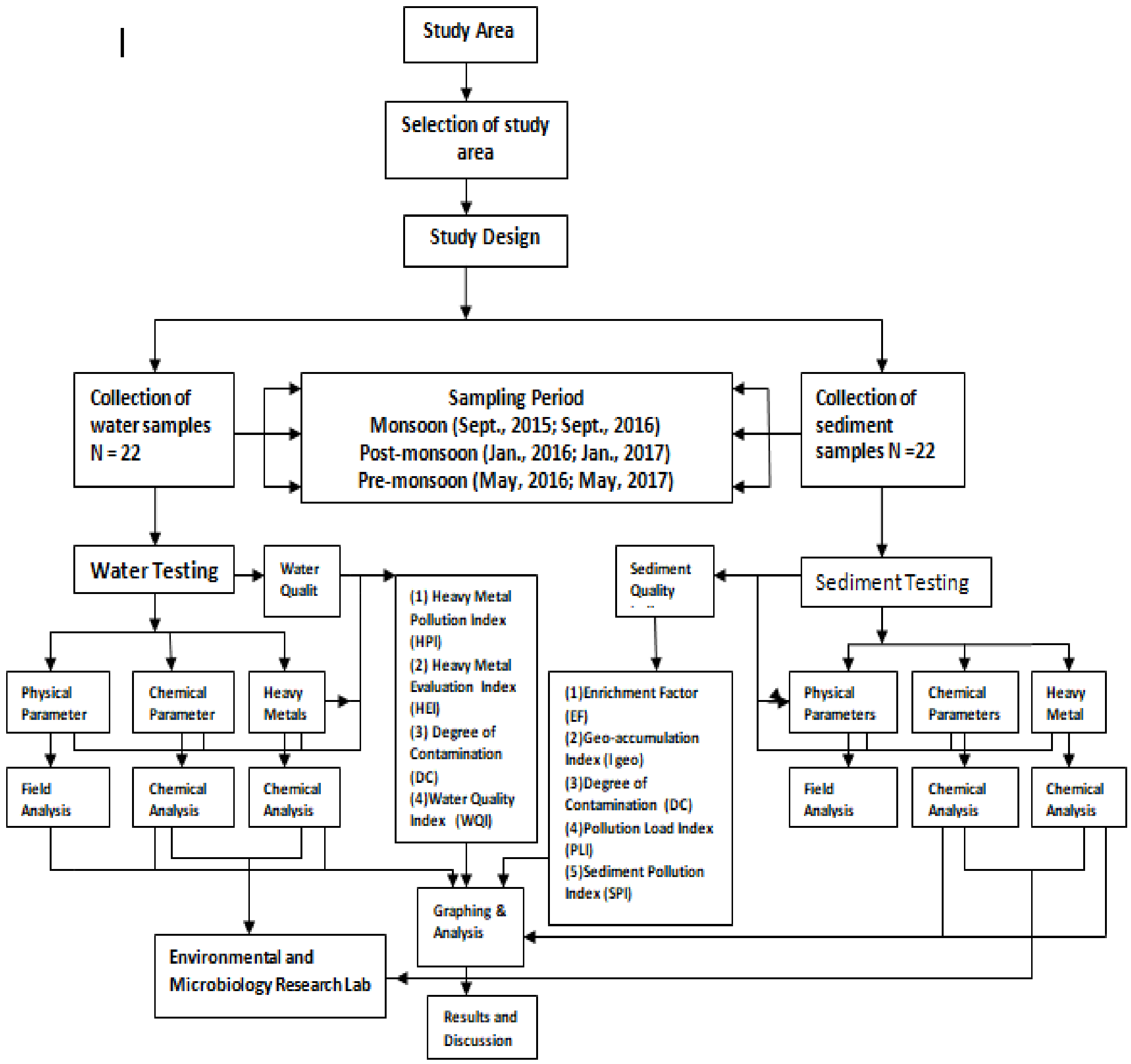

Figure 3.2 Flow diagram showing the overall methodology.

3.2 Collection of Water Samples and Storage

In order to determine the spatial variation of water quality, the wetland was divided into grids of equal size. Twenty (20) representative samples of water were collected from each grid. Besides this, two samples from wetland inlet (JLN Canal) and outlet (Drain No. 8) were also taken from wetland area in three different seasons, monsoon (September), post-monsoon (January) and pre-monsoon (May) at an interval of four months for two successive years (September, 2015 to May, 2017). Twenty sites from S1 to S20 were selected from wetland, Si from inlet, so from outlet and details of all sampling sites have been given in Table 3.1. For analysis of various physicochemical characteristics of collected water samples from wetland were done with different analytic methods (Table 3.2).

Table 3.1 Sampling sites in Bhindawas Wetland

Sr. No.	Sampling Sites	Latitude	Longitude
1	Inlet	28°31'47	76°32'29
2	Outlet	28°32'6	76°33'9
3	S1	28°32'17	76°33'32
4	S2	28°32'3	76°33'18
5	S3	28°32'5	76°33'32
6	S4	28°31'17	76°33'32
7	S5	28°31'40	76°33'8
8	S6	28°31'43	76°33'2
9	S7	28°31'47	76°32'43
10	S8	28°31'52	76°33'1
11	S9	28°32'4	76°33'11
12	S10	28°32'15	76°33'22
13	S11	28°31'56	76°33'7
14	S12	28°31'49	76°32'46
15	S13	28°31'50	76°32'49
16	S14	28°32'2	76°32'41
17	S15	28°32'5	76°32'40
18	S16	28°32'9	76°32'59
19	S17	28°32'7	76°32'45
20	S18	28°32'57	76°32'51
21	S19	28°32'9	76°32'59
22	S20	28°32'11	76°33'8

Various parameters like, Dissolved Oxygen (DO), Temperature, hydrogen ion concentration (pH) and total dissolved solids (TDS) were measured at field between time duration of 10 a.m. to 2 p.m. Clean reagent bottles were used for collecting surface water samples and kept in ice box at 4^0 C temperature and transported immediately to laboratory for analysis of other parameters. All the samples were analysed according to standard methods as prescribed by American Public Health Association (APHA 2005).

3.3 Analysis of Water

Table 3.2 Analytical methods for physiochemical characteristics of surface water samples in Bhindawas wetland.

Parameters	Unit	Methods/ Instruments
Temperature	°C	Conductivity Meter (Orion (USA)* 320A+ model)
pH		Potentiometric (Hanna Digital meter)
Electrical Conductivity (EC)	µS/cm	Conductivity Meter (Orion (USA)* 320A+ model)
Total Dissolved Solids (TDS)	mg/l	Conductivity Meter (Orion (USA)* 320A+ model)
Total Suspended Solids (TSS)	mg/l	Gravimetric Method
Dissolved Oxygen (DO)	mg/l	Electrode Method (Orion (USA)* 320A+ model)
Biological Oxygen Demand (BOD)	mg/l	5 days Incubation at 25°C
Chemical Oxygen Demand (COD)	mg/l	Open Reflux (Potassium dichromate Method)
Chloride (Cl^{-})	mg/l	Titrimetric (Mohr Method)
Bicarbonate(HCO_3^-)	mg/l	Titrimetric
Total Hardness	mg/l	Titrimetric (EDTA Method)
Cations (Na^+, K^+, Ca^{2+})	mg/l	Flame Photometer
Total Phosphate (TP)	mg/l	UV-VIS Spectrophotometer (Stannous Chloride Method)
Nitrate-N (NO_3^-)	mg/l	UV-VIS Spectrophotometer (Brucine Sulphanilic Acid)
Ammonia (NH3)	mg/l	UV-VIS Spectrophotometer (Nessler's Reagent)
Sulphate (SO_4^{2-})	mg/l	UV-VIS Spectrophotometer (Barium Chloride Method)
Dissolved Organic Carbon (DOC)	mg/l	NDIR Spectroscopy (TOC Analyser, Analytik-jena Multi N/C-2100)
Heavy Metals (Cd, Cr, Cu, Fe, Ni, Pb, Zn)	mg/l	Atomic Absorption Spectrophotometer (Analytik Jena Nova 350)
Total Kjeldhal Nitrogen (TKN)	mg/l	TKN Assembly (Total Kjeldahl Nitrogen Method)
Chlorophyll Content	mg/l	UV-VIS Spectrophotometer (80 % Acetone Method)

3.3.1 Physical Parameters

Temperature

Water temperature of all sampling sites of Bhindawas wetland were measured by using Orion (USA)* 320A+ model + multiparameter and noted in ° C.

Electrical Conductivity (EC)

Electric conductivity was determined by using Orion make Star A320 model multiparameter. Before analysing water samples, firstly EC electrode was calibrated with standard KCl solution (1413 μS/cm). The values observed from the multimeter was noted and expressed in μS/cm.

Total Dissolved Solids (TDS)

Total dissolved solids were determined in all samples with the help of multimeter Orion (USA) make Star 320 model and noted in mg/l.

Total Suspended Solids (TSS)

Total suspended solids were determined by gravimetric method by filtering water sample of 50 ml through a pre weighed Whattmann filter paper of pore size, then again weighing the filter paper after drying all water in oven at 105° C for 24 hrs. Filter papers are made of glass fibres which are used for TSS measurements. Dry weight of suspended particles presents in water increased the weight of filter paper and expressed in mg/l.

$$\text{TSS (mg/l)} = \frac{(\text{Wo}-\text{Wi}) \text{ x } 1000}{\text{V}} \quad (3.1)$$

Where, Wo represents final filter paper weight; Wi is initial filter paper weight and V is sample volume (50 ml) filtered.

3.3.2 Chemical Parameters

Hydrogen ion concentration (pH)

Digital pH meter (HANNA) was used to determine pH of water samples. Before analysing of all samples, calibration of pH meter was done with buffer solutions of pH strengths, 4.0, 7.0 and 9.2.

Dissolved Oxygen (DO)

Dissolved oxygen in surface water samples was determined at field with the help of DO multimeter Orion (USA)* 320A+ model.

Chemical Oxygen Demand (COD)

Chemical oxygen demand of water samples was determined with the help of dichromate method through open reflux process. Strong oxidising reagent ($K_2Cr_2O_7$ + Conc. H_2SO_4). sample, potassium dichromate and concentrated H_2SO_4 was taken in 1:2:3 ratios. 5 ml sample was taken in test tube with 10 ml of $K_2Cr_2O_7$ and 15 ml of COD acid (5gm $AgSO_4$ per litre). A pinch of $HgSO_4$ was added to remove the hinderance of chloride ions. Then samples were digested at 140℃ for two hrs. After cooling, samples were titrated with FAS with 0.01 normality. Calculations for COD were done by using formula:

$$\text{COD (mg/l)} = \frac{(A-B) X\ N\ X\ 8\ X\ 1000}{Vs} \quad (3.2)$$

Where, A = Blank Test value, B = Volume of FAS consumed, N = Normality of Ferrous Ammonium Sulphate (FAS) Solution (0.01N), Vs = sample volume (5 ml).

Anions (Chloride, Bicarbonate, Phosphate, Nitrate and Sulphate)

Chloride (Cl^-)

Chloride in water samples was determined by Mohr titration method by using silver nitrate as titrant. 10 ml sample volume was taken in conical flask and after adding 2-3 drops of indicator (pottasium chromate) samples were titrated against standard $AgNO_3$ solution to obtain end point with brick red colour. Chloride concentration was determined using the formula:

$$\text{Chloride(mg/l)} = \frac{N\ x\ V\ x\ 35.5\ x\ 1000}{Vs} \quad (3.3)$$

Where, N represents normality of $AgNO_3$ (0.01 N); V is volume of titrant ($AgNO_3$) used (ml); and Vs, sample volume (10 ml).

Bicarbonates (HCO_3^-)

Bicarbonate (HCO_3^-) in water sample was determined by titrating 10 ml sample volume with standard solution H_2SO_4 by the formula:

$$HCO_3^- \text{ (mg/l)} = \frac{\text{B x N x Eq.Wt.of HCO3}- \text{ x 1000}}{\text{Vs}} \quad (3.4)$$

Where, B is the volume of titrant consumed; N, normality of titrant (H_2SO_4); Vs represents sample volume (10 ml), Equivalent weight of HCO_3^- = 61

Phosphate (PO_4^{3-})

Total phosphate in water samples were determined by stannous chloride method. A stock solution of 100 ppm was prepared from using salt potassium dihydrogen phosphate (KH_2PO_4). Standard solutions of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5 ppm was prepared from stock solution. For converting bound state phosphate into free form or organic phosphate into inorganic form add 1 ml of acid solution (1 ml H_2SO_4 + 3ml HNO_3) into 10 ml of sample in conical flask and heat the solution until it boils. After that cool the solution and add one drop of phenolphthalein indicator and add 6N NaOH till colour changed from colourless to pink. Now note down increased volume and calculate dilution factor. Now take equal sample volume (10 ml) in each test tube and added 0.4 ml of Ammonium Molybedate solution into sample, pink colour disappeared. Now add one drop of stannous chloride and mix properly and blue colour developed and intensity of developed blue colour was measured at 690 nm by using UV-VIS Spectrophotometer.

Nitrate (NO_3^-)

UV-VIS Spectrophotometer was used for estimation of nitrate in water samples by using Brucine Sulphanilic Acid. By using stock solution of 100 ppm prepared from KNO_3, standard solutions of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 ppm were prepared 10 ml sample from each locations was taken in 50 ml test tubes and 1 ml Brucine sulphanilic acid was added into it . After that 10 ml of nitrate acid (60 ml H_2SO_4 + 40 ml Distilled Water) was added into each test tubes and kept the test tubes in dark for 25 minutes. After 25 minutes 10 ml distilled water was added into each test tube and mixed the solution properly. Yellow colour developed. Further solution was transferred into glass cuvette and intensity of colour was measured at 410 nm wavelength in UV- VIS Spectrophotometer.

Sulphate (SO_4^{2-})

Turbidimetric method (Barium Chloride method) was used to estimate the sulphate content in collected samples. By using stock solution, standard solution of 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 ppm were prepared from Na_2SO_4. 1 ml of conditioning agent is added in 10 ml of each sample and after that 1ml of HCl is added and stirred continuously to get turbid solution. Pour that turbid solution in glass cuvette cell and measured the absorbance at 420 nm by using UV-VIS Spectrophotometer.

Cations (Sodium, Na^+; Potassium, K^+; Calcium, Ca^{2+} and Magnesium, Mg^{2+})

Sodium (Na^+), Potassium (K^+) and Calcium (Ca^{2+}) cations were determined by using Flame photometer. Standard solutions of 10, 20, 40, 60, 80, 100 ppm were made using stock solution. By using these standard solutions, standard graph was prepared by following standard methods (APHA 2005).

Magnesium concentration in water samples was calculated from volume of titrant (EDTA) used in estimation of both calcium and total hardness and calculated by formula:

$$Mg^{2+} \text{ (mg/l)} = \frac{(V1 - V2) \text{ x } 400.8}{Vs \text{ x } 1.645} \quad (3.5)$$

Where V_1 is EDTA used for total hardness (Ca + Mg) determination; V_2 is EDTA used for CaH determination; Vs = sample volume (10 ml).

Dissolved Organic Carbon (DOC)

Analytik-jena Multi N/C-2100 TOC analyzer was used to determine dissolved organic carbon (DOC) of water samples which is based on non-dispersive infra-red (NDIR) spectroscopy .For estimation of DOC, stock solution of 100 ppm was prepared from potassium hydrogen phthalate salt. By using stock solution, standard solution of 10, 20, 30, 50 ppm were prepared to form standard graph and determined DOC value at each sampling locations.

Total Hardness (TH)

Standard EDTA titration method was used for estimation of $CaCO_3$ hardness in surface water samples of wetland. 10 ml sample volume was taken in conical flask and after adding 1ml of ammonium buffer and pinch of Eriochrome Black T (EBT) indicator (powdered form), samples were titrated against standard EDTA solution (0.01 M) to obtain end point with blue colour and the formula used for calculation of total hardness is:

$$\text{TH (as } CaCO_3\text{) (mg/l)} = \frac{\text{M x V x M.W.x } 1000}{Vs} \quad (3.6)$$

Where, M represents molarity of EDTA solution (0.01M); V is volume of EDTA used; M.W. denotes molecular weight of CaCO3 (100) and Vs is sample volume (10 ml).

Calcium Hardness (CaH)

Calcium hardness of water samples were determined by titration against Standardized EDTA solution. 10 ml sample volume was taken in conical flask and 1 ml sodium hydroxide (NaOH) solution was added into sample. Further a pinch of mureoxide indicator (powdered form) was added into sample solution and titrated with 0.01 M solution of EDTA to obtain end point with purple colour. Formula used for determination of Calcium Hardness is:

$$\text{CaH (mg/l)} = \frac{\text{M x V x M.W.x 1000}}{\text{Vs}} \quad (3.7)$$

Where, M represents molarity of EDTA solution (0.01M); V is volume of EDTA used; M.W. denotes molecular weight of Calcium (40) and Vs is sample volume (10 ml).

Ammonia (NH_3)

Ammonia in water samples was determined by spectrophotometer by using Nessler's reagent. Stock solution of 100 ppm was prepared by using NH_4Cl salt and standard solutions of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5 ppm were prepared from stock solutions. 10 ml of each water sample in test tube, 1 ml Nessler's reagent was added after that one drop of EDTA solution was added and mixed properly. After 5-10 minutes, colour developed and intensity of colour was measured at 410 nm using UV-VIS Spectrophotometer.

Total Kjeldhal Nitrogen (TKN)

Nitrogen in water samples were determined by using steam distillation by Kjeldhal method. Distillation process is carried out by transferring 10 ml of water sample to reactor chamber along with 1ml of alkali mixture and started distillation. In steam distillation process, excess alkali liberates free ammonia from the solution. Distillate collected in a receiver containing excess boric acid indicator where ammonia is absorbed in it. Nitrogen is determined by the titration of distillate against 0.01 N HCl acid. Total Nitrogen is calculated by formula:

$$\text{TKN (mg/l)} = \frac{\text{V x N x 14 x 1000}}{\text{Vs}} \quad (3.8)$$

Where V = volume of HCl used, N = normality of HCl (0.01 N), Equivalent wt. of Nitrogen = 14, Vs = volume of sample taken (10 ml).

3.3.3 Heavy Metals

Collected water samples were analysed to determine the concentrations of various heavy metals, Cd, Cr, Cu, Fe, Ni, Pb, Zn in sediments with help of atomic absorption spectrophotometer Analytik Jena Nova 350. In this technique concentration of heavy metal is determined by measuring the absorption characteristics of radiation by the atomic vapour of the element. The major source of radiation is a hollow cathode lamp. Water samples investigated for heavy metals were filtered with Whattman filter paper 42 and acidified with Nitric acid (HNO_3). Standard solutions in optimum range were prepared for each heavy metal

(Cd, Cr, Cu, Fe, Ni, Pb, Zn) separately by their stock solutions. After that each standard was aspirated in turn into flame and absorbance was recorded. Calibration curve between absorbance and concentrations of standards were plotted and concentration of heavy metals in sediment samples was determined by using at respective wavelengths at 357.9 nm, 324.8 nm, 248.3 nm, 232.0 nm, 283.0 nm and 213.9 nm for cadmium, chromium, copper,iron, nickel lead and zinc respectively.

3.3.4 Chlorophyll Content

Chlorophyll content is determined by the 80 % acetone extraction method which was given by Arnon (1949). Followed by optical density of samples was determined by spectrophotometer at 663 nm and 645 nm for Chl- a and Chl- b respectively and chlorophyll was calculated by formula:

$$\text{Chl a (mg/l)} = (12.70 \text{ x O.D. } 663) - (2.69 \text{ x } 0.0645) \quad (3.9)$$

$$\text{Chl b (mg/l)} = (22.90 \text{ x O.D. } 645) - (4.68 \text{ x O.D. } 663) \quad (3.10)$$

$$\text{Total Chl (mg/l)} = (20.2 \text{ x O.D. } 645) + (8.02 \text{ x O.D. } 663) \quad (3.11)$$

3.3.5 Productivity

Photosynthesis results in production of green plant matter (productivity) with the production of oxygen proportionally. So oxygen production in water body will reflect or determine as a measure of productivity. Along with photosynthesis, respiration process also happens side by side, resulting in consumption of oxygen. So to measure this loss, it is required to calculate productivity. Productivity is determined in situ by the measurement of dissolved oxygen change in subsamples held in light and dark bottles.

For determination of productivity, two bottles were taken. Out of which one bottle made light proof by wrapping aluminium foil. These bottles will act as light and dark bottles. Now, collected sample of water from the middle of the upper half of water body and measure the DO (Oi). Now filled both dark and light bottles with same water sample and suspended both of these bottles in water body at depths corresponding to where water sample was taken. The time of exposure for these bottles will be either dawn to noon and noon to dusk.

At the end of exposure period, remove the bottles and measure the DO in each O_l and Od for light and dark bottles respectively. Productivity of water body is calculated by formula as given by Gaarder and Gran (1927):

$$Pn = O_l - O_i \tag{3.12}$$

$$Pg = R + Pn$$

$$Pg = (O_i - O_d) + (O_l - O_i)$$
$$= O_l - O_d \tag{3.13}$$

Daily Pg (mg $O_2L^{-1}day^{-1}$) = Pg x Length of photoperiod per day x water depth (m) /Length of exposure time

Daily Pg (mg O_2 $m^{-3}day^{-1}$) = Pg x Length of photoperiod per day x 10^3water depth (m) /Length of exposure time.

Where, Pn, Pg represent net photosynthesis and gross photosynthesis and O_i,O_d and O_l are initial, dark and light bottle respectively.

3.3.6 Trophic Status Index (TSI)

Trophic state index (TSI) was calculated using lograrithmic conversion of Secchi disk depth (SD) in meters, algal chlorophyll (Chl-a)in mg/l, and total phosphorus (TP)in mg/l according to equations given by Carlson (1977). The following equations can be used to compute the Carlson's TSI:

$$TSI\ (SD) = 60 - 14.41 \ln (SD) \tag{3.14}$$

$$TSI\ (Chl) = 9.81 \ln (Chl) + 30.6 \tag{3.15}$$

$$TSI\ (TP) = 14.42 \ln (TP) + 4.15 \tag{3.16}$$

$$CTSI = [(TSI\text{-}SD) + (TSI\text{-}Chl) + (TSI\text{-}TP)] / 3 \tag{3.17}$$

Where, SD is Sechhi depth (m), Chl is chlorophyll (mg/l), and TP is total phosphorus (mg/l). Where, TSI-SD = Trophic state index referenced to Secchi depth, SD = Secchi depth in meters, TSI Chl = Trophic state index referred to chlorophyll-a, Chl = chlorophyll (mg/l), TSI-TP = Trophic state index referred to total phosphorus, (TP) = total phosphorus (mg/l), while In = natural logarithm.

3.4 Collection of Sediments and Sample preparation

Fresh sediments were collected at 20 different locations within the wetland and from inlet and outlet. The surface sediment samples from the wetland are collected with the help of Ekmann dredge sampler. Soon After collecting the sediment samples, they are transported to the laboratory and spread for air drying, grind and passed through a 2 mm sieves before analysis. The sediment samples were studied for the Moisture content, pH, EC, major cations, Na^+, K^+, Ca^{2+} and Available phosphate (AP), Total Phosphate (TP), Percentage Total Organic Carbon (% TOC) and Percentage Organic matter (% OM).

Sample Preparation for TP, Major cations (Na^+, K^+, Ca^{2+}) and Heavy Metals in wetland sediment

To evaluate various parameters viz. TP, Na^+ ,K^+, Ca^{2+} and heavy metals (Cd, Cr, Cu, Fe, Ni, Pb, Zn), 200 mg oven dried sediment sample was taken in titration flask (100 ml volume). Now add 10 ml of 1:3 ratio (1 part H_2SO_4 and 3 parts HNO_3) acid solutions in each titration flask along with glass beads to avoid bumping. Now digest all the sediment samples on hot plate at temperature of 140 °C until colour changes from muddy brown to colourless/ white. Now made the volume 100 ml with distilled water to analyze the results for various parameters.

Sample Preparation for TKN

About 500 mg of sediment sample was weighed and placed into conical flask of 100 ml capacity. This was followed by the addition of 10 ml solution of K_2SO_4+H_2SO_4 solution. The samples were digested on the hot plate at 140 °C until digestion has completed (soil brown colour converted into colourless / white). After digestion cool samples and made the volume 50 ml in volumetric flask by adding deionised water.

3.5 Analysis of Sediments

Table 3.3 Analytical methods for physiochemical characteristics of sediment samples in Bhindawas wetland.

Parameters	**Unit**	**Methods/ Instruments**
Moisture Content	%	Gravimetric
pH		Potentiometric (Hanna Digital meter)
Electrical Conductivity (EC)	µS/cm	Conductivity Meter (Orion (USA)* 320A+ model)
Cations, Na^+, $K,^+$ Ca^{2+}	mg/kg	Flame Photometer
Available Phosphate (AP)	mg/kg	UV-VIS Spectrophotometer (Stannous Chloride Method)
Total Phosphate (TP)	mg/kg	UV-VIS Spectrophotometer (Stannous Chloride Method)
Total Khjeldal Nitrogen (TKN)	mg/kg	TKN Assembly (Total Kjeldahl Nitrogen Method)
Total Organic Carbon (TOC)	%	Titrimetric (Walkely and Black method)
Heavy Metals (Cd, Cr, Cu, Fe, Ni, Pb, Zn)	mg/kg	Atomic Absorption Spectrophotometer (Analytik Jena Nova 350)

3.5.1 Physico - chemical parameters

Moisture Content

Water content of sediment was determined by keeping sediment samples in hot air oven at 105◦C in pre weighed aluminium foil separately. After 24 hrs they were again weighed to determine moisture content by the formula:

$$\%\ \mathrm{MC} = \frac{(\mathrm{Wi} - \mathrm{Wf})\ \mathrm{x}\ 100}{\mathrm{Wi}} \tag{3.18}$$

Where, MC is moisture content, W_i is initial weight of sediment, W_f is final weight of sediment.

pH and EC

pH and EC of sediments were determined by mixing 1:5 ratio (20 g soil + 100 ml Distilled Water) soil suspension and stir for one hour at regular intervals. After that pH and EC were determined by using pH meter (HANNA) and conductivity Meter (Orion (USA)* 320A+ model).

Total Organic Carbon (%)

50 mg of dried sediment samples from different locations were transferred in separate Erlenmeyer flask of 500 ml capacity. 10 ml of 1 N $K_2Cr_2O_7$ solution was added into it and mixed properly. Then 20 ml H_2SO_4 is added. As the enormous amount of heat is generated during this process. So sample solution was allowed to cool to room temperature for 30 minutes. After that 50 ml Distilled water and 5 ml phosphoric acid is added in successive flasks. Afterwards, ferroin indicator was added and sample was titrated against ferrous ammonium sulphate solution (FAS) of 0.01 Normality. The colour changed from blue brown to greenish colour. Same procedure was followed with Blank. TOC was calculated by the formula:

$$\text{OC (\%)} = \frac{(\text{B} - \text{S})\text{x Nx } 0.003 \text{ x } 1000}{\text{Vo x Ws}} \quad (3.19)$$

Where, B represents volume of FAS used during Blank; S represents volume of FAS used during by sample; N is normality of titrant (Ferrous Ammonium Sulphate solution); V_o is volume of $K_2Cr_2O_7$ used; and W_s is weight of sediment sample in mg.

Total Organic Matter (%)

Percentage Total Organic Matter was determined by using formula:

$$\text{OM (\%)} = \text{\% } C_{org} \text{ x } 100/58 \quad (3.20)$$

Total Kjeldhal's Nitrogen (TKN)

Total nitrogen in sediments was analysed by using steam distillation method. In presence of In steam distillation process, excess alkali usually liberate free ammonia from the solution. Distillation process is carried out by transferring 10 ml of digested sample to reactor chamber along with 1ml of alkali mixture and started distillation. Distillate collected in a receiver containing excess boric acid indicator. Nitrogen is determined by the titration of distillate against 0.01 N HCl acid. Total Kjeldahl Nitrogen is calculated by formula:

$$\text{TKN (mg/kg)} = \frac{\text{V x N x } 14 \text{ x } 1000}{\text{V x Ws}} \quad (3.21)$$

Where, V denotes volume of HCl used; N is normality of titrant (HCl) (0.01 N); Equivalent Wt. of Nitrogen is 14; Vs and Ws represents sample volume and weight of sediment sample (500 mg) respectively.

Available Phosphate

Available Phosphate (AP) of sediments was determined by mixing 1:5 ratio (20 g soil + 100 ml Distilled Water) soil suspension and stir for one hour at regular intervals. After centrifugation, sediment sample at 5300 rpm for 10 minutes, supernatant is collected. Now take equal sample volume (10 ml) of supernatant in each test tube and added 0.4 ml of ammonium molybdate solution into sample. Now add one drop of stannous chloride and mix properly until blue colour developed and intensity of developed blue colour was measured at 690 nm by using UV-VIS Spectrophotometer.

Total Phosphate

Take 10 ml of prepared sediment samples (after digestion 3:1; HNO_3 : H_2SO_4) of different sampling sites in test tubes and add one drop of phenolphthalein indicator and add 6N NaOH till colour changed from colourless to pink. Now note down increased volume and calculate dilution factor. Now take equal sample volume (10 ml) in each test tube and added 0.4 ml of ammonium molybdate solution into sample, pink colour disappeared. Now add one drop of stannous chloride and mix properly and blue colour developed and intensity of developed blue colour was measured at 690 nm by using UV-VIS Spectrophotometer.

Sodium, Potassium and Calcium (Na^+, K^+, Ca^{2+})

Similar procedure was done for evaluating the Sodium (Na^+), Potassium (K^+) and Calcium (Ca^{2+}) concentrations with prepared sediment samples (after digestion 3:1;HNO_3:H_2SO_4) of wetland sediments by using Flame photometer.

3.5.2 Heavy Metals

Digested sediment samples were analysed to determine the concentrations of various heavy metals, Cd, Cr, Cu, Fe, Ni, Pb, Zn in sediments with help of atomic absorption spectrophotometer Analytik Jena Nova 350. In this technique concentration of heavy metal is determined by measuring the absorption characteristics of radiation by the atomic vapour of the element. The major source of radiation is a hollow cathode lamp. Standard solutions in optimum range were prepared for each heavy metal (Cd, Cr, Cu, Fe, Ni, Pb, Zn) separately by their stock solutions. After that each standard was aspirated in turn into flame and absorbance was recorded. Calibration curve between absorbance and concentrations of standards were plotted and concentration of heavy metals in sediment samples was determined by using at respective wavelengths at 357.9 nm, 324.8 nm, 248.3 nm, 232.0 nm, 283.0 nm and 213.9 nm for cadmium, chromium, copper,iron, nickel lead and zinc respectively.

3.6 Indices for Water Quality

Various water quality indices viz. heavy metal pollution index (HPI); heavy metal evaluation index (HEI); degree of contamination (C_d); and water quality index (WQI) were incorporated to define suitability of water for aquatic and irrigation use. Narrative and Numeric criteria (modified category) for aquatic and irrigation use was represented in Table 3.4 and 3.5 respectively.

Table 3.4 Narrative and Numeric criteria for Aquatic life.

	Modiefied Category						
Index	**Degree of pollution**	**September, 2015**	**September, 2016**	**Jan., 2016**	**Jan., 2017**	**May, 2016**	**May, 2017**
HPI	Low Medium High	< 50 50 – 100 > 100	< 50 50 – 100 > 100	< 25 25 – 50 > 50	< 25 25 – 50 > 50	< 30 30 – 60 > 60	< 40 40 – 80 > 80
HEI	Low Medium High	< 160 160 –320 > 320	< 160 160 –320 > 320	< 80 80 –160 > 160	< 90 90 –180 > 180	< 110 110–220 > 220	< 130 130–260 > 260
C_d	Low Medium High	< 150 150 –320 > 320	< 150 150 –300 > 300	< 75 75 –150 > 150	< 80 80 –160 > 160	< 100 100 –200 > 200	< 130 130 –260 > 260
WQI	Excellent Good Poor Very Poor Unsuitable	0-25 25-50 51-75 76-100 >100	0-25 25-50 51-75 76-100 >100	0-25 25-50 51-75 76-100 >100	0-25 25-50 51-75 76-100 >100	0-25 25-50 51-75 76-100 >100	0-25 25-50 51-75 76-100 >100

Table 3.5 Narrative and Numeric criteria for Irrigation Use.

	Modified Category						
Index	**Degree of pollution**	**September, 2015**	**Septemb er, 2016**	**Jan., 2016**	**Jan., 2017**	**May, 2016**	**May, 2017**
HPI	Low Medium High	< 1 1– 2 > 2	< 0.7 0.7– 1.4 > 1.4	< 1 1– 2 > 2	< 0.5 0.5– 1 > 1	< 0.3 0.3–0.6 > 0.6	< 0.6 0.6– 1.2 > 1.2
HEI	Low Medium High	< 2 2 – 4 > 4	< 0.5 0.5 –1 > 1	< 1.5 1.5 –3 > 3	< 2 2 – 4 > 4	< 0.2 0.2–0.4 > 0.4	< 0.3 0.3–0.6 > 0.6
C_d	Low Medium High	< -3 -3 –0 > 0	< -3 -3 –0 > 0	< -4 -4 –0 > 0	< -3 -3 –0 > 0	< -4 -4 –0 > 0	< -3 -3 –0 > 0
WQI	Excellent Good Poor Very Poor Unsuitable	0-25 25-50 51-75 76-100 >100	0-25 25-50 51-75 76-100 >100	0-25 25-50 51-75 76-100 >100	0-25 25-50 51-75 76-100 >100	0-25 25-50 51-75 76-100 >100	0-25 25-50 51-75 76-100 >100

3.6.1. Water Quality Index

WQI is known as thumbnail index of water quality and a depicted non-regulatory measurement index. For the very first time, Horton (1965) calculated and developed WQI in United States by selecting 10 most widely used parameters of water quality. Later, it was widely used in Europe, Africa and Asia. The assigned weight represented the significance of a parameter for a particular use and it had a major impact onto the index. In addition, the Brown group also created a fresh WQI comparable to Horton's index in 1970 (Brown et al., 1970; Tyagi et al., 2013) that was based on the weights of parameter. Later, different researchers and professionals have modified the Horton's WQI (Bhargava et al., 1983; Tiwari and Mishra, 1985; Dwivedi et al., 1997; Tyagi et al., 2013). WQI is being used by a number of researchers, scientists and policy makers to evaluate water quality of lakes, rivers, reservoirs as well as ground water in a number of countries.

WQI of Bhindawas Bird Sanctuary was determined by using the Weighted Arithmetic Index method given by Brown et al (1972). For calculating the WQI in the present study, total 21 parameters (namely Temperature, pH, total dissolved solids, total suspended solids, dissolved oxygen, chemical oxygen demand, chlorides, nitrate nitrogen, Ammonium nitrogen, phosphate, sulphate, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cu^{2+}, Fe^{2+}, Ni^{2+}, Pb^{2+}, Zn^{2+}) were considered. The quality rating (Qi) for each parameter (Qi) was calculated by using this expression:

$$WQI = \frac{\sum_{i=1}^{n} Wi\, Qi}{\sum_{i=1}^{n} Wi} \qquad (3.22)$$

Wi is the weighting factor calculated by using equation

$$Wi = K/Si \qquad (3.23)$$

K is known as proportionality constant and derived from Eq. 3.23

$$K = \frac{1}{\sum_{i=1}^{n} 1/Si} \qquad (3.24)$$

where Si is the standard value (WHO, 2011) of the water quality parameter. Quality rating (Qi) is further formulated as:

$$Qi = [\,(V a - V i\,)\,/\,(Vs - Vi\,)]\ x\ 100 \qquad (3.25)$$

where i represents water quality parameters, Va represents the value of parameter analysed, Vi represents ideal value of parameter analysed and V is zero except for pH and D.O. and V standard is recommended standard of corresponding parameter. Water quality was categorised as excellent (0-25), good (26-50), poor (51-75), very poor (76-100) and unsuitable (> 100) based on Water Quality Index (Chatterji and Raziuddin, 2002).

3.6.2 Calculation of Metal Contamination

Indexing concept helps in determining the status of water quality with respect to selected parameters. To investigate pollution level of the wetland due to different heavy metals, two major quality indices were used to evaluate metal pollution of Bhindawas wetland.

3.6.2.1 Heavy Metal Pollution Index (HPI)

HPI index helps in determining the water quality status of surface water with respect to various selected parameters. For calculating HPI, each chosen parameter is assigned a rating or weightage (Wi) which is an arbitrary value, lies between 0 and 1 and defined as inversely proportional to standard permissible values (Si) for each selected parameter. HPI is calculated by using following equation (Mohan et al., 1996):

$$\text{HPI} = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi} \qquad (3.26)$$

Where,HPI is heavy metal pollution index; n, number of parameters studied; Wi is unit weight of ith parameter and Qi denotes unit weight of sub index.
The following equation was used for calculation of Qi value :

$$\text{Qi} = \sum_{i=1}^{n} \frac{\{\text{Ci}(-)\text{Ii}\}}{\text{Si}-\text{Ii}} \, X\, 100 \qquad (3.27)$$

Where, Qi is quality rating; Ci is observed value of heavy metal analysed; Si is standard value of heavy metal analysed and Ii is ideal value of heavy metal. And the (-) sign shows the numerical variation between two values, neglecting the algebraic sign.

3.6.2.2 Heavy Metal Evaluation Index (HEI)

In Metal Index, the relative contamination of different metals was calculated and a single representative number is identified which is calculated by dividing sum of all the concentrations of heavy metals by sum of maximum allowable concentrations of each heavy metal studied. If the value of a metal is higher than its respective maximum allowable concentration value, it indicates the worse water quality. Bakan et al. (2010) stated that metal index value beyond 1 indicates signals for threshold warning. The MEI is determined by using the following formula (Edet and Offiong, 2002):

$$\text{MEI} = \sum_{i=1}^{n} \frac{\text{Ci}}{(\text{MAC})\text{i}} \qquad (3.28)$$

Where, HEI and Ci are heavy metal evaluation indexand the observed value of each heavy metal respectively and MAC indicates its maximum allowable concentration.

3.6.2.3 Degree of Contamination (C_d)

Combined effect of various water quality parameters is summarized in a single index called contamination index (Backman et al., 1997) and was calculated by formula:

$$\mathrm{Cd} = \sum_{i=1}^{n} \mathrm{Cfi} \qquad (3.29)$$

$$\text{Where, } \mathrm{Cfi} = \frac{\mathrm{Coi}}{\mathrm{Cni}} - 1$$

Where, C_{fi} is contamination factor of n number of samples, Coi, observed value while Cni represents normative value. Here, normative value is taken same as MAC value.

3.7 Indices for Sediment Quality

3.7.1 Enrichment Factor

Enrichment factor is an effective tool applied for determination of the magnitude of contaminants present in the environment. In this method, the metal concentrations are normalized as per the background values (either average crust or average shale values) of the earth's crust. But in the present study, average shale values were considered as background values. Background values for Fe, Pb, Cu, Cr, Zn and Ni was taken as 47200, 20, 45, 90, 95 and 68, respectively and for Cd background shale value were taken 0.3 (Turekian and Wedepohl, 1961). In most of the studies, researchers have used mainly Al and Fe as normalization factor as these elements are present in large and inactive state in earth crust, and these are chemically inert to the contaminants in their environment. So these are best suited to calculate or identifying the abnormal concentrations of other metals present in environment. In present study, Fe was used as normalization factor with value 9800. Best results were found out by using Fe as normalization factor due to its good solid surface and regularities of natural sediment concentrations (Birth, 2003) by a number of researches in their studies. The metal enrichment factor is calculated as follows:

$$\mathrm{EF} = (\mathrm{M}/\mathrm{M}_{\mathrm{Fe}})\mathrm{s} \,/\, (\mathrm{M}/\mathrm{M}_{\mathrm{Fe}})\mathrm{b} \qquad (3.30)$$

Where, EF represents enrichment factor; $(M/M_{Fe})s$ is the metal to Fe ratio in the samples selected and $(M/M_{Fe})b$ is average background values of metal to Fe ratio. EF values were interpreted and suggested by Sakan et al. (2009), where, EF < 1 indicates background concentration; 1-2, minimal enrichment; 2–5 is moderate enrichment; 5 - 20 is significant enrichment; 20– 40 is very high enrichment and > 40 is extremely high enrichment.

3.7.2 Contamination Factor (CF), Pollution Load Index (PLI) and Degree of Contamination (DC)

CF is used for evaluating the contamination level of a metal. PLI provide information regarding the area with respect to quantity of a component in the environment. DC gives the sum value of all the contamination factor for a given site. CF values are categorised as 1, 1-3, 3-6 and ≥ 6 indicating low , moderate , considerable and very high CF respectively. CF is calculated by:

$$CF = \frac{C\,m}{C\,b} \qquad (3.31)$$

Where, CF and Cm are contamination factor and concentration of metal. Cb is background concentration of metal in average shale.

$$PLI = (CF1*CF2*CF3\ldots\ldots\ldots CFn)^{1/n} \qquad (3.32)$$

Where, PLI, n and CF represent pollution load index; n, number of metals studied (7 taken here) and contamination factor respectively. Values of PLI > 1 show polluted and < 1 shows no pollution.

$$DC = \sum_{i=1}^{n} CFi \qquad (3.33)$$

Where, DC, n and CF represent degree of contamination, number of heavy metals and contamination factor respectively. DC is categorised as < n (low), n ≤ DC < 2n (moderate), 2n < DC < 4n (considerable) and DC > 4n (very high)

3.7.3 Geo-accumulation Index (I_{geo})

Geo-accumulation index is widely used for assessment of degree of contamination in sediments to determine pollution level. To determine the level of metal pollution in the sediments , the value of geo-accumulation index was calculated by following equation (Muller, 1969):

$$I_{geo} = \log 2\ \frac{C\,n}{1.5\,Bn} \qquad (3.34)$$

Where I_{geo} is geo-accumulation index, C_n is the observed concentration of metal in sediments and B_n is geochemical background value of element (Yu et al., 2011). And factor 1.5 is used as co-efficient as based on lithogenic effects which also help in minimizing the variations in the background values.

I_{geo} is categorised as $I_{geo} < 0$ (unpolluted), $0 < I_{geo} \leq 1$ (unpolluted to moderately polluted), $1 < I_{geo} \leq 2$ (moderately polluted), $2 < I_{geo} \leq 3$ (moderately to strongly polluted), $3 < I_{geo} \leq 4$ (strongly polluted), $4 < I_{geo} \leq 5$ (strongly to extremely polluted) (Varol and Sen, 2009).

3.7.4 Sediment Pollution Index (SPI)

Sediment Pollution Index (SPI) is an efficient method in overall assessment of sediment quality with respect to number of selected heavy metals. Being a multimetal assessment method, it determines relative metal toxicity. It is defined as sum of the metal enrichment factors by sum of metal toxicity weights. Metal toxicity weight depends on relative metal toxicity of studied heavy metals and inversely related to lithogenic limits of their average crust values. Different metals were assigned with different numbers like weight 1 to Cr and Zn which are less toxic, 2 for Ni and Cd, and 5 for Pb.

SPI can be calculated as below:

$$\text{SPI} = \frac{\sum(EFm\ x\, Wm)}{\sum Wm} \qquad (3.35)$$

Where, SPI and EF is sedimrent pollution index and enrichment factor,and Wm represents toxicity weight of metal m.

3.8 Statistical Analysis

3.8.1 Principal Component Analysis/ Factor Analysis

Factor analysis for surface water samples were computed by using Statistical Package SPSS-20. Principal Component Analysis and Varimax Rotation were major extraction method in the factor analysis for deriving factors.

3.8.2 Cluster Analysis

Cluster analysis is an important data reduction method, helps in classification of various entities with similar properties for cluster analysis by single linkage method. In this method the distance between the clusters was determined by the distance of the two closet objects in different clusters. Cluster analysis has been carried out by using SPSS version 25.

CHAPTER 4

RESULT AND DISCUSSION

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4.1 Land Use Land Cover

Using Google Earth historical imagery from 2015 to 2017, the area distribution within the Bhindawas Lake was carried out using polygon feature. Google Earth maps the Earth by the superimposition of images obtained from satellite imagery, aerial photography and geographic information system (GIS) onto a 3D globe. Most land areas are covered in satellite imagery with a resolution of about 15 m per pixel. As our study area was limited, the spatial resolution wasn't clear enough to sufficiently distinguish between green belt, algal growth, submerged /floating plants, and islands. Area distributing mapping of Bhindawas wetland was done during the study period from September, 2015 to May, 2017. It was observed that green belt remained almost permanent throughout the time period of study. Maximum percentage of water content in wetland was observed during post-monsoon (35.88%) in first year and in second year maximum percentage area (33.37%) was covered during monsoon by water. Islands are more prominent in pre-monsoon as compare to post-monsoon and monsoon season due to low water level. Maximum growth of vegetation was noticed in pre-monsoon during both year of study with percentage area covering 20.48% and 21.92% respectively. Also the agricultural field surrounding the wetland are major contributing non point source of increased nutrient concentration in surface water. Human activities especially scattered settlement in surrounding villages, contributes significantly to the nutrient loading (Phosphorous and Nitrogen), through storm water and untreated sewage waste disposal.

Table . 4.1 Area distributing mapping of Bhindawas Wetland (2015-2017).

LULC	**September, 2015**	**(%)**	**Jan., 2016**	**(%)**	**May, 2016**	**(%)**	**September, 2016**	**(%)**	**Jan., 2017**	**(%)**	**May, 2017**	**(%)**
Green Belt	180.90	44.01	194.50	47.32	194.50	47.32	194.50	47.32	194.50	47.32	194.50	47.32
Submerged /Floating Plant	128.10	31.17	58.00	14.11	84.19	20.48	74.50	18.13	78.10	19.00	90.10	21.92
Water	94.95	23.10	147.45	35.88	120.43	29.30	137.17	33.37	129.24	31.45	117.24	28.53
Islands	7.05	1.72	11.05	2.69	11.88	2.89	4.83	1.18	9.16	2.23	9.16	2.23
Total	411	100	411	100	411	100	411	100	411	100	411	100

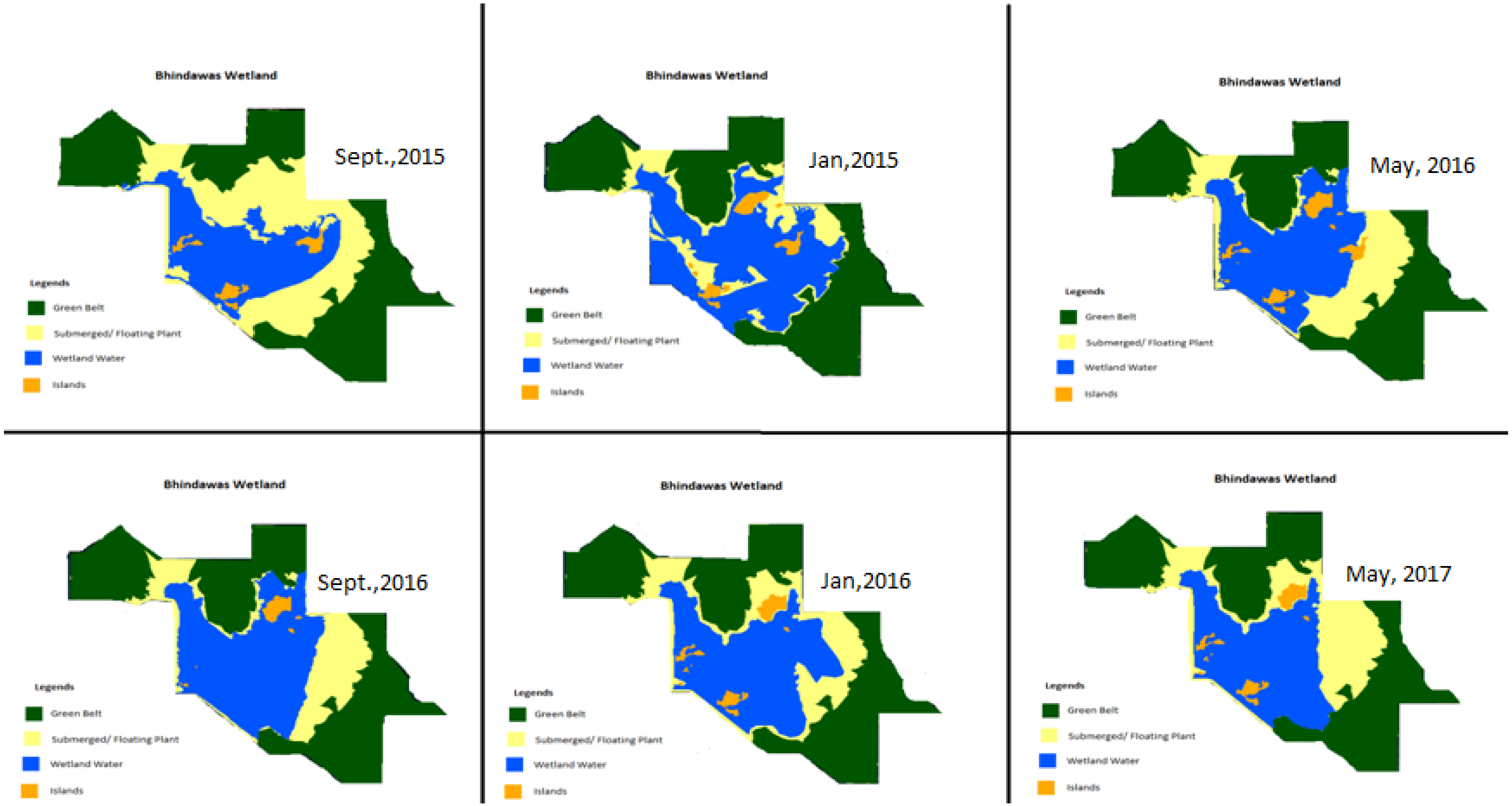

Figure 4.1 Land Use Land Cover Map of Bhindawas Wetland during study period (September, 2015- May, 2017)

4.2 Water quality Analysis

4.2.1 Physicochemical Parameters

Water quality assessment of Bhindawas wetland was performed with the help of detail study of various physico-chemical parameters *viz*. temperature, pH, EC, TDS, TSS, DO, ORP, BOD, COD, DOC, Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{-}, SO_4^{2-}, PO_4^{3-}, NO_3^{-}, NH_3-N, and TKN during the study period.

Spatial and Seasonal variations (September, 2015 to May, 2017)

In the present study physical and chemical characteristics of water samples were studied spatially and seasonally for the time period of two years, September, 2015 to May, 2016 (1st Year) and September, 2016 to May, 2017 (2nd Year) respectively, covering three major seasons i.e. monsoon, post-monsoon and pre-monsoon. The study for monsoon, post-monsoon and pre-monsoon season was carried out during September, 2015; January, 2016; and May, 2016 of 1st Year and September, 2016; January, 2017; and May, 2017 of 2nd Year, respectively. Analytical results of water quality with respect to various parameters with mean values and inlet and outlet concentrations were shown in Table 4.2 to 4.7 to highlight the difference in their concentrations at different locations during study period and Fig. 4.2 to 4.21 represented the comparision between various physicochemical parameters seasonally.

Temperature

Temperature plays a vital role to carry out various biochemical processes and known most important regulating factor in variety of ecosystems. Besides, it influences various physico-chemical characteristics and biological activities, directly or indirectly. During present investigation, the maximum water temperature (37.3°C) was noted at site S12 during May, 2016 and minimum (14.1°C) was recorded at S12 site in January, 2016. Both maximum (33.2°C) and minimum (13.7°C) value of water temperature was detected in outlet during May, 2016 and January, 2016 respectively. Maximum temperature was observed during pre-monsoon 33 ± 3.2 (2015-16); 35 ± 1.2 (2016-17) followed by monsoon 33 ± 0.5 (2015-16); 30 ± 0.4 (2016-17) and post-monsoon 16 ± 0.7 (2015-16); 17 ± 0.2 (2016-17) for two consecutive years. The main reason for increased temperature in pre-monsoon is long photo period with maximum solar radiation hours and decreased temperature in post-monsoon is lesser sun radiation hours. The similar results were supported by authors Sawhney (2004) and Murugan and Prabaharan (2012).

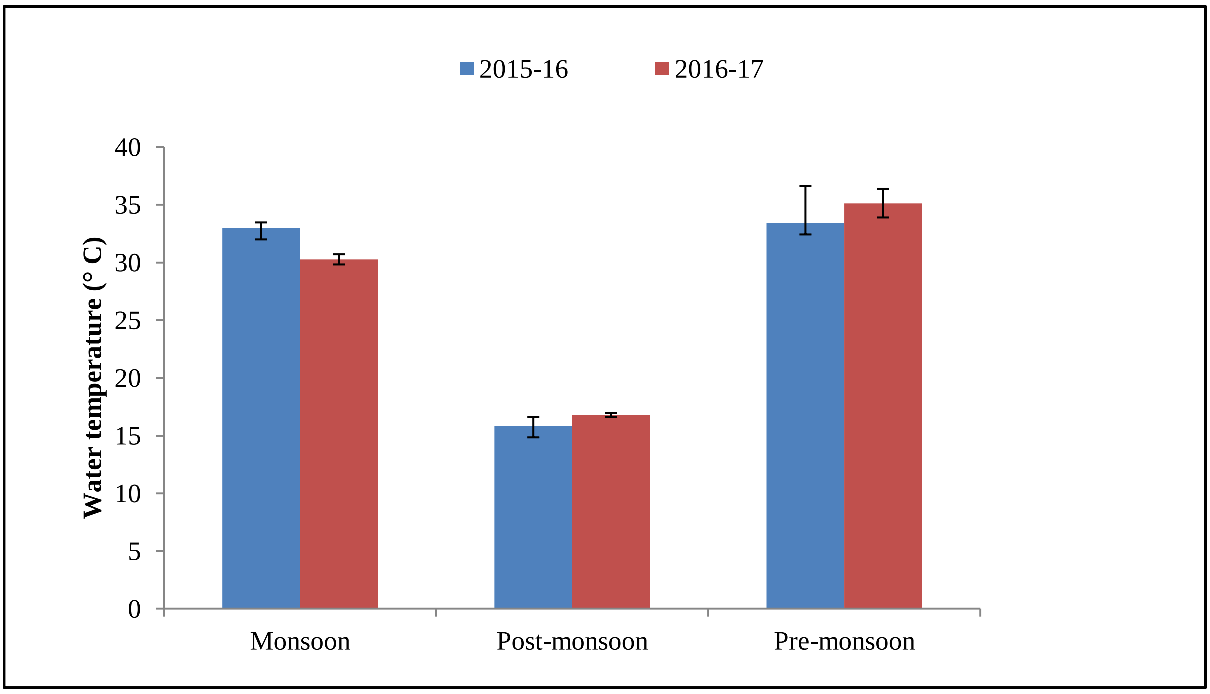

Figure 4.2 Seasonal variations in water temperature (°C) of Bhindawas wetland in different seasons for two successive years.

pH

pH value in Bhindawas wetland varied between 6.5 to 9.6 with minimum at sampling location, S18 and maximum at S11 during May, 2016 and September, 2015 respectively. Inlet and outlet possess significant difference in pH values with maximum (8.3) in inlet (January, 2016) and minimum (7.2) in outlet (September, 2016). The mean pH value of surface water during first and second year of monsoon was found 8.00 and 7.62 respectively which indicate slightly alkaline nature of surface water. pH value in wetland water has remained more or less uniform throughout the study period. This slight seasonal fluctuation in pH value can be attributed to the cumulative effect of CO_2 balance, temperature, release of ions during various chemical processes and buffering capacity of water. Generally, a low level of carbonates, bicarbonates and phosphates constitutes low buffering capacity of water (Agrawal, 1999). Depending upon season, maximum mean pH value was observed for the monsoon 8.00 ± 0.6 (2015-16) 7.62 ± 0.4 (2016-17) followed by post-monsoon 7.47 ± 0.2 (2015-16); 7.50 ± 0.18 (2016-17) and pre-monsoon 7.1 ± 0.3 (2015-16); 7.29 ± 0.2 (2016-17) for two consecutive years, which may be due to surface run off from agricultural fields containing inorganic salts. Similar trend for pH value was observed in monsoon for first year (7.98) and second year (7.62). The maximum pH value, 9.6 was observed at S11 in monsoon first year, which may be due to mixing of inorganic salts during rain fall and aerial fall out (Chandran and Ramamoorthi, 1984).

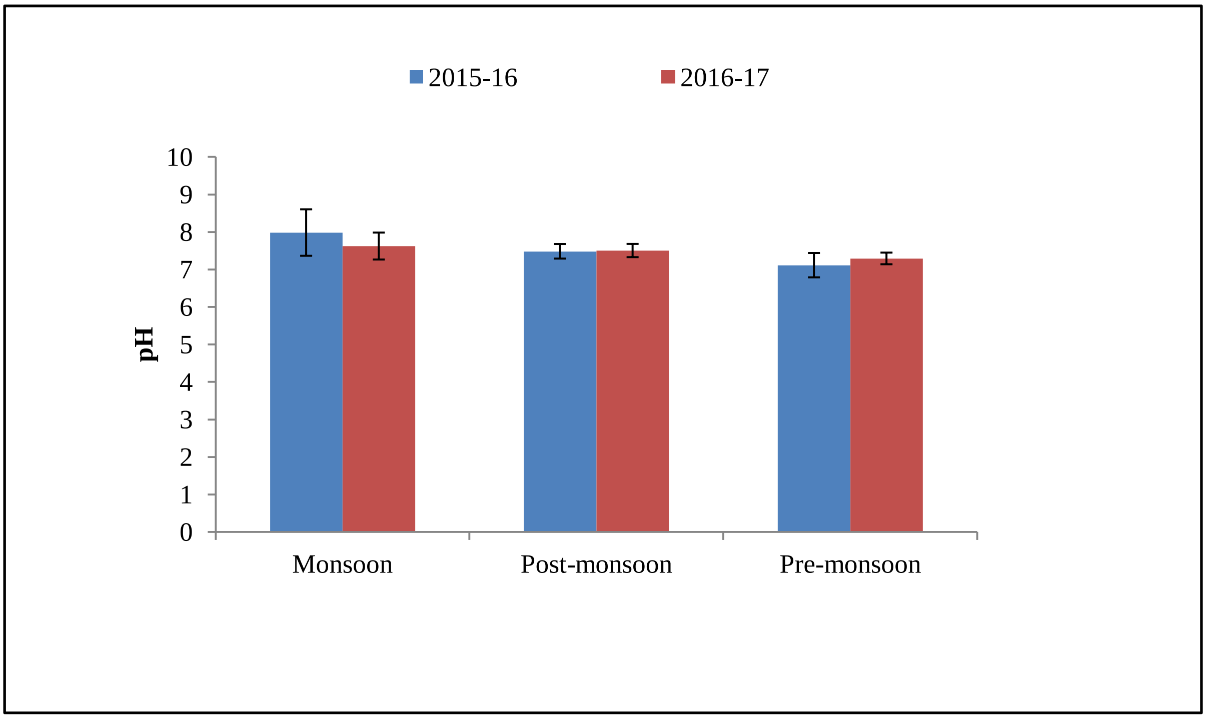

Figure 4.3 Seasonal variations in water pH of Bhindawas wetland in different seasons for two successive years

Electrical Conductivity (EC)

Minimum value of conductivity, 182 µS/cm was observed at sampling location S5 (January, 2016) and maximum, 690 µS/cm at S15 (May, 2017). Maximum and minimum conductivity was found in outlet and inlet during May, 2017 and January, 2016 respectively. During the study period, mean EC value fluctuated between 212 µS/cm to 613 µS/cm (Fig. 4.4) with maximum value in pre-monsoon 473 ± 26.2 (2015-16); 613 ± 41 (2016-17) followed by monsoon 392 ± 110.1 (2015-16); 277.4 ± 7.6 (2016-17) and post-monsoon 224 ± 79.4 (2015-16); 212 ± 5.1 (2016-17).

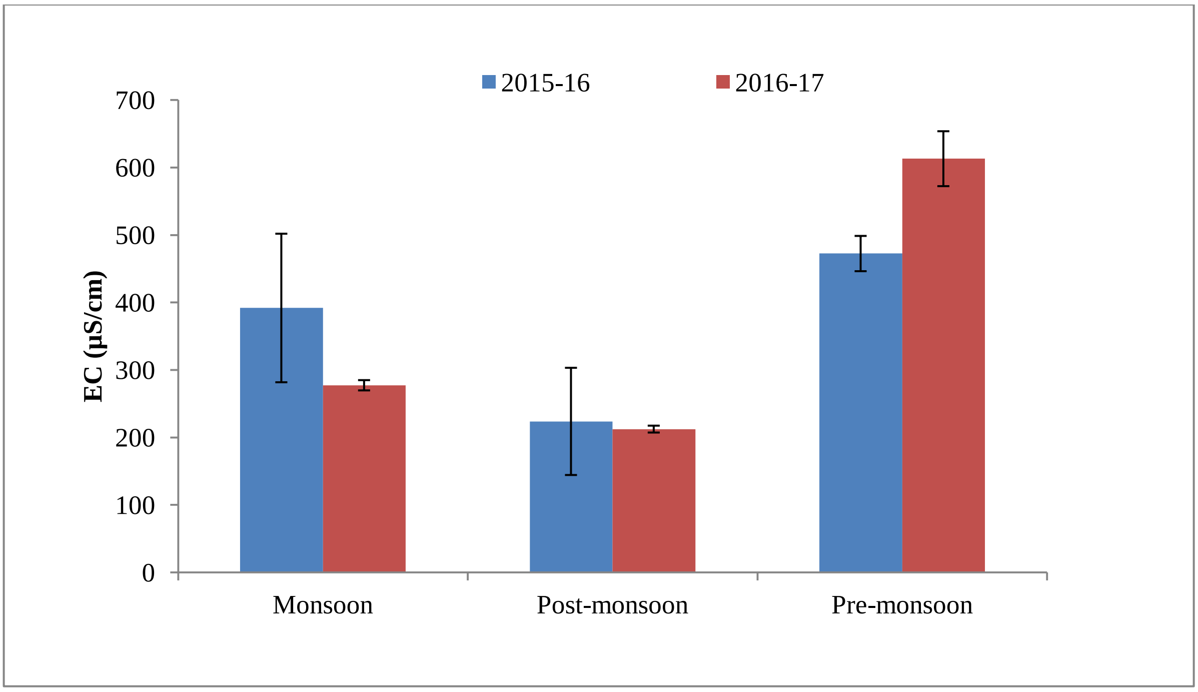

Figure 4.4 Seasonal variations in mean value (µS/cm) of electrical conductivity (EC) of Bhindawas wetland in different seasons for two successive years.

The highest value of conductivity during pre-monsoon season can be mainly due excessive evaporation of surface water in Bhindawas wetland which lead to more concentrate water with mineral and salts dissolved in water. The lowest value of conductivity in post-monsoon may be due to low decomposition rate of organic matter, due to lesser microbial activity at low temperature in cold environment and decreased ions input in wetland from surroundings agricultural land (Bhattarai, 2004).

Total Dissolved Solids (TDS)

Minimum values of TDS (86 mg/l) was observed during January, 2016 at sampling locations S12 and maximum value, 345 mg/l was found at S15 in May 2016. Maximum TDS value i.e. 341 mg/l was observed in outlet during September, 2017 and minimum values 87.8 mg/l was found in inlet in January, 2016. The mean TDS value during the study varied from 107 mg/l to 301 mg/l (Fig. 4.5). Seasonal variations for TDS was documented with decreasing mean concentrations from pre-monsoon 301 ± 21.45 (2015-16); 299 ± 26.7 (2016-17) to monsoon 234 ± 9.62 (2015-16); 238 ± 13.58 (2016-17) and followed by post-monsoon 112 ± 42.11 (2015-16); 107 ± 2.9 (2016-17). The high TDS value in pre-monsoon may be high evaporation rate of water mixed with municipal waste

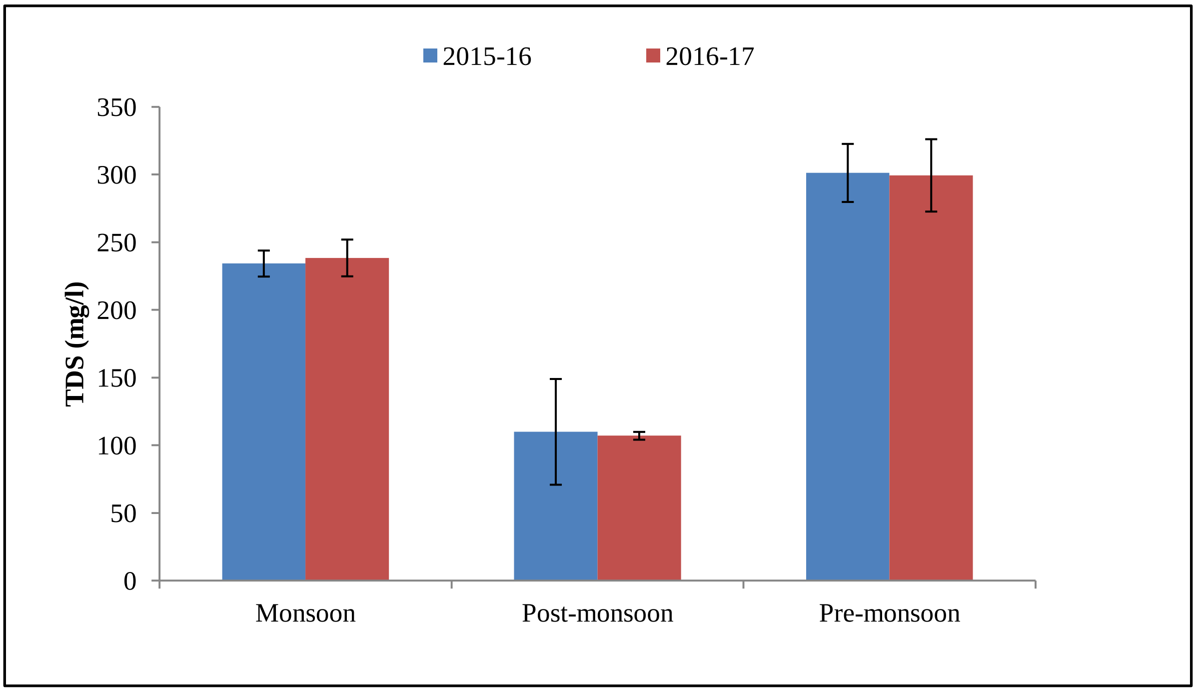

Figure 4.5. Seasonal variations in mean concentration (mg/l) of Total Dissolved Solids (TDS) in Bhindawas wetland in different seasons for two successive years.

water and fertilizers leaving dissolved inorganic salts and products of dead decaying vegetation. Similar results were obtained by Shib (2014) during study in Rudrasagar wetland, Tripura with maximum TDS value during pre-monsoon and minimum in post-monsoon. Sahni and Yadav (2012) also investigated similar results in Bharawas Pond, Rewari, Haryana.

Total Suspended Solids (TSS)

Present investigation during the study revealed that minimum concentration of TSS i.e., 86 66 mg/l was observed during January, 2016 at sampling location S20 and maximum values i.e. 692 mg/l was observed at S7 in September, 2016. Maximum TSS value, 212 mg/l was observed in outlet during September, 2016 and minimum (68 mg/l) was found in outlet during May, 2016. The mean TSS value of surface water during the study period varied from 244 mg/l to 534 mg/l (Fig. 4.6). The maximum value was observed to be high in monsoon 465 ± 111.6 (2015-16); 534 ± 82.2 (2016-17) followed by post-monsoon 309 ±169.67 (2015-16); 294.3 ± 125 (2016-17) and pre-monsoon 272 ± 59.17 (2015-16); 244 ± 146.43 (2016-17) for the two successive years. The reason for maximum concentration may be due to high precipitation rate resulting intermixing of both phases (water and sediments) majorly due to disturbance of bottom sediment layer below water column. Surface run off from catchment area containing inorganic salts and increased concentration of insoluble organic matter of sewage waste (Sakhare and Kamble, 2014).

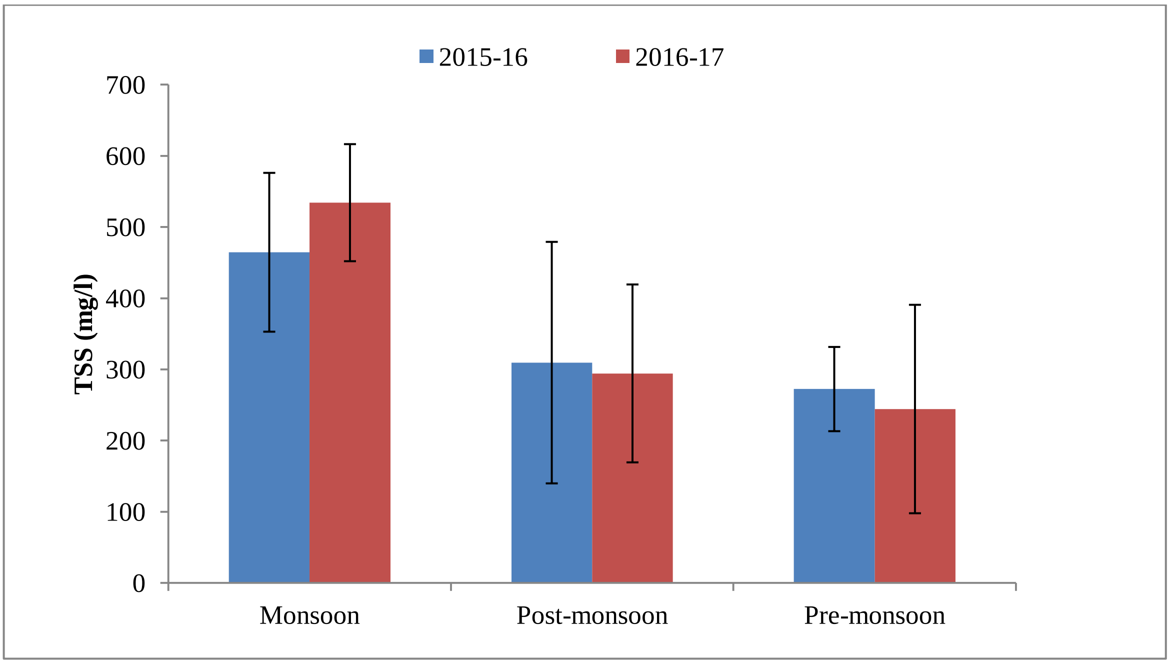

Figure 4.6 Seasonal variations in mean concentration (mg/l) of Total Suspended Solids (TSS) in Bhindawas wetland in different seasons for two successive years.

from residential areas located in surrounded villages are also major contributors of increased TSS concentration in wetland water. TSS concentration in post- monsoon is less as compared to monsoon due to settling of suspended particles thus making wetland water stabilized. Sharma et al. (2008) stated that high concentration of TSS causes negative impacts on various physicochemical and biological processes in wetland system viz. decreased transparency, increased water temperature, decreased photosynthetic activity and decreased DO.

Dissolved Oxygen (DO)

DO is one of the vital parameter which reflects the water quality and moreover it is the primary requirement for existence of life (plants and animals) in water. The DO value of < 10 indicates the water pollution due to organic impurities. DO value in Bhindawas wetland varied between 2.2 to 10.9 with minimum at sampling location, S18 and maximum at S13 during May, 2016 and September, 2015 respectively. Inlet and outlet possess significant difference in DO values with maximum (9.74) in inlet (September, 2016) and minimum

(3.95) in outlet (May, 2017). The mean value of DO in surface water during the study period was observed in range from 5 mg/l to 8 mg/l (Fig. 4.7). Depending upon season, maximum mean DO value was observed for the monsoon 8 ± 1.44 (2015-16); 7.4± 0.60 (2016-17) followed by post-monsoon 7 ± 0.73 (2015-16); 6.2 ± 1.44 (2016-17) and pre-monsoon 5 ± 1.29 (2015-16); 5.4 ± 0.8 (2016-17) for study of two consecutive years. Similar results were stated by Rajgopal et al. (2010) during study of two perennial ponds in Sattur Area, Tamilnadu. Increased DO value in monsoon may be due to aeration during rainfall and high oxygen solubility. The least DO concentration observed in pre-monsoon, which may be due to warm water with lower water holding capacity along with accelerated rate of oxidation in living and nonliving components demanding oxygen (Kumar et al., 2005). Temperature and DO in water is directly and indirectly related to each other (Chaurasia and Pandey, 2007).

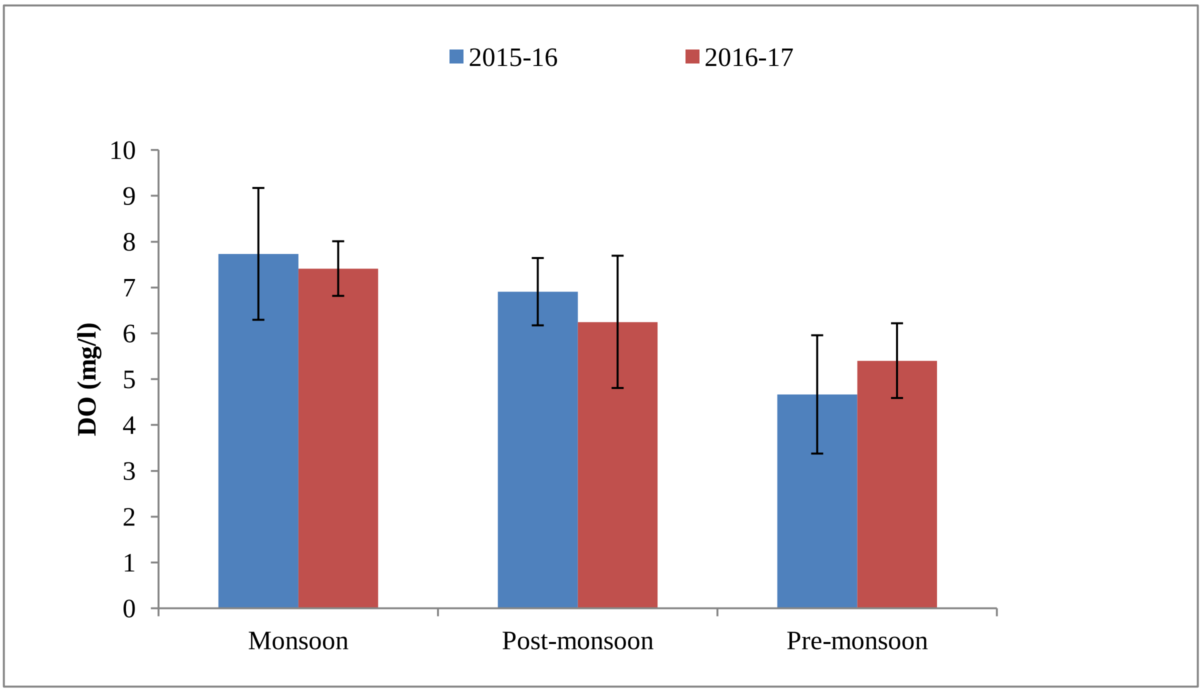

Figure 4.7 Seasonal variations in mean concentration (mg/l) of Dissolved Oxygen (DO) in Bhindawas wetland in different seasons for two successive years.

Biological Oxygen Demand (BOD)

Maximum BOD value, 7mg/l was observed at sampling location S19 during May, 2016 and minimum 0.1 mg/l was observed at sampling site, S3 during May, 2017. Maximum BOD (3.9 mg/l) concentration was observed in outlet during May, 2017.The mean value of BOD in surface water during the study period was observed in range from 0.9 mg/l to 3.4 mg/l (Fig.

4.8). The maximum value of BOD was observed to be high in pre-monsoon 3.4 ± 1.5 (2015-

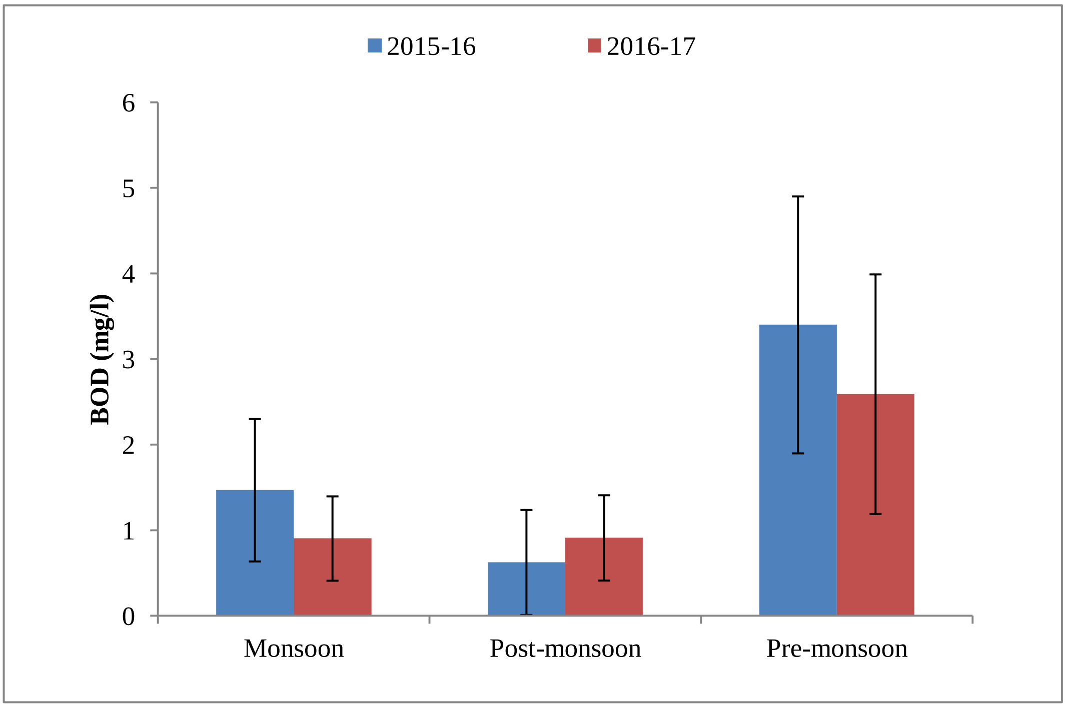

Figure 4.8. Seasonal variations in mean concentration (mg/l) of Biological Oxygen Demand (BOD) in Bhindawas wetland in different seasons for two successive years.

16); 2.6 ± 1.40 (2016-17) followed by monsoon 1.5 ± 0.83 (2015-16); 1.5 ± 0.49 (2016-17) and post-monsoon 1 ± 0.65 (2015-16); 0.9 ± 0.49 (2016-17) for the two years. Increased value in pre-monsoon may be attributed due to organic enrichment of wetland through degradation of decaying aquatic weeds and animal parts; increase in bacterial population due to high water temperature; increase in organic load and suspended solids; influx of sewage and increased concentration of fish faecal matter containing carbohydrates that are not digestible to fishes (Nudds, 2002, Adeyeye and Abulude, 2004). The lowest value of BOD was observed in the post-monsoon due to less vegetation and reduced microbial activity at low temperature.

Chemical Oxygen Demand (COD)

Maximum COD value was observed at sampling location S5, S9, S13 in May, 2017 Maximum COD (80 mg/l) concentration were observed in outlet during May, 2017 and minimum (18.4 mg/l) was found in inlet in September, 2015. The mean value of COD in surface water during the study period was observed in range from 24 mg/l to 60 mg/l (Fig. 4.9). The maximum value of COD was observed to be high in pre-monsoon 44 ± 10.4 (2015-

16); 60 ± 23 (2016-17) followed by post-monsoon 28 ± 8.3 (2015-16); 39 ± 14.5 (2016-17) and monsoon 24 ± 1.9 (2015-16); 27 ± 8.6 (2016-17) for the study of two successive years. Similar results were determined by Basavaraja and Kiran (2016) during study of physico-chemical parameters of Sagara Lake (Karnataka) during different seasons.

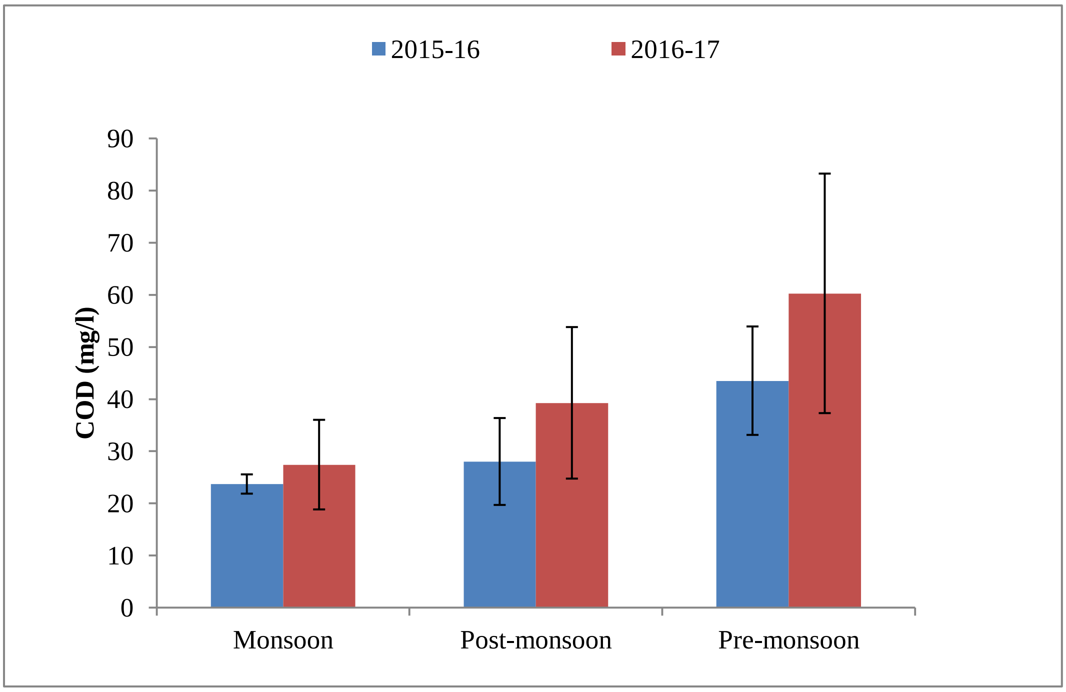

Figure 4.9 Seasonal variations in mean concentration (mg/l) of Chemical Oxygen Demand (COD) in Bhindawas wetland in different seasons for two successive years.

Mathur et al. (1991) stated that low COD value in monsoon may be due to washed off decaying and degradable plant debris as well as inorganic salts in heavy rain and flooding of wetland through waste influx from surrounding land. Similar trend for COD value was observed in monsoon for first year (23.68 mg/l) and second year (27.4 mg/l).

Dissolved Organic Carbon (DOC)

The mean DOC value of surface water during the study period varied from 17.5 mg/l to 61.7 mg/l (Fig.4.10). The maximum value was observed to be high in pre-monsoon 43 ± 8.8 (2015-16); 61.7 ± 4.25 (2016-17) followed by post-monsoon 25 ±1.8 (2015-16); 37.4 ± 2.45 (2016-17) and monsoon 17.5 ± 5.55 (2015-16); 28.6 ± 2.09 (2016-17) for the two years, which may be due to surface run off containing organic waste.

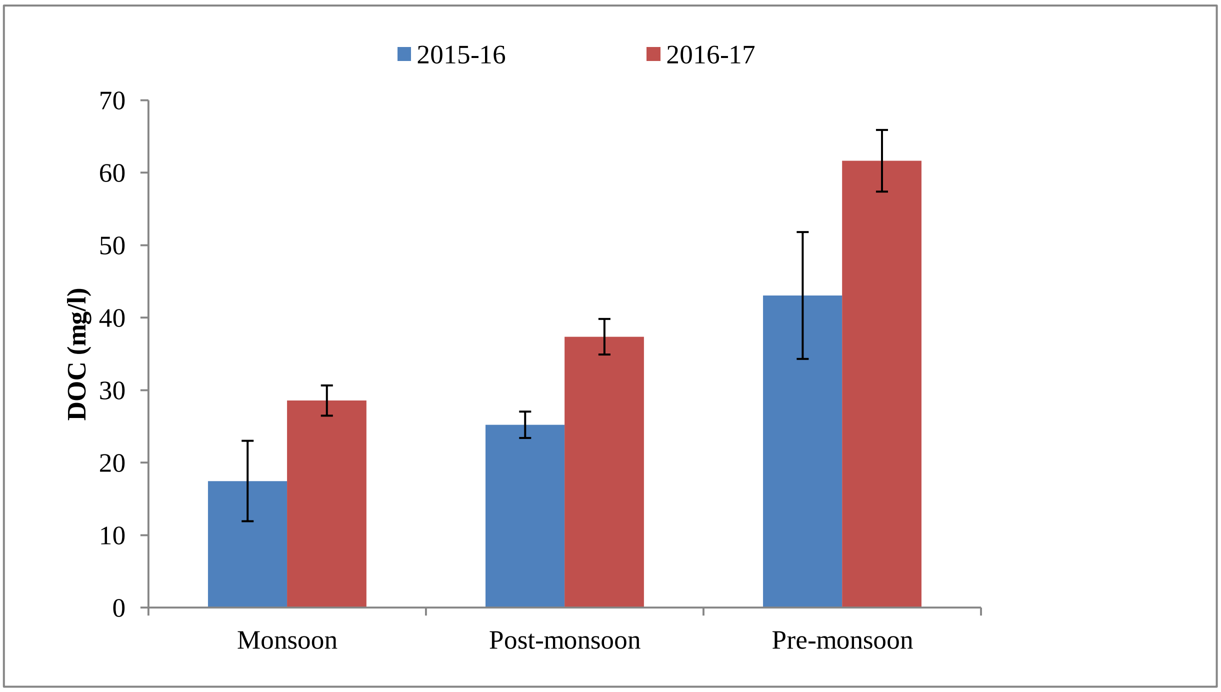

Figure 4.10 Seasonal variations in mean concentration (mg/l) of Dissolved Organic Carbon (DOC) of Bhindawas wetland in different seasons for two successive years.

Cations (Na^+, K^+, Ca^{2+} and Mg^{2+})

Among major cations, Na^+, K^+, Ca^{2+} and Mg^{2+} were observed with maximum mean values,

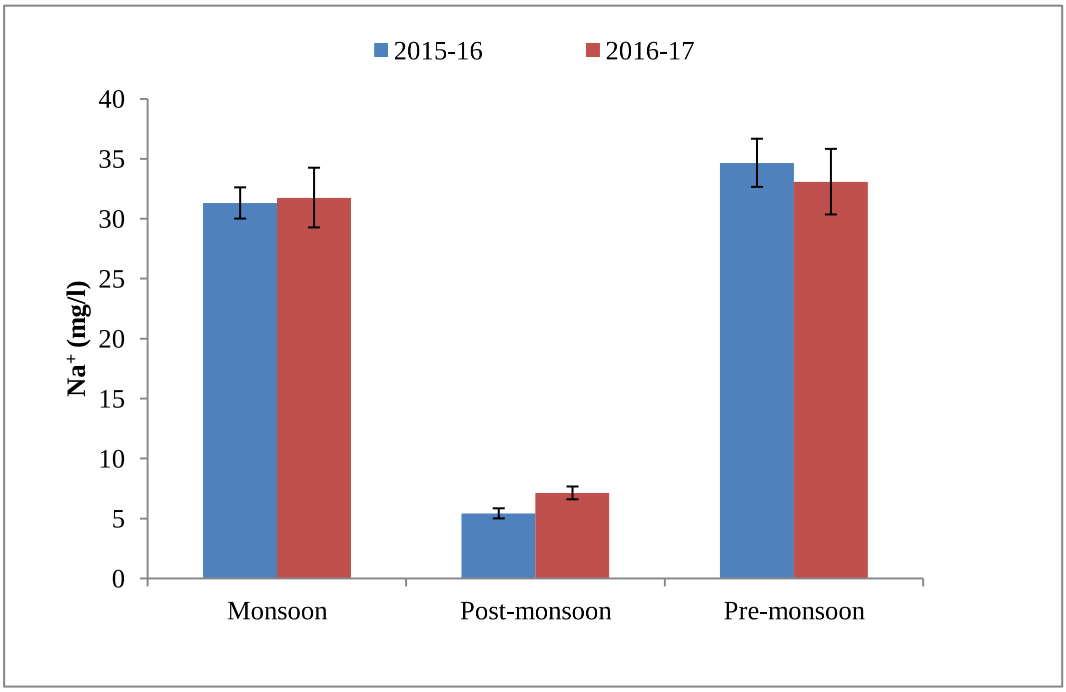

Figure 4.11 Seasonal variations in mean concentration (mg/l) of sodium (Na^+) in Bhindawas wetland in different seasons for two successive years.

35 mg/l, 6 mg/l, 21 mg/l and 21 mg/l respectively with slight variations within nearby

sampling locations. All the cations showed similar seasonal trend, maximum in pre-monsoon and minimum in post-monsoon except magnesium with least concentration during monsoon. Na^+ with maximum concentration (34 mg/l) was found in outlet in May, 2016 and K^+ with minimum concentration (2mg/l) was observed during September, 2015.

Sodium (Na^+)

The mean Na^+ value of surface water during the study period varied from 5 mg/l to 35 mg/l (Fig.4.11). The maximum value was observed to be high in pre-monsoon 35 ± 2 (2015-16); 33 ± 2.7 (2016-17) followed by monsoon 31 ± 1.3 (2015-16); 32 ± 2.5 (2016-17) and post-monsoon 5 ± 0.4 (2015-16); 7 ± 0.5 (2016-17) for the two years. The reason for increased concentration of Na^+ ions might be increased evaporation rate in pre-monsoon due to high temperature and least concentration in post-monsoon due to dilution of wetland water by JLN Feeder canal. Similar results were found by Padma and Periakali (1999) during study in Pulicat lake, east coast of India.

Potasium (K^+)

The mean K^+ value of surface water during the study period varied from 2 mg/l to 6 mg/l (Fig.4.12). The maximum value was observed to be high in pre-monsoon 6 ± 0.4 (2015-16);

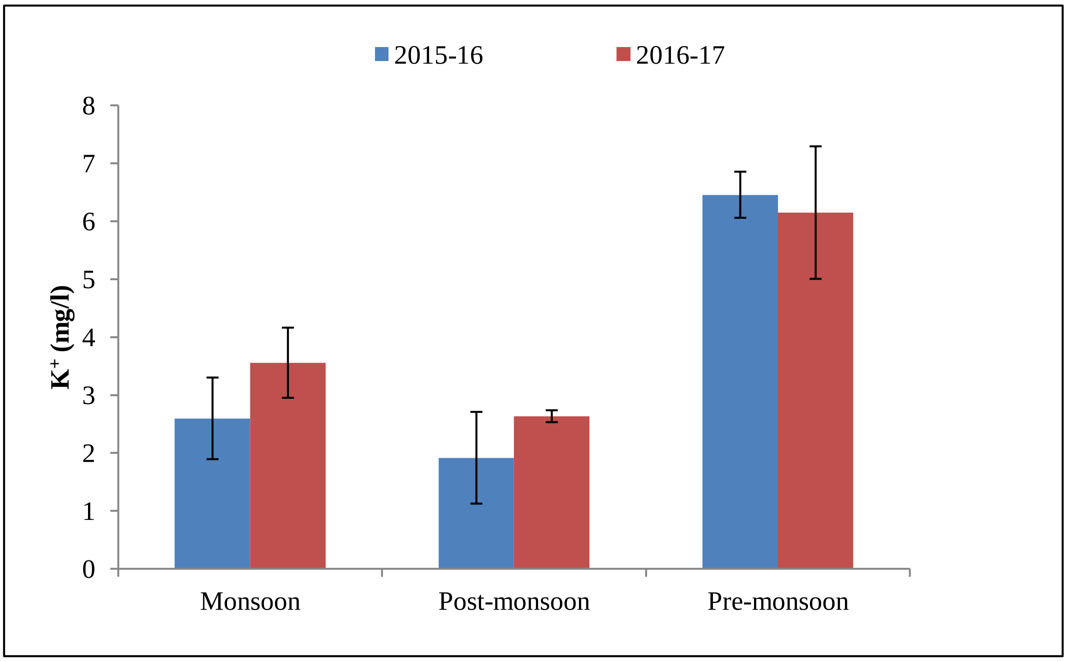

Figure 4.12. Seasonal variations in mean concentration (mg/l) of potassium (K^+) in Bhindawas wetland in different seasons for two successive years.

6 ± 1.1 (2016-17) followed by monsoon 2.6 ± 0.7 (2015-16); 4 ± 0.6 (2016-17) and post-

monsoon 2 ± 0.8 (2015-16); 3 ± 0.1 (2016-17) for the two years, which may be due to surface run off containing inorganic salts.

Calcium (Ca^{2+})

The mean value of Calcium (Ca^{2+}) ions in surface water during the study period varied from 8 mg/l to 21 mg/l (Fig.4.13). Calcium is major nutrient essential for growth of cell wall in plants as well as functioning of various physiological processes in animals (Kumar et al., 2006). The maximum value was observed to be high in pre-monsoon 21 ±1.6 (2015-16); 17± 1.3 (2016-17) followed by monsoon 19 ± 1.1 (2015-16); 12 ± 1.2 (2016-17) and post-monsoon 8 ± 0.3 (2015-16); 8 ± 0.8 (2016-17) for the two successive years, which may be due to faster evaporation, oxidation and as well as decomposition of organic compounds. The

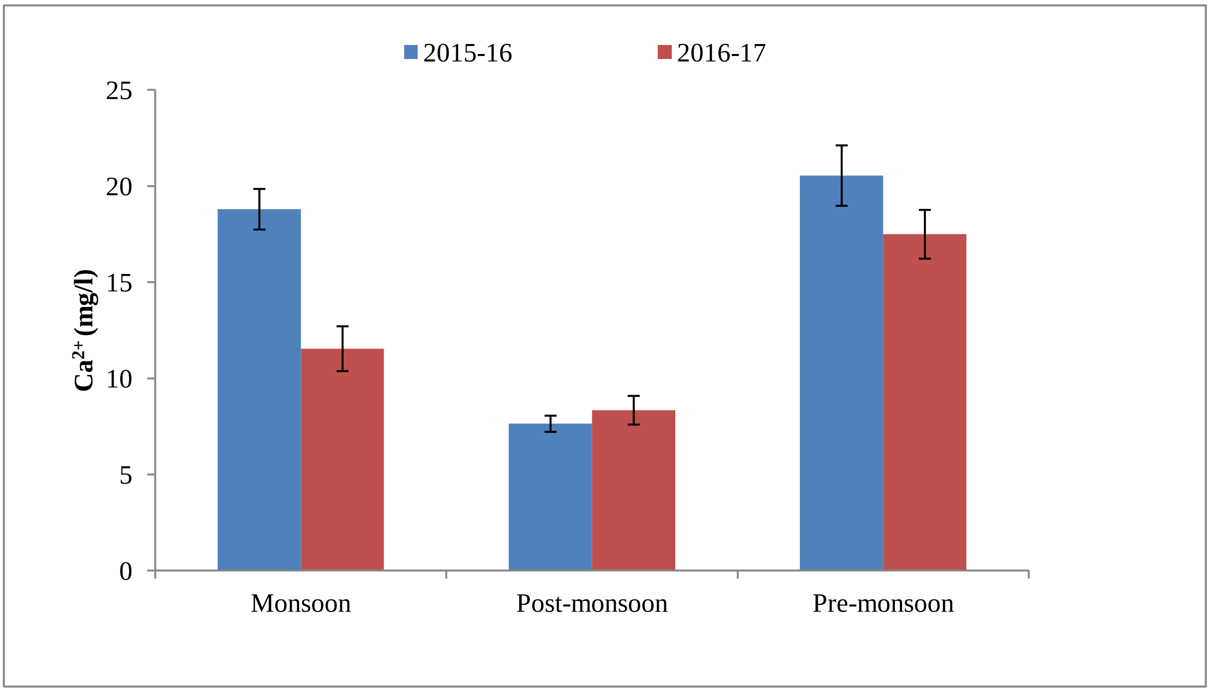

Figure 4.13 Seasonal variations in mean concentration (mg/l) of calcium (Ca^{2+}) in Bhindawas wetland in different seasons for two successive years.

observed values were within permissible limit i.e.75 mg/l, of BIS 1991. Ca^{2+} acts as a vital micronutrient in the water bodies, and naturally its higher concentrations might be due to geological formations too. During post-monsoon reduced Ca^{2+}content may be due to reduce calcium solubility in water. Sayed et al. (2011) also supported similar results, highest in pre-monsoon and least in post-monsoon.

Magnesium (Mg^{2+})

The mean value of magnesium (Mg^{2+}) ions in surface water during the study period varied from 12 mg/l to 21.2 mg/l (Fig.4.14). The maximum value was observed to be high in pre-monsoon 19 ± 2.7 (2015-16); 21.2 ± 4.1 (2016-17) followed by monsoon 17 ± 6.0 (2015-16); 18 ± 2.9 (2016-17) and post-monsoon 12 ± 2.7 (2015-16); 9.78 ± 2.8 (2016-17) for the two years in all the sites. Similar results were found by Deepa et al. (2016) during study in Korattur lake, Chennai. Being an important mineral, magnesium carried out various enzymatic transformations within the cell mainly in the trans-phosphorylation in algal, fungal and bacterial cell (Manios et al., 2002). Magnesium ions contribute to the hardness of water along with calcium and other ions.

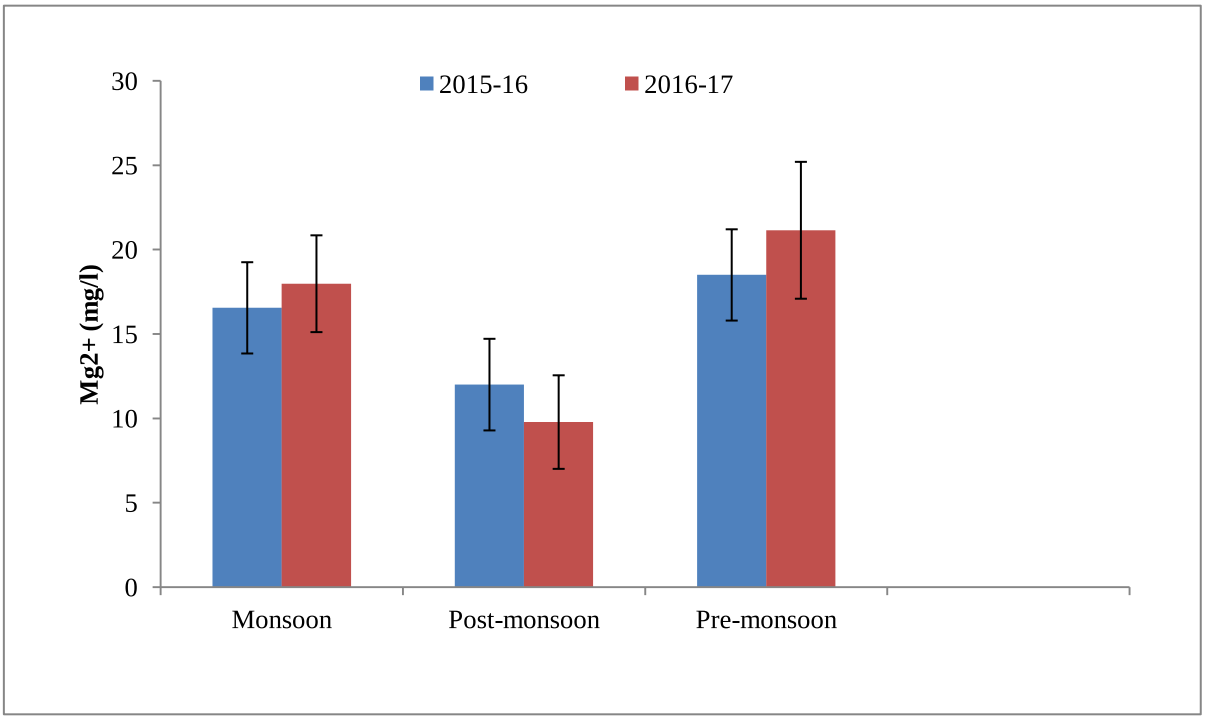

Figure 4.14 Seasonal variations in mean concentration (mg/l) of magnesium (Mg^{2+}) in Bhindawas wetland in different seasons for two successive years.

Sahni and Yadav (2012) also found high Mg^{2+} concentration during pre-monsoon and least in post-monsoon from Bharawas pond, Rewari, Haryana. Increased concentration of Mg^{2+} during pre-monsoon may be due to rock's leaching in the wetland, evaporation of water and sewage input (Verma, 2009).

Anions (Cl^-, HCO_3^- and SO_4^{2-})

Chloride (Cl^-)

Cl^- concentration in Bhindawas wetland varied between 8 mg/l to 90 mg/l with minimum at sampling location, S9 and S17 and maximum at S18 in January, 2016 and 2017 respectively. Inlet possess minimum (24 mg/l) Cl^- in January, 2016 whereas maximum Cl^- content was detected at outlet during May, 2017. The mean Cl^- value of surface water during the study period varied from 36 mg/l to 63.2 mg/l (Fig.4.15). The maximum value was observed to be high in monsoon 58 ± 7.6 (2015-16); 63.2 ± 8.0 (2016-17) followed by pre-monsoon 42 ± 9.5 (2015-16); 36 ± 13.9 (2016-17) and post-monsoon 15 ± 4.1 (2015-16); 46 ± 16.7 (2016-17) for the two years in all the sites, which may be due to surface run off containing chloride salts along with higher concentration of organic waste from livestock, sewage disposal from villages. Similar results were reported by Hulyal and Kaliwal (2011).

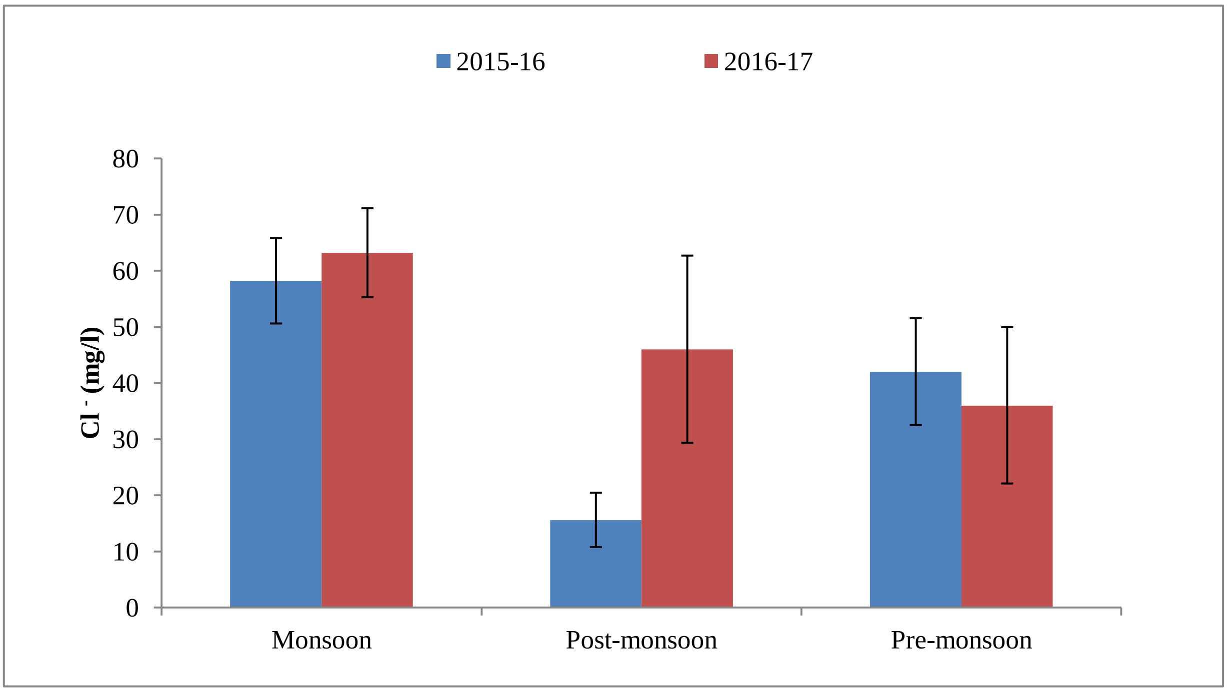

Figure 4.15 Seasonal variations in mean concentration (mg/l) of chloride (Cl^-) in Bhindawas wetland in different seasons for two successive years.

High concentration of chlorides is harmful to aquatic life and matter of concern/troublesome in irrigation water and (Rajkumar et al., 2004). The results obtained were very low as compare to WHO standards (desirable level: 200 mg/l; permissible level: l600 mg/l) and Bureau of Indian Standard, 1991 (Permissible limit: 300 mg/l), which indicates the water is free from chloride hazard.

Bicarbonate (HCO_3^-).

Surface water in wetland with maximum bicarbonate concentration (181 mg/l) was detected during May, 2017 at site S7 and minimum (49 mg/l) was investigated in January, 2016 at S7.

Outlet possesses maximum HCO_3^- value (188 mg/l) whereas inlet possesses minimum (41 mg/l) value in January, 2016 and May, 2017 respectively. The mean HCO_3^- value of surface water during the study period varied from 78.6 mg/l to 134.6 mg/l (Fig.4.16). The maximum value was observed to be high in pre-monsoon 133 ± 20.5 (2015-16); 134.6 ± 28.1 (2016-17) followed by monsoon 106 ± 6.6 (2015-16); 111.1 ± 16.6 (2016-17) and post-monsoon 78.6 ± 16.1 (2015-16); 86.6 ± 19.1 (2016-17) for the two years. A higher value of alkalinity was observed during pre-monsoon might be due to excess of the free CO_2 product, resulted from microbial degradation of water mixed with domestic and sewage waste.

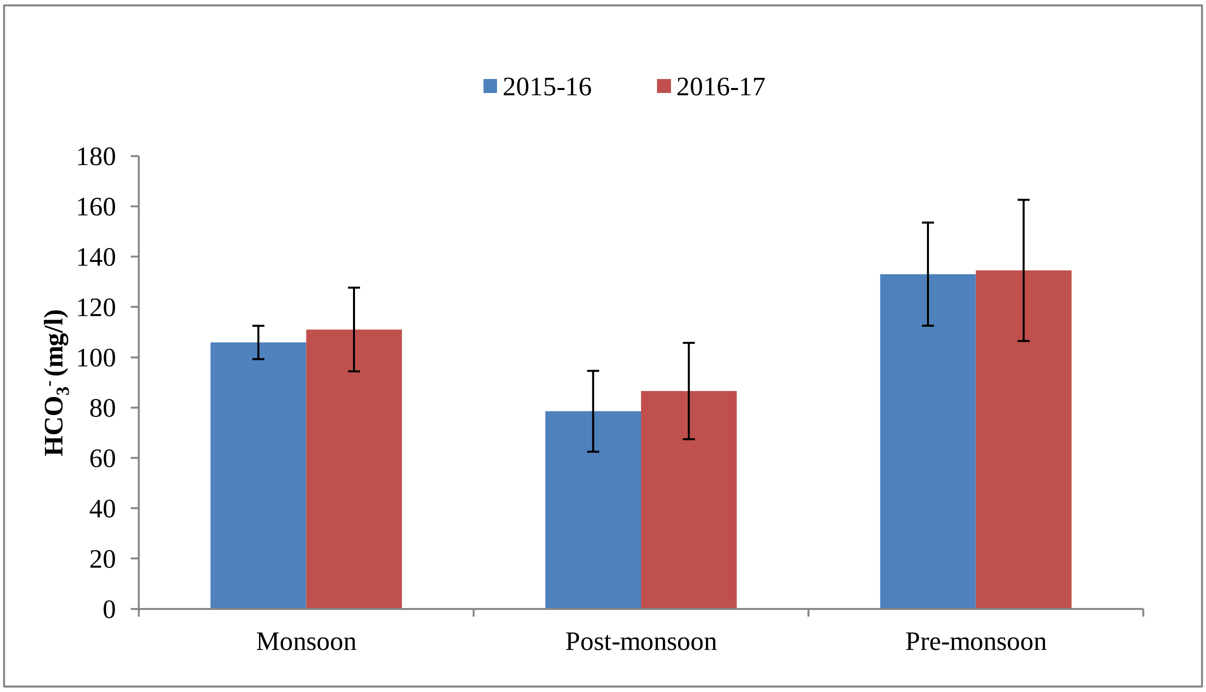

Figure 4.16 Seasonal variations in mean concentration (mg/l) of bicarbonate (HCO_3^-) in Bhindawas wetland in different seasons for two successive years.

The low concentration of alkalinity in monsoon season may be due to dilution of incoming water from catchment area (Jain and Seethapati, 1996). Subramanian (2009); Sajitha and Vijayamma (2016) also documented similar results during study of Pulankurichi and Athiyannoor Panchayath water bodies respectively.

Sulphate (SO_4^{2-})

Maximum (504 mg/l) sulphate concentration was found at sampling site S9 and minimum (23 mg/l) value was observed at S10 in May, 2017 and January, 2016. Outlet during May, 2016 posses maximum sulphate value and minimum value was found in inlet during January, 2016 with values 278 mg/l and 38 mg/l respectively.

The mean SO_4^{2-} value of surface water during the study period varied from 82.3 mg/l to 236 mg/l (Fig.4.17). The maximum value was observed to be high in pre-monsoon 236 ± 78.3 (20

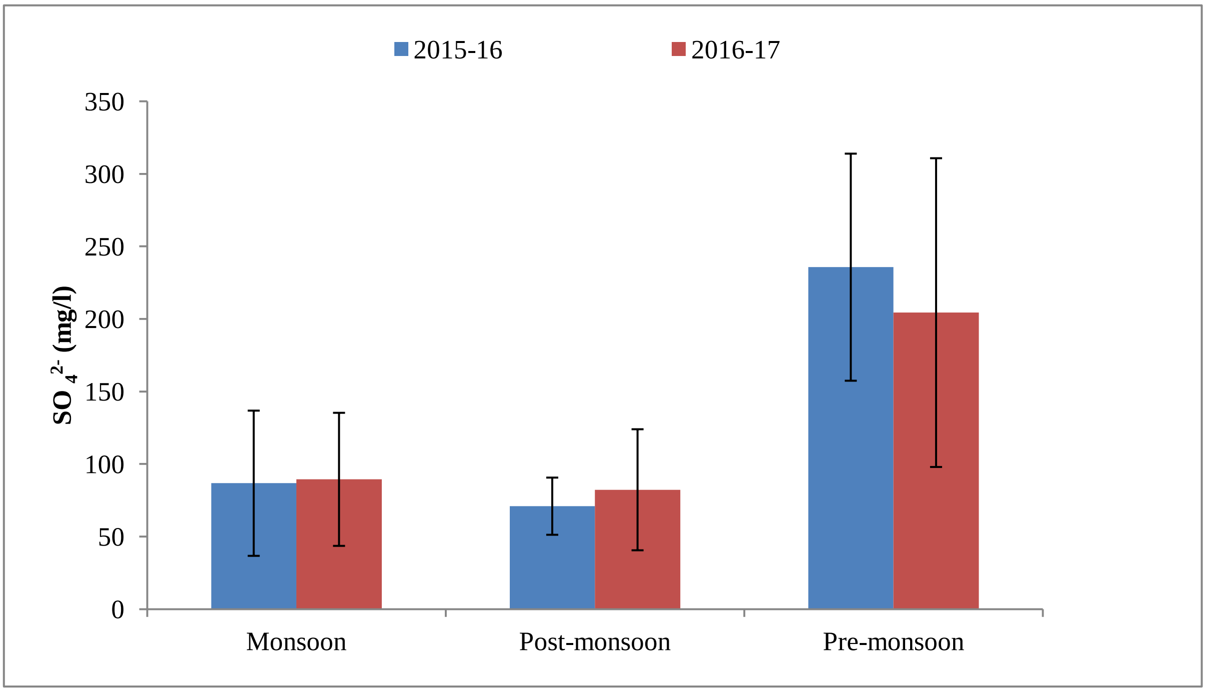

Figure 4.17 Seasonal variations in mean concentration (mg/l) of sulphate (SO_4^{2-}) in Bhindawas wetland in different seasons for two successive years.

15-16); 204.4 ± 106.4 (2016-17) followed by monsoon 87 ± 50.1 (2015-16); 89.48 ± 45.9 (2016-17) and post-monsoon 71 ± 20.8 (2015-16); 82.3 ± 41.7 (2016-17) for the two years. Decreased water level, inflow of detergents, soaps, sewage and human faecal matter contribute increase sulphate content during pre-monsoon (Agarkar and Garode, 2000). Also accelerated releasing rate of sulphate during waste decomposition with increased temperature than its actually consumption by aquatic plants may be another reason for high sulphate concentration in pre-monsoon. Similar findings were documented by Sehgal (1980) and Tripathi and Pandey (1990). Major sources of sulphate are SO_4^{2-} minerals dissolution, pyrite oxidation of organic sulphites and fertilizers. The minimum concentration of SO_4^{2-} was observed during post-monsoon which may be due to reduction of sulphite forming H_2S gas, dilution effect induced by local rains; reduced decomposition of organic matter at low temperature; overturning of lake leading to mixing of sulphate–poor hypolimnetic waters with the eplimnetic layer; low temperature and reduction of sulphates into sulphides which is subsequently oxidized rapidly. As per BIS standard 1991, the permissible limit for human consumption is 100 mg/l.

Phosphate (PO_4^{3-})

Maximum concentration of phosphate (10.6 mg/l) was found at sampling sites S10 during September, 2015 and minimum value, 0.22 mg/l was observed at sampling sites S2; S7 during January, 2017. Increased concentration of total phosphorous was observed in outlet in both monsoon season during the study i.e. September, 2015 and September, 2016. The mean

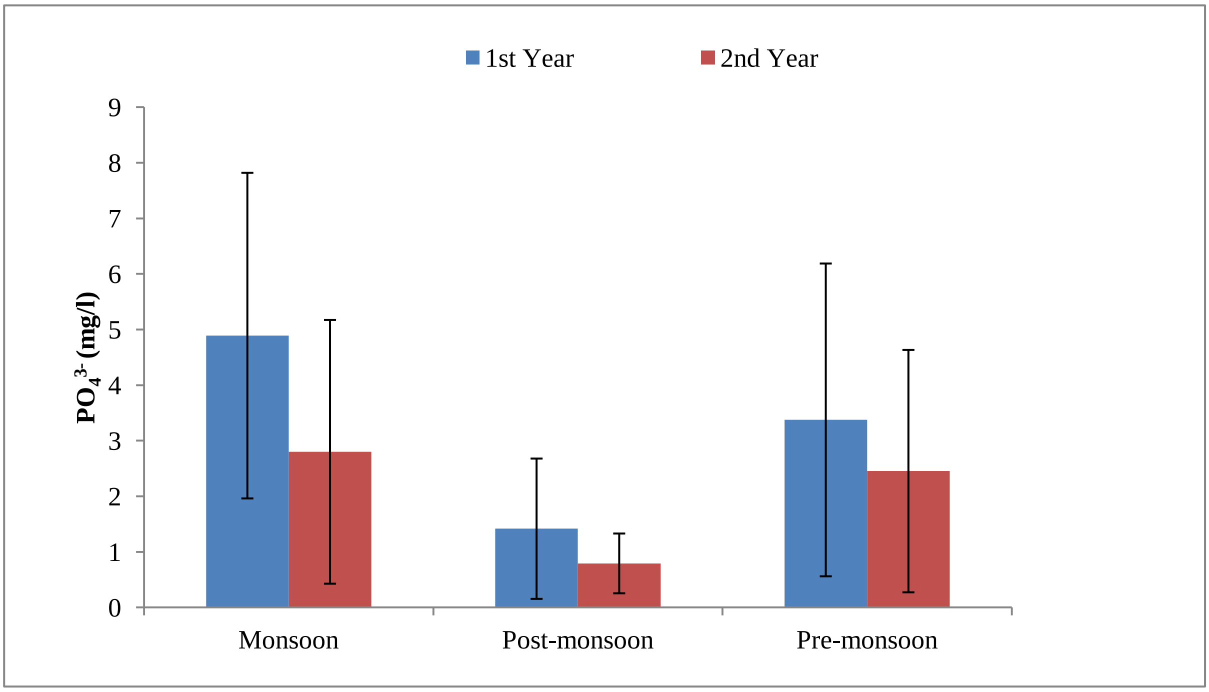

Figure 4.18 Seasonal variations in mean concentration (mg/l) of Phosphate (PO_4^{3-}) in Bhindawas wetland in different seasons for two successive years.

PO_4^{3-} value of surface water during the study period varied from 0.79 mg/l to 4.9 mg/l (Fig.4.18). The maximum value was observed to be high in monsoon 4.9 ± 2.9 (2015-16); 2.80 ± 2.4 (2016-17) followed by pre-monsoon 3.4 ± 2.8 (2015-16); 2.5 ± 2.2 (2016-17) and post-monsoon 1.4 ± 1.3 (2015-16); 0.79 ± 0.5 (2016-17) for the two years, which may be due to agricultural runoff containing inorganic fertilizers, domestic effluents through catchment area. Similar results (maximum value of PO_4^{3-} concentration in monsoon) were also reported by Upadhyay and Gupta (2013) and Murugavel and Pandian (2000). The observed PO_4^{3-} concentrations in the pre-monsoon might be resulted from decay and mineralisation of organic compounds and the lower concentration of PO_4^{3-} in post-monsoon might be resulting from utilisation of nutrients from vegetation. PO_4^{3-} acts as a limiting nutrient in the water bodies. The lowest value of PO_4^{3-} observed in post-monsoon which may be due to utilization of PO_4^{3-} by phytoplankton's and macrophytes, and decreased their concentration in water.

Phosphorous in water comes naturally from leaching of phosphate from rocks and organic matter after decomposition.

Nitrate (NO_3^-)

Maximum concentration of nitrate (44.1mg/l) was investigated at sampling site S9 during September, 2015 and minimum, 0.9 mg/l was observed at S11 during January, 2016. Maximum value of total nitrogen was observed in outlet in both monsoon season during the study period i.e. September, 2015 and September, 2016. The maximum value was observed

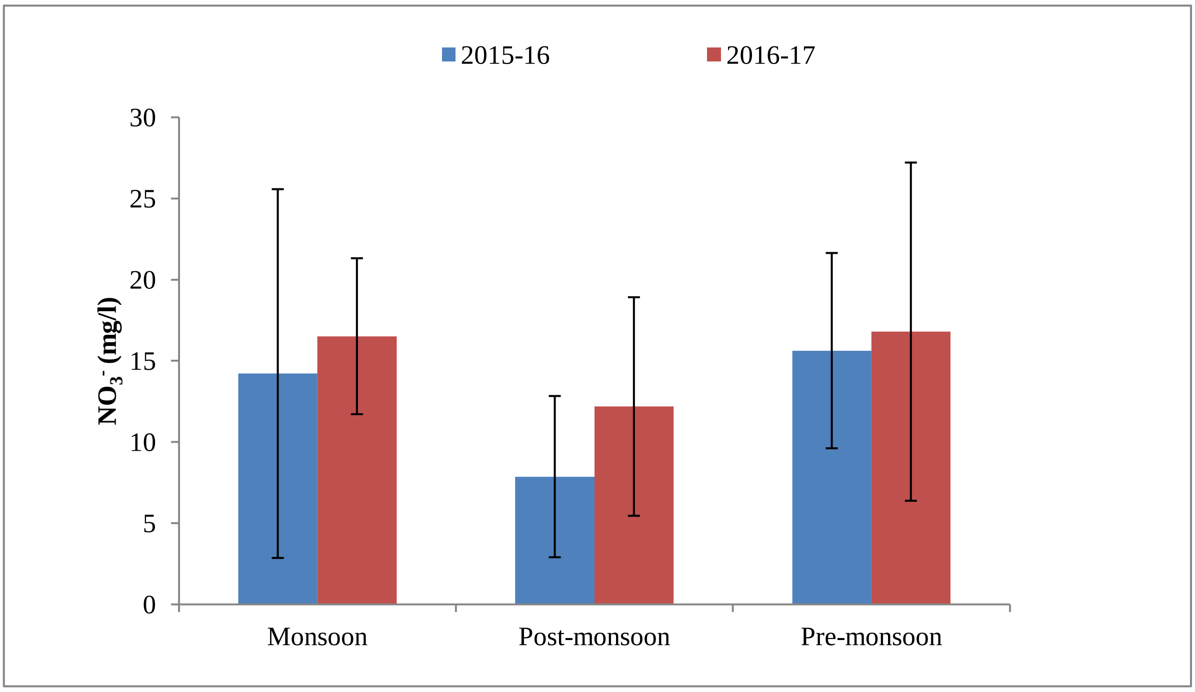

Figure 4.19 Seasonal variations in mean concentration (mg/l) of Nitrate (NO_3^-) in Bhindawas wetland in different seasons for two successive years.

To be high in pre-monsoon 15.6 ± 6.0 (2015-16); 16.8 ± 10.4 (2016-17) followed by monsoon 15 ± 11.2 (2015-16); 16.5 ± 4.8 (2016-17) and post-monsoon 8 ± 5.0 (2015-16); 12.2 ± 6.7 (2016-17) for the two years.

High nitrate concentration in water body supports the higher growth of zooplanktons and phytoplankton (water weeds and algae) causing formation of algal mats on the surface (Sunderraj and Krishnamurthy, 1981; Knepp and Arkin, 1973). The main reason for increased NO_3^-concentration in pre-monsoon may be due to fast decomposition of organic matter (aquatic plants and weeds), which on decomposition release locked nutrients of their body tissue into the water and hence increased its productivity. Also high temperature (Pasternak and Kasza, 1979) along with excessive evapo-transpiration decaying vegetation, nitrogen influx from water bird guano (Manny et al., 1994), direct leaf fall (Wetzel, 2001), untreated sewage discharge (Goel et al., 1981) from surrounded villages increased nitrate level in wetland. This observation is in agreement with the findings of Sehgal (1980), Tripathi and Pandey (1990) and Gochhait (1991).

High concentration of NO_3^- was recorded at some sampling locations in pre-monsoon, which might be the result of water contaminated by animal waste or agricultural runoff (Malik & Nadeem, 2011; Müller et al., 2008). Decreased concentration of nitrate in post monsoon may be due to fastly uptake and consumption of nitrates by macrophytes (Lee et al., 1975), decreased decomposition rate at low temperature and increased nitrification at low temperature (Maulood and Hinton, 1980). Similar results were also found by Gonzalves and Joshi (1946), Singh (1968), Sahai and Sinha (1969), Sehgal (1980) and Gochhait (1991). Wetland water were within the range of permissible limit given by WHO i.e 45 mg/l.

Ammonical nitrogen (NH_3-N)

The maximum value (1.5 mg/l) of NH_3-N was observed at location S10 during September,

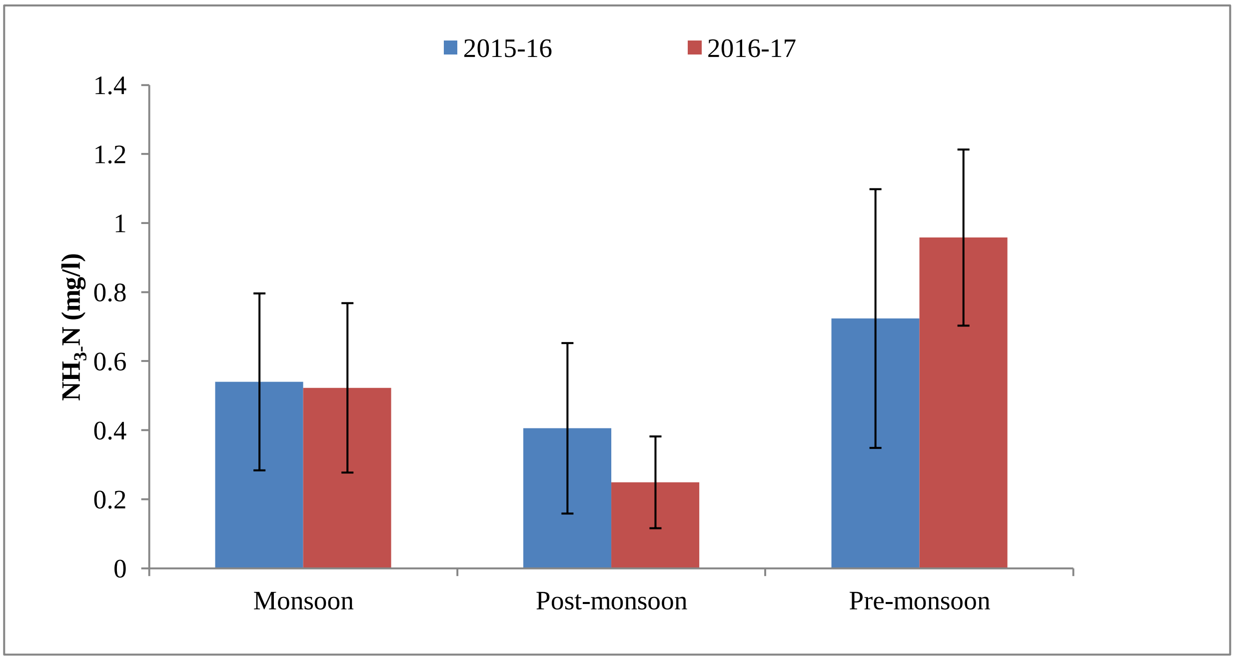

Figure 4.20 Seasonal variations in mean concentration (mg/l) of Ammonical nitrogen (NH_3-N) in Bhindawas wetland in different seasons for two successive years

2016 and whereas, concentration of NH_3-N was not detected at sampling sites, S11, S12; and S9 during January, 2016 and 2017 respectively. Maximum value (1.48mg/l) was detected in outlet in January, 2017 and minimum (0.1 mg/l) was investigated in inlet in May, 2016. The mean value of NH_3-N in surface water during the study period varied from 0.25 mg/l to 0.96

mg/l (Fig.4.20). The maximum value was observed to be high in pre-monsoon 0.7 ± 0.4 (2015-16); 0.96 ± 0.3 (2016-17) followed by monsoon 0.5 ± 0.3 (2015-16); 0.52 ± 0.3 (2016-17) and post-monsoon 0.41 ± 0.3 (2015-16); 0.25 ± 0.1 (2016-17) during the study of two years. Similar results were found by Deepa et al. (2016) during study of various physicochemical parameters of Korattur lake, Chennai, Tamil Nadu, India. Golterman (1975 a, b) and Kumar et al. (2002) also recorded maximum concentration of ammonia during pre-monsoon in the water bodies studied by them which may be due to surface run off from agricultural fields and domestic waste. Ammonia is known major source of nitrogen also act as nutrient for algae and other forms of plant life but increased level of ammonia in water may cause pollution of natural water systems. High concentration of ammonia in water can block oxygen transfer in the gills of fish, thereby causing immediate and long term gilldamage. The relative concentration of ammonia is pH and temperature dependent.

pH and ammonia are directly proportional to each other, increase in the pH value, causes increase value of ammonia. Anoxic conditions also affect many other chemical processes within the lake that can be detrimental to organisms, such as the conversion of organic nitrate to toxic ammonia.. Similar trend for NH_3 was observed in monsoon for first year (0.54 mg/l) and second year (0.52 mg/l). Large amounts of ammonium-N are derived mostly from organic sources by the degradation of nitrogenous organic matter and are taken up at a higher rate during the day than at night time (Wetzel, 2001).

Primarily ammonia occurs as NH_4^+ and NH_4OH form in water bodies with very small amount of ammonia and ammonium compounds with less than 0.1 ppm of average concentration in aquatic resources while the concentration more than 1ppm indicated organic pollution (Ellis et al., 1946) and concentration more than 2.5 ppm have detrimental effects on aquatic biota and highly toxic to many organisms especially fish (Trussel, 1972).

Total Khjeldhal Nitrogen (TKN)

Maximum TKN value was detected at sampling site S1 in May, 2016 whereas minimum was observed at S5, S11, S14 and S18 sites in September, 2015. Maximum value (14 mg/l) was detected in outlet and minimum (4 mg/l) was found in inlet during September, 2015 and May, 2017 respectively. Adoni (1985) and Wetzel (2001) stated that maximum amount of ammonia is produced during microbial degradation of nitrates and nitrogenous organic waste.

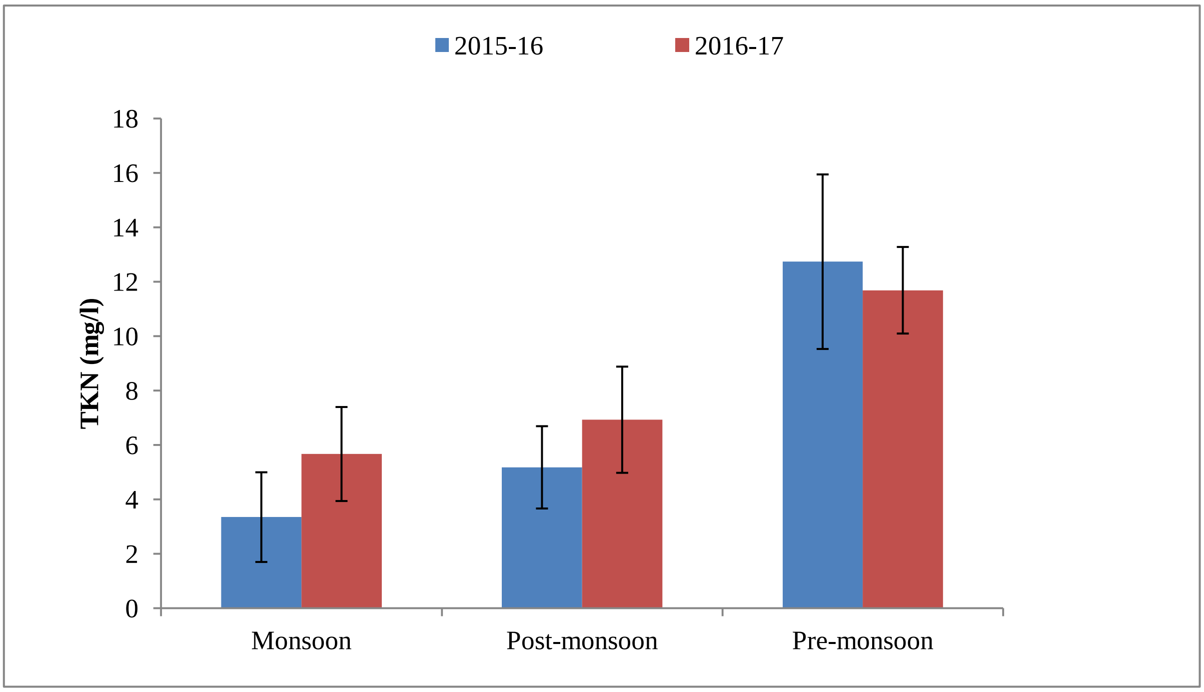

Figure 4.21 Seasonal variations in mean concentration (mg/l) of Total Kjeldhal Nitrogen (TKN) in Bhindawas wetland in different seasons for two successive years.

Also ammonia is major source of nitrogen for a number of plants (Welch, 1952) as ammonical nitrogen requires less energy to assimilate nitrogen as compared to nitrate-nitrogen (Wetzel, 2001). The mean value of TKN in surface water during the study period varied from 3.4 mg/l to 12.74 mg/l (Fig.4.21). The maximum value was observed to be high in pre-monsoon 12.74 ± 3.21 (2015-16); 11.7 ± 1.59 (2016-17) followed by post-monsoon 5.18 ± 1.51 (2015-16); 6.9 ± 1.95 (2016-17) and monsoon 3.4 ± 1.65 (2015-16); 5.67 ± 1.73 (2016-17) during the study of two years, which may be due to surface run off from agricultural fields and domestic waste. Further during the dry phase, as the stations were like grassland, many cattle pastured there. The animal excreta could have also contributed to the phosphorus loading in the dry phase.

Table 4.2 Physico-chemical characteristics of surface water of Bhindawas Wetland in monsoon (September, 2015).

Sites	Temp	pH	EC	TDS	TSS	DO	ORP	BOD	COD	DOC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	PO_4^{3-}	NO_3^-	NH_3-N	TKN
Inlet	28.7	6.4	207	221	531	0.7	ND	1	ND	9.7	33	2	19	17	60	106	76	1.1	9	1.1	6.1
Outlet	28.1	8.1	344	249	689	6.6	-281	2	23	19.0	34	3	20	19	56	146	40	7.8	19.7	1	14
S1	32.5	7.1	338	234	602	5.9	30	2	25	15.8	31	4	19	16	60	112	94	6	9.7	1.4	8.4
S2	32.9	7.9	335	232	498	7.6	42	1	24	15.8	31	2	19	15	56	93	89	4.7	10.3	0.5	5.4
S3	33.2	7.8	337	245	562	7.2	85	2	27	15.0	34	4	20	17	60	112	64	4.6	3.8	0.7	4.2
S4	33.8	7.9	335	250	684	7.3	80	3	21	17.1	33	3	20	17	60	102	93	4.6	4.3	0.5	2.8
S5	33.3	8	341	246	404	8.3	98	2	25	17.4	34	3	20	19	56	107	108	7.7	17	0.5	1.4
S6	33.9	8.1	331	242	622	7.2	88	1	24	16.0	32	2	19	17	52	107	78	1.4	BDL	0.5	4.2
S7	33	8	348	243	468	8.1	98	1	23	21.2	33	3	19	17	60	102	95	1.8	4.6	0.6	2.8
S8	32.2	8.5	346	227	374	8.7	86	1	23	15.4	31	2	18	15	60	102	61	5.5	24.2	0.2	2.8
S9	33.4	7.8	700	235	290	8.9	126	3	24	16.2	30	3	19	15	60	102	69	4.5	44.1	0.6	2.8
S10	32.5	7.3	700	231	324	5.3	118	1	25	17.2	30	3	18	11	52	112	27	10.6	40.5	0.5	4.2
S11	33.5	9.6	347	203	426	9.9	77	2	23	8.7	31	1	15	13	60	117	42	0.4	16	0.5	1.4
S12	33.2	8.5	353	237	378	9.3	102	1	24	16.9	31	2	19	17	56	98	81	7.9	18.3	0.5	2.8
S13	33.1	8.7	352	233	344	10.9	104	1	21	14.8	31	3	19	16	56	112	240	1.8	18.9	0.2	2.8
S14	33	8.5	353	232	544	7.4	86	1	23	14.7	32	2	19	15	88	98	68	1.7	10.6	0.6	1.4
S15	33	8.7	346	227	414	9.3	93	3	20	38.8	31	2	18	15	56	102	65	7	3.8	0.5	4.2
S16	32.2	7.6	343	233	426	6.3	120	2	22	17.6	30	3	19	19	56	107	57	2.1	12.6	0.3	2.8
S17	32.8	7.4	424	235	422	6.5	102	2	23	18.0	30	3	19	19	52	117	60	7.1	8	0.3	4.2
S18	32.9	7.5	416	234	406	7.5	103	1	24	16.7	30	4	19	15	52	102	124	10.2	14.9	0.7	1.4
S19	32.9	7.3	445	235	456	6.7	103	1	26	19.5	30	2	19	19	56	102	186	5.4	12.1	0.8	4.2
S20	32.4	7.4	347	232	646	6.3	103	0.4	27	17.0	31	3	19	24	56	112	35	2.8	10.5	0.4	2.8
Range	32.2-33.9	7.1-9.6	331-700	203-250	290-684	5.3-10.9	30-126	0.4 - 3.08	20-27	8.7-38.8	30-34	1-4	15-20	7-28	52-88	93-117	27-240	0.4-10.6	BDL-44.1	0.2-1.4	2.8-8.4
Mean ±SD	33 ±0.5	8 ±0.6	392 ±110.1	234 ±9.62	465 ±111.6	8 ±1.44	92 ±23.3	1.5 ±0.83	24 ±1.9	17 ±5.55	31 ±1.3	2.6 ±0.7	19 ±1.1	17 ±6.0	58 ±7.6	106 ±6.6	87 ±50.1	4.9 ±2.9	15 ±11.2	0.5 ±0.3	3.4 ±1.65

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites). All the Parameters have value in mg/l except Temp (°C), pH, EC (µS/cm), ORP (mV). ND and BDL represents Not Detected and Below Detection Limit.

Table 4.3 Physico-chemical characteristics of surface water of Bhindawas Wetland in Post-monsoon (January, 2016).

Sites	Temp	pH	EC	TDS	TSS	DO	ORP	BOD	COD	DOC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	PO_4^{3-}	NO_3^-	NH_3-N	TKN
Inlet	13.8	7.3	178	88	164	7.2	166	2.4	30	25.9	5	2	7	11	24	61	67	2.2	12.7	0.7	5.6
Outlet	13.7	7.3	196	96	48	6.1	281	3.6	60	27.5	6	4	8	16	8	85	38	1.6	7.8	3.4	7
S1	16.2	7.2	195	96	506	5.9	203	0.1	30	26.3	5	1	8	15	28	61	83	0.9	4.4	0.2	7
S2	16.2	7.4	198	98	492	6.2	210	0.5	20	22.9	6	2	8	8	12	61	78	6.1	9.9	0.6	4.2
S3	15.5	7.5	196	97	126	6.7	217	0.4	30	26.3	6	2	8	12	12	73	54	1.1	1.4	0.5	4.2
S4	15	7.7	192	93	138	5.9	233	0.0	20	25.1	6	1	8	14	20	85	84	0.8	4.0	0.4	4.2
S5	14.4	7.8	182	90	396	6.5	234	0.3	20	23.4	6	3	8	17	16	61	82	1.2	11.5	0.5	5.6
S6	16	7.6	192	91	332	7.8	161	0.2	20	23.7	6	2	8	13	12	85	77	2.2	16.4	0.3	4.2
S7	16.1	7.8	191	94	208	7.4	159	0.2	20	24.4	5	1	8	13	20	49	76	1.0	7.1	0.4	4.2
S8	16.3	7.3	191	94	390	7.5	174	1.0	40	25.9	5	2	8	12	16	73	71	1.1	8.9	0.6	5.6
S9	15.2	7.3	405	199	585	6.9	154	1.3	20	28.3	5	1	7	10	8	85	57	0.9	1.9	0.3	7
S10	15.3	7.6	403	198	600	8.8	165	2.8	30	30.0	5	2	7	9	16	85	23	0.8	9.8	0.5	5.6
S11	15.4	7.5	415	204	110	6.4	154	0.9	40	25.9	5	1	8	10	16	73	35	1.6	0.9	0.0	8.4
S12	14.1	7.8	175	86	466	7.3	252	0.3	40	23.7	5	2	8	11	20	73	76	0.4	16.8	0.0	4.2
S13	16	7.5	190	94	160	7.4	162	1.1	20	25.5	5	3	8	13	20	73	78	1.4	13.7	0.3	4.2
S14	16.3	7.4	191	94	96	7.5	166	0.5	40	22.6	5	2	7	7	20	85	77	2.1	14.7	0.4	8.4
S15	16.6	7.4	190	94	384	7.1	170	0.4	30	24.4	5	3	7	11	12	85	57	1.3	5.5	0.2	4.2
S16	16.6	7.4	191	94	248	7.0	171	0.6	30	24.1	5	3	7	13	16	73	63	2.8	8.8	0.3	5.6
S17	16.5	7.2	191	94	374	6.7	174	0.5	20	24.2	5	3	7	11	8	122	57	1.4	2.4	1.0	4.2
S18	15.9	7.5	196	97	346	6.0	187	0.2	40	25.7	5	2	7	12	12	98	102	0.5	4.3	0.2	5.6
S19	16.1	7.2	195	96	166	6.5	197	0.8	30	26.8	6	2	7	11	12	98	102	0.4	9.7	0.8	4.2
S20	17	7.4	196	97	66	6.8	202	0.5	20	25.6	6	3	8	18	16	73	87	0.5	5.2	0.7	2.8
Range	14.1-17	7.2-7.8	182-415	86-204	66-600	5.9-8.8	154-252	0.02-2.8	20-40	22.6-30	5 - 6	1- 3	7- 8	7- 18	8-28	49-122	23-102	0.4-2.81	0.9-16.8	0-1	2.8-8.4
Mean ±SD	16 ±0.7	7.47 ±0.2	224 ±79.4	112 ±42.11	309 ±169.67	7 ±0.73	183 ±30.31	1 ±0.65	28 ±8.3	25 ±1.8	5 ±0.4	2 ±0.8	8 ±0.3	12 ±2.7	15 ±4.1	78.6 ±16.1	71 ±20.8	1.4 ±1.3	8 ±5	0.41 ±0.3	5.18 ±1.51

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites). All the Parameters have value in mg/l except Temp (°C), pH, EC (μS/cm), ORP (mV). ND and BDLrepresents Not Detected and Below Detection Limit.

Table 4.4 Physico-chemical characteristics of surface water of Bhindawas Wetland in Pre-monsoon (May, 2016).

Sites	Temp	pH	EC	TDS	TSS	DO	ORP	BOD	COD	DOC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	PO_4^{3-}	NO_3^-	NH_3-N	TKN
Inlet	27.8	7.5	451	142	270	7.4	-21.7	ND	20	22.8	32	3	19	16	40	110	158	1.1	31.3	0.3	ND
Outlet	33.2	6.7	487	321	310	5.1	-463	1.4	40	48.1	34	8	20	18	50	171	278	1.6	10.5	0.4	8.4
S1	33.1	6.9	476	317	262	7.2	-182.9	2.2	40	36.6	32	7	20	16	50	155	236	0.8	18.4	0.4	21
S2	33	7.4	472	292	248	5.3	-148.7	2.4	60	39.4	33	6	20	20	30	123	240	3.4	19.5	1.4	7
S3	32	7.1	500	315	280	5.0	-164.9	2.5	60	41.2	37	7	21	20	30	119	481	0.9	12.2	1.4	8.4
S4	33.7	7.6	508	282	310	5.8	-137.2	3.0	40	37.9	37	7	21	19	50	139	146	2.3	13.3	1.0	12.6
S5	33.2	7.1	502	284	338	3.5	-162.2	3.5	40	42.2	32	7	18	29	30	171	267	6.1	24.9	0.8	15.4
S6	33	7	493	279	202	2.8	-144.2	2.3	40	41.3	34	6	21	19	40	126	296	5.3	4.9	0.8	11.2
S7	36.2	6.8	494	277	286	3.9	-256.6	3.7	60	41.6	31	7	21	18	40	158	198	1.1	14.3	0.4	8.4
S8	36.4	7.2	463	274	382	5.6	-147.2	3.5	40	42.3	38	7	20	18	40	146	148	8.4	12.1	0.8	12.6
S9	35.8	7.4	478	301	184	5.8	-104.8	3.2	40	30.1	36	6	23	18	30	112	162	1.6	9.9	0.2	11.2
S10	35.8	7.5	471	282	206	5.4	-87.8	2.2	40	36.1	37	7	21	16	30	102	291	1.1	15.5	0.3	11.2
S11	34.4	7.6	403	300	284	6.2	103.7	5.1	30	37.5	34	7	18	19	40	119	280	0.5	14.8	0.5	14
S12	37.3	6.7	412	278	284	3.8	-135.2	3.8	40	41.4	35	6	17	18	40	121	306	1.8	10.7	1.0	12.6
S13	34.9	7.2	474	289	290	5.5	-120.6	4.8	30	44.2	34	6	20	18	50	112	177	3.0	12.6	0.7	11.2
S14	34.7	7	473	336	294	4.6	-114	0.5	40	43.2	36	7	21	17	40	136	210	0.9	18.6	0.5	12.6
S15	34.7	7.4	450	345	390	5.1	-97	3.8	40	39.1	33	6	23	17	40	102	173	1.9	30.3	0.5	12.6
S16	35.7	7.3	475	300	286	5.2	-98.6	1.7	40	40.1	34	7	21	17	40	134	230	3.7	15.0	1.1	12.6
S17	26.9	6.8	479	313	208	3.3	-212.5	3.0	60	58.2	34	6	23	17	50	128	172	1.6	11.9	0.7	18.2
S18	26.5	6.5	476	306	214	2.2	-425	3.9	30	60.7	37	6	21	18	60	165	182	7.1	10.6	0.3	12.6
S19	26.7	6.6	478	328	308	3.3	-366.8	6.7	40	66.5	36	6	21	18	60	159	224	9.9	17.3	1.2	14
S20	34.3	7.1	473	327	190	3.8	-93	6.3	60	41.8	33	6	20	18	50	134	297	6.2	25.6	0.3	15.4
Range	26.5-37.3	6.5-7.6	403-508	274-345	184-390	2.2-7.2	-366.8 -87.8	0.5-6.7	30-60	30.1-66.5	31-38	6 - 7	17-23	16-29	30-60	102-171	146-481	0.5-9.9	4.9-30.3	0.2-1.4	7-21
Mean± SD	33 ±3.2	7.1 ±03	473 ±26.2	301 ±21.45	272 ±59.17	5±1 .29	-155 ±107.7	3.4 ±1.5	44 ±10.4	43 ±8.8	35 ±2	6 ±0.4	21 ±1.6	19 ±2.7	42 ±9.5	133 ±20.5	236 ±78.3	3.4 ±2.8	15.6 ±6.0	0.7 ±0.4	12.74 ±3.21

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites). All the Parameters have value in mg/l except Temp (°C), pH, EC (μS/cm), ORP (mV). ND and BDL represents Not Detected and Below Detection Limit.

Table 4.5 Physico-chemical characteristics of surface water of Bhindawas Wetland in Monsoon (September, 2016).

Sites	Temp	pH	EC	TDS	TSS	DO	ORP	BOD	COD	DOC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	PO_4^{3-}	NO_3^-	NH_3-N	TKN
Inlet	29.6	7.6	268	232	680	9.7	ND	2.5	21	27.5	31	3	17	15	14	118	86	4.2	19.9	0.6	5.6
Outlet	30	7.1	310	251	412	5.7	-312	3.6	32	31.3	35	4	22	19	64	132	53	9.7	19.2	0.7	9.8
S1	31.8	7.4	271	217	686	7.8	97	1.1	23	31.2	30	3	11	14	78	108	102	1.2	14.8	1.2	7
S2	29.8	7.5	266	243	652	8.1	112	0.9	23	27.2	32	4	12	17	64	88	98	10.3	20.9	1.3	2.8
S3	29.9	7.4	273	256	566	7.9	134	0.4	20	28.9	33	3	11	24	71	118	73	1.5	29.9	1.1	5.6
S4	30	7.2	278	242	470	7.5	114	0.8	22	29.3	30	4	13	17	57	113	107	1.6	11.4	0.9	4.2
S5	30	7.3	275	234	468	6.8	134	0.5	27	27.0	33	3	10	22	50	120	97	2.7	12.8	0.8	2.8
S6	30.2	7.4	278	259	454	6.9	107	1.0	40	26.4	30	4	11	19	57	99	87	0.5	11.0	0.8	4.2
S7	30.2	7.1	277	247	692	7.0	128	0.7	40	28.6	35	4	10	18	57	87	102	0.9	11.4	0.8	7
S8	30.3	7.3	277	234	656	7.2	181	0.6	20	29.8	29	4	13	15	57	117	58	2.1	13.4	0.8	5.6
S9	30.4	7.9	279	231	512	8.0	165	0.9	27	31.5	31	4	10	16	57	102	72	5.3	18.5	1.0	7
S10	30	7.5	296	222	548	6.1	179	0.7	22	28.3	32	3	12	16	64	106	32	5.1	18.4	1.5	5.6
S11	30.5	7.7	283	232	562	7.3	187	0.9	22	27.9	36	3	10	18	57	123	49	3.0	9.2	0.7	5.6
S12	30.1	7.4	277	248	594	7.5	112	0.7	40	26.2	37	5	13	19	64	105	81	1	19.5	0.6	8.4
S13	30	8	261	259	486	7.6	153	0.6	23	25.5	34	3	12	15	57	116	212	3.9	18.8	0.7	4.2
S14	30	7.9	286	226	516	6.6	171	0.7	50	29.0	33	3	13	17	71	79	56	3.2	20.4	0.7	7
S15	30.2	8.1	284	215	522	6.8	178	0.9	24	24.7	30	4	10	19	71	108	78	1.4	18.2	1.2	4.2
S16	30	7.8	280	220	450	8.0	186	1.1	26	27.7	29	3	12	15	57	98	60	0.6	13.0	1	8.4
S17	30.6	8.6	278	243	468	7.9	159	1.1	34	29.5	31	4	13	24	64	125	64	2.6	17.6	1.5	4.2
S18	30.1	7.8	285	246	450	7.0	123	1.1	23	31.5	28	3	11	17	64	134	127	0.9	14.8	0.9	5.6
S19	30.2	7.6	272	248	456	8.0	112	0.5	22	28.8	29	4	13	19	78	128	194	2.5	15.5	0.7	5.6
S20	30.8	7.5	271	247	476	8.2	123	2.8	20	32.5	33	3	10	17	71	147	41	5.7	20.8	0.8	8.4
Range	29.8-31.8	7.1-8.6	261-296	215-259	450-692	6.1-8.2	97-187	0.4-2.8	20-50	24.7-32.5	28-37	3 - 4	10 - 13	14-24	50-78	79-147	32-212	0.5-10.3	9.2-29.9	0.6-1.5	2.8-8.4
Mean ±SD	30 ±0.4	7.62 ±0.4	277.4 ±7.6	238 ±13.58	534 ±82.2	7.4 ±0.60	143 ±30.52	1.5 ±0.49	27 ±8.6	28.6 ±2.09	32 ±2.5	4 ±0.6	12 ±1.2	18 ±2.9	63.2 ±8.0	111.1 ±16.6	89.48 ±45.9	2.80 ±2.4	16.5 ±4.8	0.52 ±0.3	5.67 ±1.73

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites). All the Parameters have value in mg/l except Temp (°C), pH, EC (µS/cm), ORP (mV). ND and BDLrepresents Not Detected and Below Detection Limit.

Table 4.6 Physico-chemical characteristics of surface water of Bhindawas Wetland in Post- monsoon (January, 2017).

Sites	Temp	pH	EC	TDS	TSS	DO	ORP	BOD	COD	DOC	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Cl^{-}	HCO_3^{-}	SO_4^{2-}	PO_4^{3-}	NO_3^{-}	NH_3-N	TKN
Inlet	16	8.2	200	100	172	7.2	137	1.4	40	25.1	6	2	7	17	60	89	76	0.6	29.9	0.1	4.2
Outlet	15.8	7.9	362	181	68	1.0	135	0.3	60	38.2	6	3	15	7	50	117	40	0.4	23.9	1.6	7.0
S1	16.6	7.8	211	106	444	5.2	144	0.3	40	35.9	7	3	9	8	50	83	94	0.3	4.8	0.6	12.6
S2	16.9	7.7	211	106	420	5.2	138	0.1	40	38.2	7	3	9	10	20	75	89	0.2	3.7	0.4	8.4
S3	16.9	7.8	216	109	434	4.5	139	1.3	20	38.6	7	3	9	8	20	98	64	1.3	23.3	0.4	7
S4	16.5	7.5	224	112	184	3.6	132	1.4	25	38.6	7	3	9	7	20	103	93	2.0	13.0	0.4	7
S5	16.9	7.3	211	106	200	5.2	123	0.9	40	36.9	7	3	9	9	60	73	108	0.4	6.9	0.2	8.4
S6	17	7.3	210	105	234	4.9	127	0.9	60	35.1	7	3	8	7	60	72	78	0.4	21.5	0.3	5.6
S7	17	7.6	210	106	203	5.1	129	0.8	80	36.7	7	3	9	9	50	63	95	0.2	25.3	0.3	7
S8	17.1	7.4	219	110	250	6.9	128	0.8	60	35.2	7	3	9	10	50	99	61	0.7	5.3	0.1	5.6
S9	16.8	7.7	218	110	354	7.4	131	1.4	20	41.9	7	3	8	8	40	77	69	0.5	14.4	0.0	4.2
S10	16.6	7.3	220	111	454	6.3	137	1.6	20	33.9	9	2	8	8	40	69	27	0.6	27.5	0.3	5.6
S11	16.5	7.5	215	108	347	5.9	126	0.2	40	41.2	7	3	8	9	60	76	42	0.7	3.5	0.1	5.6
S12	16.9	7.3	202	101	236	4.5	128	0.9	40	35.9	7	3	6	8	50	83	68	0.8	31.2	0.3	7
S13	16.5	7.4	208	104	162	7.5	131	0.7	40	35.5	6	3	7	12	50	94	188	1.1	1.7	0.2	7
S14	16.7	7.3	211	106	108	7.6	133	0.9	40	36.1	8	3	9	9	40	103	68	1.4	28.2	0.3	8.4
S15	16.6	7.5	212	106	574	8.3	139	1.4	40	39.7	8	3	8	11	30	113	65	0.3	9.6	0.2	7
S16	16.9	7.6	211	108	244	7.4	142	1.0	40	37.4	7	3	9	10	50	65	57	0.5	9.7	0.2	9.8
S17	16.8	7.5	205	102	232	8.9	131	2.0	40	38.4	7	3	7	17	60	143	60	1.4	26.9	0.2	7
S18	16.7	7.3	211	106	314	7.6	130	1.0	30	32.5	8	2	9	9	90	84	99	1.6	24.4	0.3	4.2
S19	16.9	7.7	211	111	362	6.3	152	0.4	40	40.1	7	3	9	10	40	81	186	1.2	29.3	0.1	5.6
S20	16.8	7.6	212	110	130	6.7	145	0.4	30	39.8	7	3	8	17	40	78	35	0.3	25.9	0.1	5.6
Range	16.5-17.1	7.3-7.8	202-224	101-112	108-574	3.6-8.9	123-153	0.1-2.0	20-80	32.5-41.9	6 - 9	2 - 3	6- 9	7 -17	20-90	63-143	27-188	0.2-2	1.7-31.2	0-6	4.2-12.6
Mean ±SD	17 ±0.2	7.50 ±0.18	212 ±5.1	107 ±2.9	294.3 ±125	6.2 ±1.44	134 ±7.39	0.9 ±0.49	39 ±14.5	37.4 ±2.45	7 ±0.5	3 ±0.1	8 ±0.8	9.78 ±2.8	46 ±16.7	86.6 ±19.1	82.3 ±41.7	0.79 ±0.5	12.2 ±6.7	0.25 ±0.1	6.9 ±1.95

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites). All the Parameters have value in mg/l except Temp (°C), pH, EC (µS/cm), ORP (mV). ND and BDLrepresents Not Detected and Below Detection Limit.

Table 4.7 Physico-chemical characteristics of surface water of Bhindawas Wetland in Pre-monsoon (May, 2017).

Sites	Temp	pH	EC	TDS	TSS	DO	ORP	BOD	COD	DOC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	PO_4^{3-}	NO_3^-	NH_3-N	TKN
Inlet	30.1	8.1	288	215	138	5.8	122	1.2	40	48.0	32	2	9	12	50	112	105	2.4	24.7	2.2	14.0
Outlet	30.8	7.2	644	181	334	2.8	154	ND	80	80.4	32	6	17	19	70	126	218	2.0	19.1	1.1	15.4
S1	32.9	7.4	635	321	476	4.9	199	5.96	25	65.1	33	5	20	19	50	171	344	1.6	7.9	0.6	12.6
S2	33.2	7.2	585	298	294	6.8	184	0.7	60	66.3	38	7	19	19	40	107	285	0.6	10.7	0.9	12.6
S3	34.1	7.3	632	320	222	5.2	171	0.1	40	62.2	36	7	19	17	20	121	297	0.8	25.8	0.7	11.2
S4	34.9	6.9	612	293	284	6.6	156	2.0	40	65.3	32	7	17	15	20	153	227	0.9	3.7	0.8	11.2
S5	33.7	7.5	567	287	328	5.6	167	2.5	100	59.8	37	7	17	22	20	156	169	1.8	16.7	0.7	7
S6	34.6	7.4	558	276	308	5.6	177	0.3	60	54.5	39	6	17	15	30	101	141	1.3	13.9	0.7	9.8
S7	33.3	7.5	545	269	102	5.2	153	0.9	60	63.7	33	7	17	17	30	181	110	4.1	15.7	0.8	9.8
S8	34.6	7.2	550	279	180	6.4	190	2.5	40	65.0	30	5	16	24	20	133	99	1.4	17.6	0.5	12.6
S9	36	7.1	603	310	666	5.7	179	3.6	100	59.5	32	7	19	23	30	116	504	4.0	19.2	0.6	11.2
S10	36.8	7.5	651	286	175	4.8	179	2.9	80	58.6	37	3	18	24	40	99	91	3.1	1.8	0.0	12.6
S11	35.9	7.2	604	306	174	6.3	150	4.1	60	65.1	31	7	17	29	30	126	331	0.5	15.2	0.5	14
S12	34.7	7.4	627	287	129	5.5	177	3.0	40	57.6	31	5	15	19	40	113	222	1.9	19.0	0.3	12.6
S13	35	7.3	580	295	126	5.5	142	3.6	100	54.7	32	7	16	16	30	131	246	3.1	17.2	0.5	11.2
S14	34.9	7.2	670	343	143	4.7	157	3.0	40	59.1	31	5	18	19	30	143	216	0.6	4.1	0.4	11.2
S15	36	7.2	690	341	294	5.4	168	2.7	60	63.0	32	6	18	24	40	86	136	3.4	2.7	0.2	11.2
S16	36.3	7.3	601	296	136	5.7	173	3.6	80	65.8	32	7	16	23	50	157	108	2.0	11.8	0.5	12.6
S17	36.3	7.3	626	309	121	4.3	132	2.7	40	56.7	30	7	17	21	40	145	89	3.9	12.5	0.7	11.2
S18	36	7.4	613	299	441	5.2	163	1.6	40	56.8	31	6	17	27	40	170	169	10.2	14.6	0.3	12.6
S19	36.5	7.1	657	232	140	5.5	163	2.7	60	67.1	33	7	18	24	40	173	155	2.4	1.4	0.6	14
S20	36.9	7.4	655	342	146	3.2	191	3.2	80	67.2	32	5	18	24	80	109	147	1.6	12.2	0.2	12.6
Range	32.9-36.9	6.9-7.5	550-690	232-343	102-666	3.2-6.8	132-199	0.1-5.9	25-100	54.5-67.2	30-39	3 -7	15-20	15-29	20-80	86-181	89-504	0.5-10.2	1.4-25.8	0-0.9	7-14
Mean ±SD	35 ±1.2	7.29 ±0.2	613 ±41	299 ±26.7	244 ±146 .43	5.4 ±0.8	168 ±16.9	2.6 ±1.40	60 ±23	61.7 ±4.25	33 ±2.7	6 ±1.1	17 ±1.3	21.2 ±4.1	36 ±13.9	134.6 ±28.1	204.4 ±106.4	2.5 ±2.2	16.8 ±10.4	0.96 ±0.3	11.7 ±1.59

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites). All the Parameters have value in mg/l except Temp (°C), pH, EC (µS/cm), ORP (mV). ND and BDL represents Not Detected and Below Detection Limit.

4.2.2 Heavy Metals

The mean (±SD) value of heavy metal concentrations are shown in Table 4.8 (September, 2015 - May, 2016) and Table 4.9 (September, 2016 – May, 2017).

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Spatial and Seasonal Variations (September, 2015 to May, 2017)

Concentration of heavy metals, Cd, Cu, Cr, Fe, Ni, Pb and Zn in water samples of Bhindawas wetland was studied spatially and seasonally for the time periods of two years (September, 2015 to May, 2017) covering three major seasons i.e. monsoon, post-monsoon and pre-monsoon. Analytical results of varying concentration of heavy metals at different sampling locations along with inlet and outlet were shown in Table 4.8 and 4.9 and Fig. 4.22 to 4.28 represented the seasonal variations of heavy metal concentrations within wetland.

Cadmium (Cd)

During the first year of study, cadmium (Cd) in the water sample was observed in the post-monsoon and pre-monsoon with the values of 0.04 (S1-S3, S5, S18, S19) to 0.08 (S16) mg/l and BDL (S1, S3, S4, S13, S14, S20) to 0.03 (S7, S10, S12, S16) mg/l, whereas for monsoon

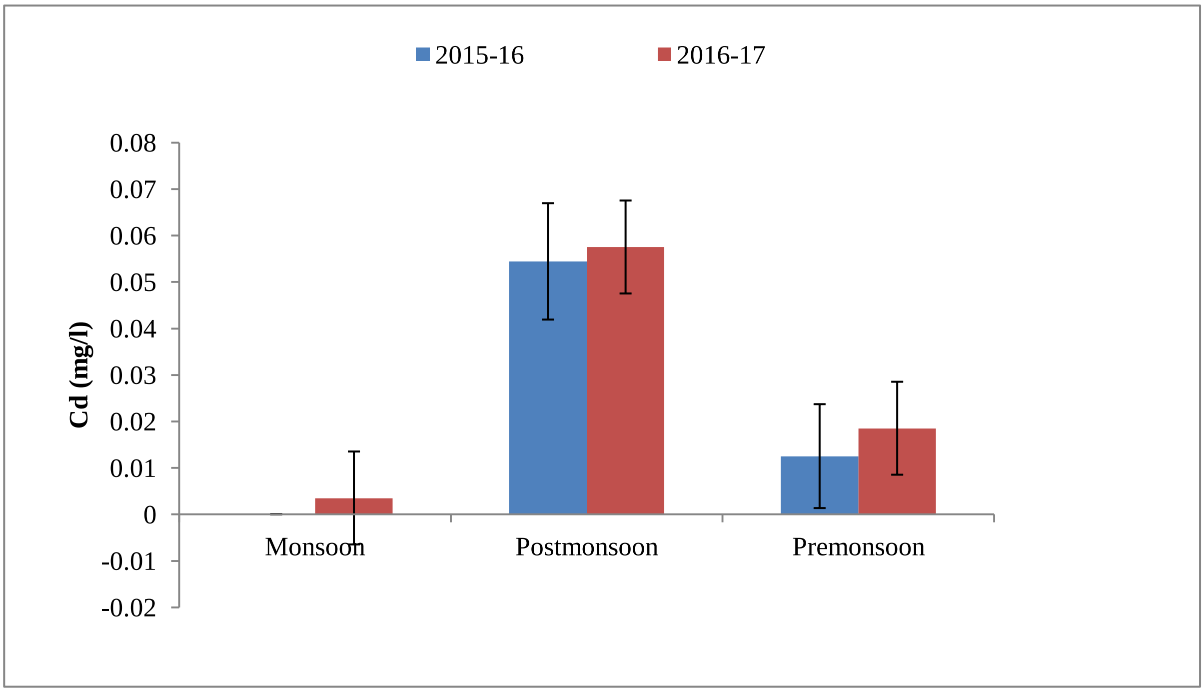

Figure. 4.22 Seasonal variations in mean concentration (mg/l) of Cadmium (Cd) in Bhindawas wetland in different seasons for two successive years.

the values were observed to be BDL whereas in second year, Cadmium (Cd) concentrations for monsoon, post-monsoon and pre-monsoon observed to be BDL (S1, S2, S4-S7, S9-S11, S13-S15, S17-S20) to 0.03 (S16) mg/l, 0.04 (S5, S6, S14) to 0.09 (S16) mg/l, BDL (S4, S5, S8, S13, S14, S18) to 0.06 (S16) mg/l respectively. The mean value of Cadmium (Cd) in surface water during the study period varied from BDL mg/l to 0.06 mg/l (Fig.4.22) The maximum value was observed to be high in post-monsoon 0.05 ± 0.01 (2015-16); 0.06 ± 0.01 (2016-17) followed by pre-monsoon 0.01 ± 0.01 (2015-16); 0.02 ± 0.02 (2016-17) and monsoon 0 ± 0 (2015-16); 0.004 ± 0.01 (2016-17) during the study of two years.

Chromium (Cr)

In the first year the value of Chromium (Cr) in the water sample varied from 0.01 mg/l (S2) to 0.11 mg/l (S13) in monsoon; BDL (S16) to 0.21 (S4) mg/l in post-monsoon; and 0.03 (S14, S15) to 0.11 (S8) mg/l during pre-monsoon (Table 4.8). Similarly, for the second year the value of Cr in the water sample varied from 0.03 (S2, S19, S20) to 0.15 (S17) mg/l during monsoon; 0.03 (S15) to 0.21 (S1, S12, S18) mg/l in post-monsoon; and BDL (S11) to 0.14 (S13) mg/l in pre-monsoon (Table 4.9).

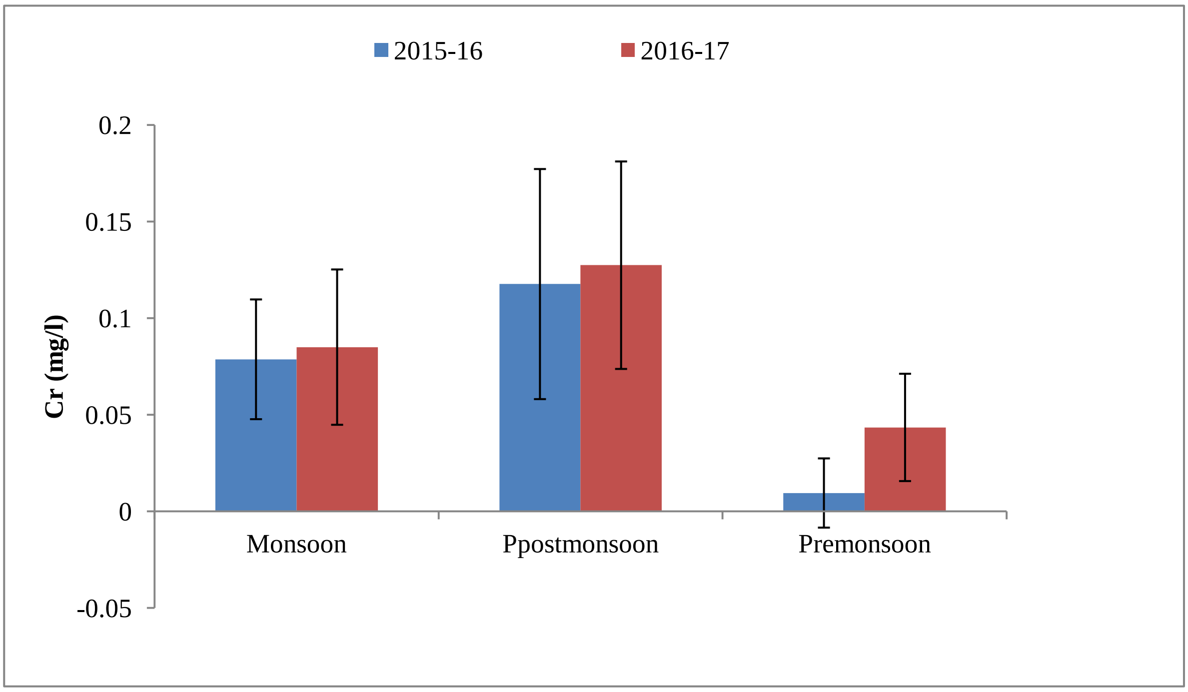

Figure. 4.23 Seasonal variations in mean concentration (mg/l) of Chromium (Cr) in Bhindawas wetland in different seasons for two successive years.

The mean value of Chromium (Cr) in surface water during the study period varied from 0.04

mg/l to 0.12 mg/l (Fig.4.23). The maximum value was observed to be high in post-monsoon 0.12 ± 0.06 (2015-16); 0.13 ± 0.05 (2016-17) followed by monsoon 0.08 ± 0.03 (2015-16); 0.09 ± 0.04 (2016-17) and pre-monsoon 0.07 ± 0.02 (2015-16); 0.04 ± 0.03 (2016-17) during the study of two years.

Copper (Cu)

Copper was detected with range, BDL (S8) to 0.09 (S2) mg/l; BDL (S6, S8, S12) to 0.08 (S1) mg/l and BDL (S1-S3, S7, S9, S12, S13, S15, S17, S19) to 0.08 (S8) mg/l during monsoon, post-monsoon and pre-monsoon respectively in first year study whereas for the second year copper for monsoon, post-monsoon and pre-monsoon was observed to be BDL (S5) to 0.12 (S2) mg/l, BDL (S5, S6, S8, S9, S12, S15, S18) to 0.08 (S1, S2) mg/l, and 0.03 (S7, S14) to 0.15 (S12) mg/l respectively. The mean value of copper (Cu) in surface water during the study period varied from 0.01 mg/l to 0.09 mg/l (Fig.4.24). The maximum value was observed to be high in pre-monsoon 0.01 ± 0.02 (2015-16); 0.09 ± 0.03 (2016-17) followed by monsoon 0.03 ± 0.03 (2015-16); 0.04 ± 0.03 (2016-17) and post-monsoon 0.02 ± 0.02 (2015-16); 0.03 ± 0.03 (2016-17) during the study of two years, which may be due to surface run off from agricultural fields and domestic waster.

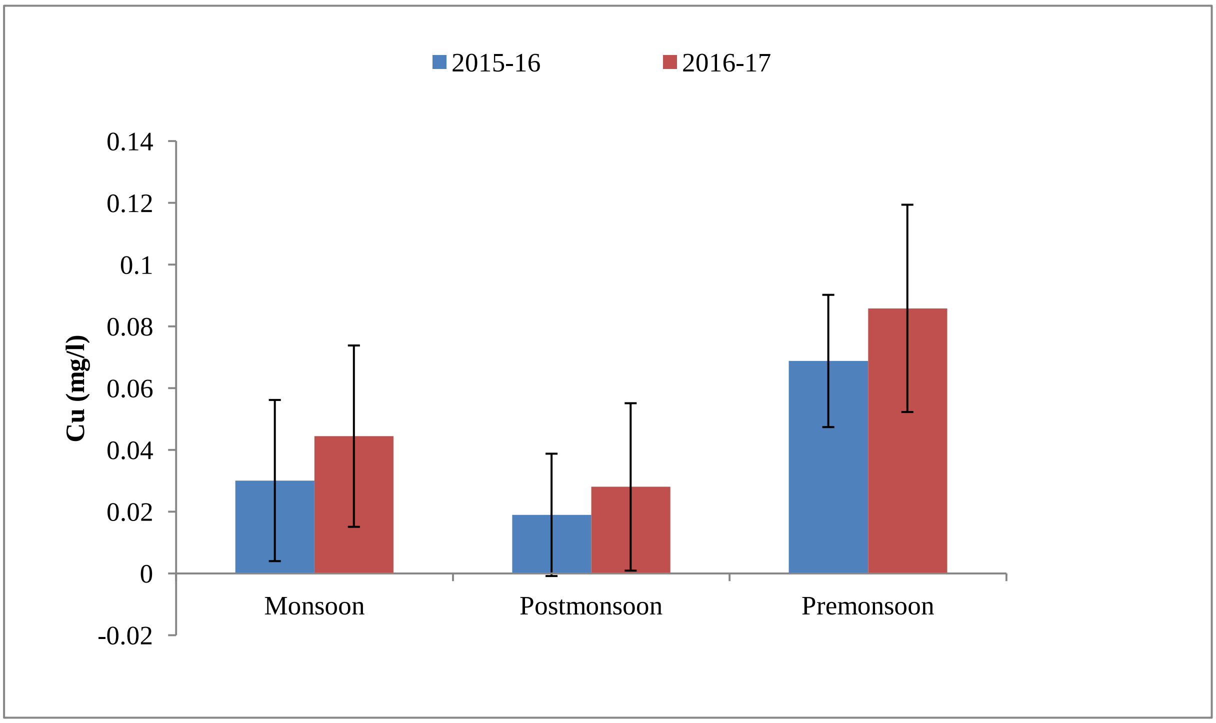

Figure. 4.24 Seasonal variations in mean concentration (mg/l) of Copper (Cu) in Bhindawas wetland in different seasons for two successive years.

Iron (Fe)

The range value for Iron (Fe) in monsoon, post-monsoon and pre-monsoon was observed to be 0.42 (S14) to 1.90 (S10) mg/l; 1.35 (S3) to 2.52 (S18) mg/l and 0.36 (S16) to 1.30 (S18) mg/l respectively during the first year whereas values, for the second year in monsoon, post-monsoon and pre-monsoon was observed to be 0.18 (S9) to 1.98 (S10) mg/l; 1.04 (S13) to 2.14 (S18) mg/l and 0.39 (S4) to 0.91 (S13) mg/l respectively.

The mean value of iron (Fe) in surface water during the study period varied from 0.66 mg/l to 1.73 mg/l (Fig.4.25). The maximum value was observed to be high in post-monsoon 1.73 ± 0.27 (2015-16); 1.72 ± 0.30 (2016-17) followed by monsoon 0.71 ± 0.37 (2015-16); 0.76 ± 0.45 (2016-17) and pre-monsoon 0.68 ± 0.23 (2015-16); 0.66 ± 0.17 (2016-17) during the study of two years.

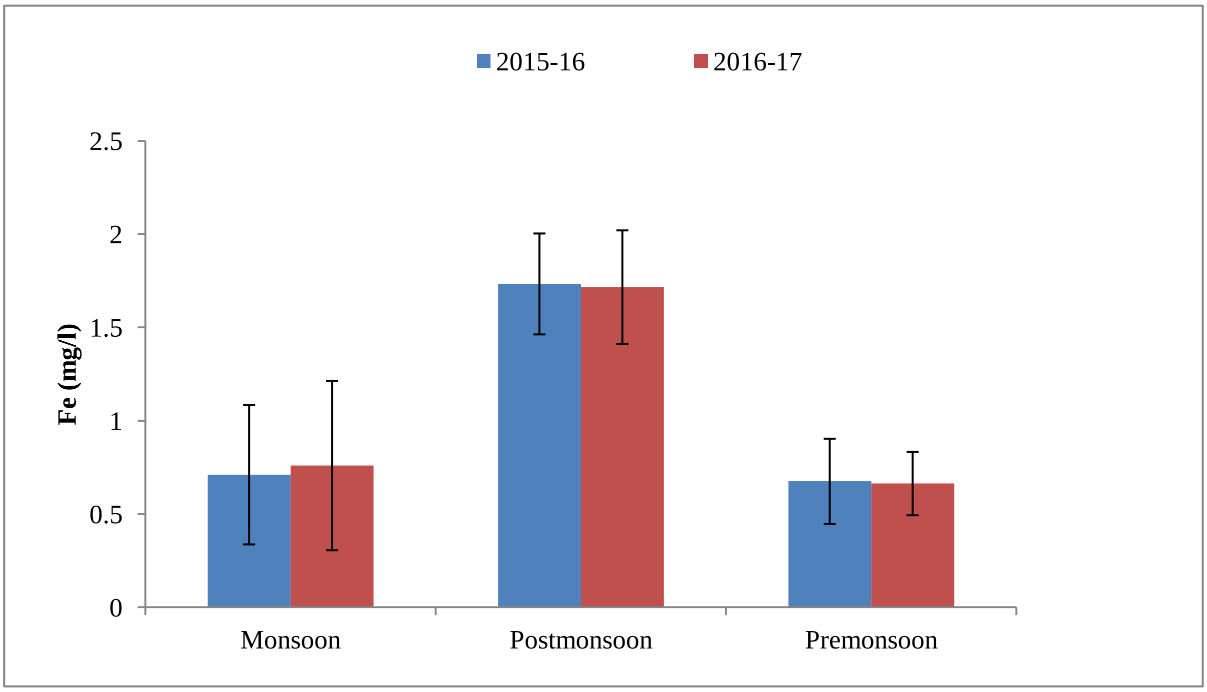

Figure. 4.25 Seasonal variations in mean concentration (mg/l) of Iron (Fe) in Bhindawas wetland in different seasons for two successive years

Nickel (Ni)

Nickel (Ni) was observed to be 0.17 (S3) to 0.32 (S15) mg/l in monsoon, BDL (S3, S4) to 0.34 (S17) mg/l in post-monsoon and BDL (S2, S3) to 0.3 (S10) mg/l in pre-monsoon during first year of the study while nickel (Ni) concentration was observed to be 0.16 (S3) to 0.36 (S15) mg/l, BDL (S4) to 0.38 (S9) mg/l and BDL (S1-S3) to 0.40 (S11) mg/l in second year of monsoon, post-monsoon and pre-monsoon respectively.

The mean value of nickel (Ni) in surface water during the study period varied from 0.12 mg/l to 0.27 mg/l (Fig.4.26). The maximum value was observed to be high in monsoon (0.25 ± 0.04 (2015-16); 0.27 ± 0.05 (2016-17) followed by post-monsoon 0.15 ± 0.12 (2015-16); 0.17 ± 0.12 (2016-17) and pre-monsoon 0.12 ± 0.09 (2015-16); 0.16 ± 0.11 (2016-17) during the study of two years.

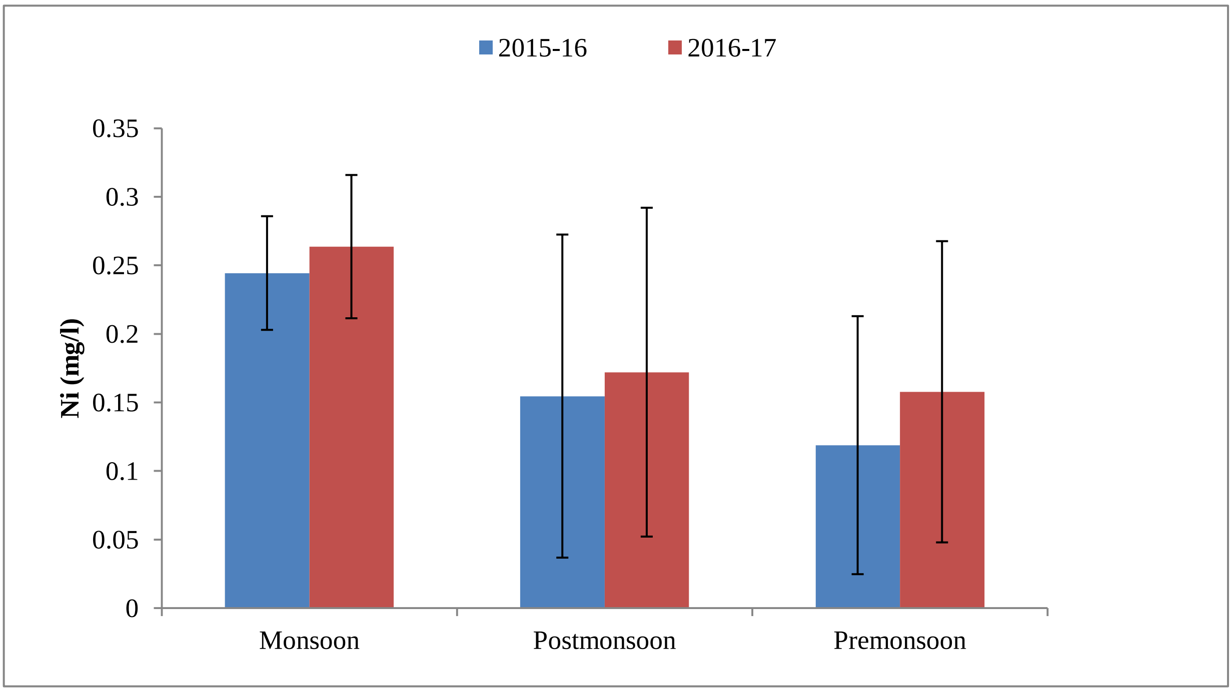

Figure. 4.26 Seasonal variations in mean concentration (mg/l) of Nickel (Ni) in Bhindawas wetland in different seasons for two successive years.

Lead (Pb)

Concentration of Lead (Pb), in monsoon, post-monsoon and pre-monsoon was investigated to be 0.21 (S19) to 3.50 (S12) mg/l, 0.12 (S1) to 0.74 (S8) mg/l and 0.57 (S3) to 0.78 (S13) mg/l and 0.70 (±0.07) mg/l respectively during the first year and in second year value were observed between, 0.2 (S2) to 3.09 (S12) mg/l; 0.15 (S1, S9) to 0.81 (S8) mg/l, and 0.08 (S1) to 0.88 (S5, S14) mg/l in monsoon, post-monsoon and pre-monsoon respectively.

The mean value of Lead (Pb) in surface water during the study period varied from 0.43 mg/l to 0.97 mg/l (Fig.4.27). The maximum value was observed to be high in monsoon 0.96 ± 0.71 (2015-16); 0.97 ± 0.60 (2016-17) followed by pre-monsoon 0.70 ± 0.07 (2015-16); 0.73 ±. 0.17 (2016-17) and post-monsoon 0.43 ± 0.21 (2015-16); 0.47 ± 0.22 (2016-17) during the study of two years.

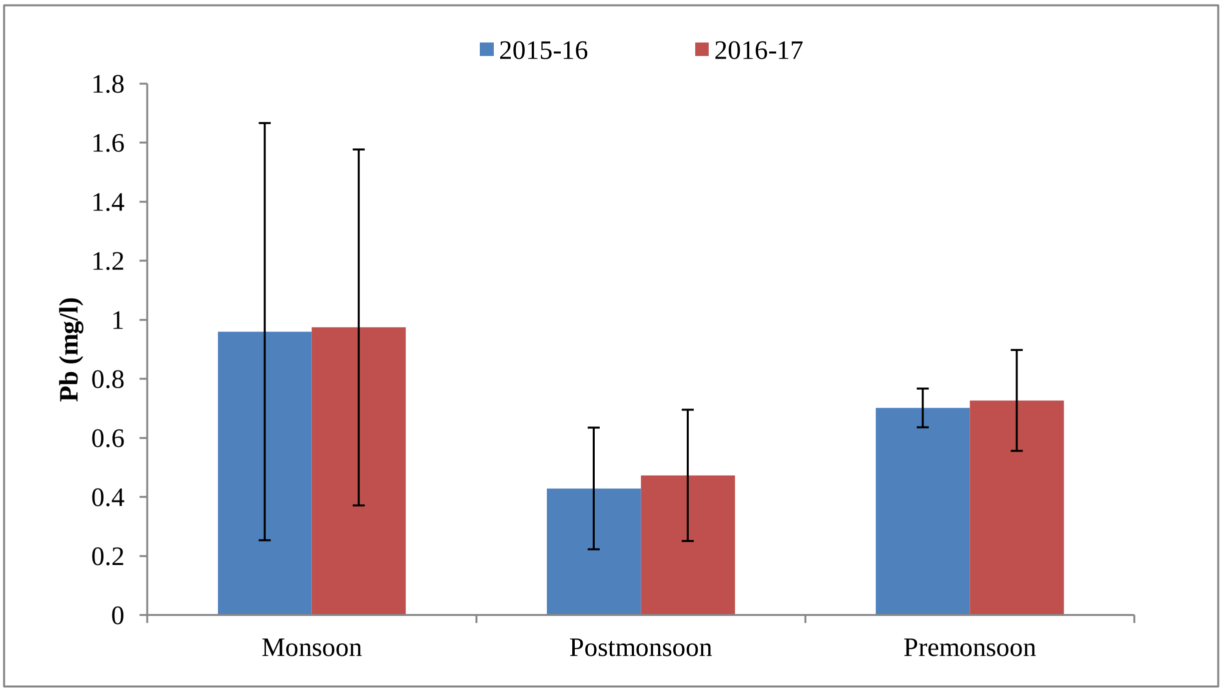

Figure. 4.27 Seasonal variations in mean concentration (mg/l) of Lead (Pb) in Bhindawas wetland in different seasons for two successive years.

Zinc (Zn)

Zinc (Zn) in monsoon, post-monsoon and pre-monsoon was observed to be BDL (S2-S6, S8, S9, S11, S13-S20) to 0.16 (S7) mg/l; 0.05 (S1) to 0.37 (S6) mg/l, and 0.09 (S1) to 0.20 (S13) mg/l respectively during first year and in second year concentration ranged from BDL (S1, S3, S6, S11, S16-S18) to 0.3 (S10) mg/l; 0.03 (S1) to 0.45 (S6) mg/l, and 0.1 (S4, S5, S8, S14, S15, S20) to 0.3 (S13) mg/l in monsoon, post-monsoon and pre-monsoon of second year be respectively The mean value of zinc (Zn) in surface water during the study period varied from 0.01 mg/l to 0.19 mg/l (Fig.4.28). The maximum value was observed to be high in post-monsoon 0.16 ± 0.07 (2015-16); 0.19 ± 0.10 (2016-17) followed by pre-monsoon 0.13 ± 0.02 (2015-16); 0.16 ± 0.04 (2016-17) and monsoon 0.01 ± 0.04 (2015-16); 0.02 ± 0.02 (2016-17) during the study of two years.

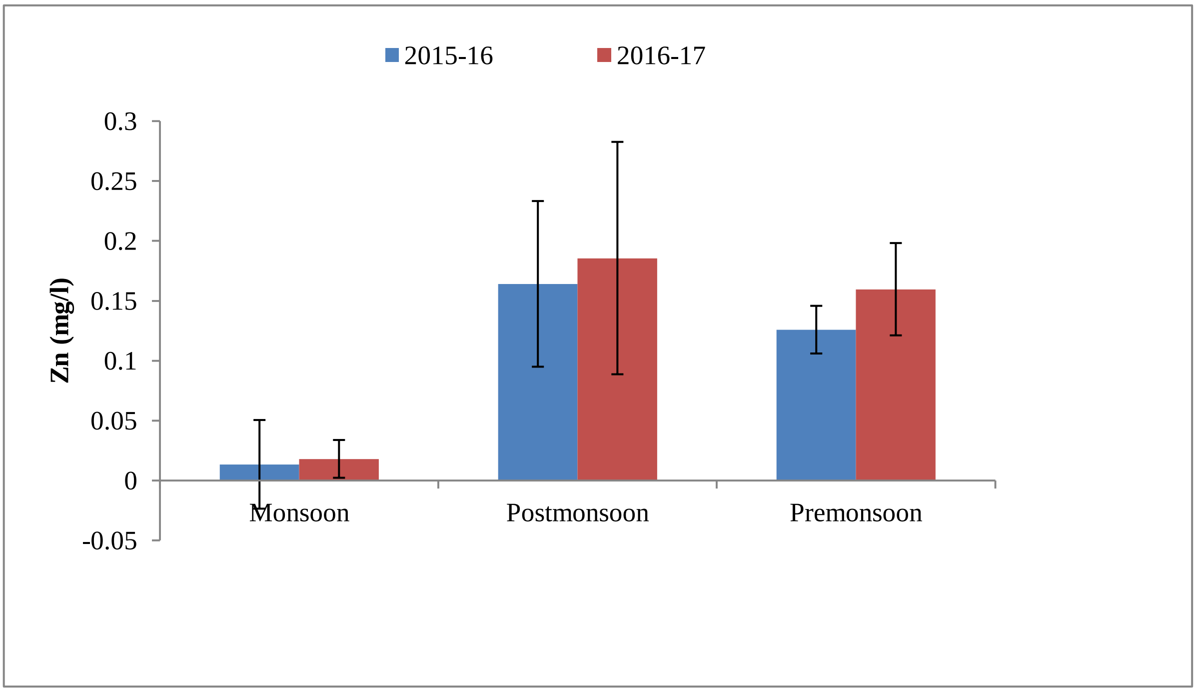

Figure. 4.28 Seasonal variations in mean concentration (mg/l) of Zinc (Zn) in Bhindawas wetland in different seasons for two successive years.

Table 4.8 Heavy metal concentration (mg/l) in surface water of Bhindawas Wetland (September, 2015 - May, 2016).

	Monsoon							**Post-monsoon**							**Pre-monsoon**						
Sites	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**	**Cd**	**Cu**	**Cr**	**Fe**	**Ni**	**Pb**	**Zn**
Inlet	BDL	0.01	0.10	0.67	0.24	0.00	BDL	0.04	0.06	0.09	2.05	0.36	0.51	0.21	BDL	0.01	0.06	1.31	0.18	0.78	0.14
Outlet	BDL	0.01	0.37	0.77	0.28	1.62	BDL	0.06	0.06	0.12	2.46	0.62	0.57	0.21	0.03	0.02	0.06	0.23	0.15	0.78	0.12
S1	BDL	0.05	0.01	0.44	0.17	0.66	0.04	0.04	0.18	0.08	1.45	0.13	0.12	0.05	BDL	BDL	0.08	0.71	0.01	0.65	0.09
S2	BDL	0.01	0.09	0.63	0.26	0.26	BDL	0.04	0.09	0.06	1.37	0.07	0.61	0.17	0.01	BDL	0.05	0.57	BDL	0.67	0.12
S3	BDL	0.10	0.02	0.42	0.17	0.57	BDL	0.04	0.12	0.02	1.35	BDL	0.67	0.14	BDL	BDL	0.05	0.42	BDL	0.57	0.11
S4	BDL	0.09	0.02	0.62	0.20	0.60	BDL	0.05	0.21	0.01	1.43	BDL	0.70	0.18	BDL	0.01	0.09	0.45	0.05	0.63	0.12
S5	BDL	0.09	0.02	0.57	0.22	0.68	BDL	0.04	0.18	0.02	1.44	0.03	0.18	0.26	0.01	0.02	0.09	1.08	0.02	0.77	0.12
S6	BDL	0.09	0.02	0.58	0.23	0.69	BDL	0.05	0.11	BDL	1.87	0.09	0.26	0.37	0.01	0.01	0.05	0.93	0.09	0.72	0.13
S7	BDL	0.07	0.02	1.44	0.23	0.79	0.16	0.05	0.11	0.04	1.71	0.06	0.59	0.18	0.03	BDL	0.06	0.59	0.01	0.61	0.14
S8	BDL	0.10	0.00	0.99	0.22	0.81	BDL	0.06	0.11	BDL	1.62	0.26	0.74	0.08	0.02	0.08	0.11	0.58	0.23	0.64	0.12
S9	BDL	0.09	0.03	0.67	0.25	0.81	BDL	0.06	0.13	0.02	1.68	0.31	0.22	0.11	0.01	BDL	0.07	0.60	0.21	0.74	0.13
S10	BDL	0.09	0.03	1.90	0.23	0.81	0.02	0.06	0.03	0.01	1.73	0.18	0.63	0.14	0.03	0.01	0.07	0.53	0.30	0.68	0.11
S11	BDL	0.09	0.04	0.46	0.25	1.00	BDL	0.06	0.12	0.01	1.99	0.27	0.35	0.25	0.01	0.01	0.06	0.71	0.23	0.77	0.13
S12	BDL	0.09	0.03	0.76	0.25	3.50	0.04	0.07	0.19	BDL	1.84	0.19	0.30	0.18	0.03	BDL	0.08	0.61	0.02	0.63	0.12
S13	BDL	0.11	0.02	0.99	0.27	1.12	BDL	0.07	0.09	0.01	1.76	0.13	0.20	0.14	BDL	BDL	0.05	0.82	0.08	0.78	0.20
S14	BDL	0.08	0.01	0.42	0.29	1.13	BDL	0.06	0.10	0.02	1.65	0.26	0.19	0.21	BDL	0.01	0.03	0.50	0.18	0.75	0.12
S15	BDL	0.10	0.02	0.44	0.32	1.71	BDL	0.07	0.01	0.01	1.77	0.08	0.51	0.11	0.01	BDL	0.03	0.58	0.17	0.76	0.12
S16	BDL	0.10	0.02	0.50	0.29	1.13	BDL	0.08	BDL	0.02	2.04	0.31	0.28	0.11	0.03	0.01	0.05	0.36	0.23	0.77	0.13
S17	BDL	0.10	0.02	0.53	0.28	1.28	BDL	0.05	0.08	0.03	1.79	0.34	0.56	0.16	0.02	BDL	0.09	0.76	0.17	0.66	0.14
S18	BDL	0.11	0.02	0.54	0.31	1.22	BDL	0.04	0.19	0.01	2.52	0.31	0.27	0.14	0.02	0.02	0.08	1.30	0.08	0.74	0.14
S19	BDL	0.01	0.08	0.69	0.21	0.21	BDL	0.04	0.12	0.01	1.83	0.02	0.59	0.17	0.01	BDL	0.09	0.85	0.13	0.77	0.13
S20	BDL	0.01	0.09	0.62	0.23	0.23	BDL	0.05	0.18	0.01	1.82	0.05	0.60	0.14	BDL	0.01	0.10	0.59	0.16	0.74	0.12
Range	BDL	0.01-0.11	BDL-0.09	0.42-1.90	0.17-0.32	0.21-3.50	BDL-0.16	0.04-0.08	BDL-0.21	BDL-0.08	1.35-2.52	BDL-0.34	0.12-0.74	0.05-0.37	BDL-0.03	BDL-0.08	0.03-0.11	0.36-1.30	BDL-0.3	0.57-0.78	0.09-0.20
Mean± SD	BDL	0.08± 0.03	0.03 ±0.03	0.71 ±0.37	0.25 ±0.04	0.96 ±0.71	0.01 ±0.04	0.05 ±0.01	0.12 ±0.06	0.02 ±0.02	1.73 ±0.27	0.15 ±0.12	0.43 ±0.21	0.16 ±0.07	0.01 ±0.01	0.01 ±0.02	0.07 ±0.02	0.68 ±0.23	0.12 ±0.09	0.70 ±0.07	0.13 ±0.02

Note: The mean and (±SD) was carried out from sampling sites (S1-S20), and BDL represents Below Ddetection Limit.

Table 4.9 Heavy metal concentration (mg/l) in surface water of Bhindawas Wetland (September 2016 - May, 2017).

	Monsoon							Post-monsoon							Pre-monsoon						
Sites	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**
Inlet	0.01	0.01	0.10	0.73	0.27	0.02	BDL	0.03	0.14	0.10	2.29	0.41	0.55	0.17	BDL	0.03	0.05	1.76	0.21	0.61	0.19
Outlet	0.03	0.03	0.32	0.81	0.25	1.83	0.07	0.07	0.085	0.14	2.43	0.53	0.61	0.33	0.04	0.03	0.07	0.16	0.19	0.91	0.11
S1	BDL	0.06	0.02	0.43	0.19	0.70	BDL	0.05	0.213	0.08	1.52	0.17	0.15	0.03	0.01	0.02	0.09	0.83	BDL	0.08	0.13
S2	BDL	0.03	0.12	0.73	0.27	0.20	0.02	0.05	0.11	0.08	1.26	0.10	0.65	0.19	0.03	0.05	0.06	0.45	BDL	0.78	0.18
S3	0.01	0.07	0.02	0.54	0.16	0.65	BDL	0.05	0.14	0.03	1.44	0.03	0.75	0.13	0.02	0.05	0.07	0.65	BDL	0.65	0.14
S4	BDL	0.1	0.04	0.55	0.26	0.70	0.01	0.06	0.12	0.04	1.26	BDL	0.75	0.21	BDL	0.03	0.11	0.39	0.08	0.59	0.1
S5	BDL	0.07	BDL	0.62	0.27	0.79	0.02	0.04	0.2	BDL	1.51	BDL	0.35	0.33	BDL	0.05	0.13	0.81	0.05	0.88	0.1
S6	BDL	0.05	0.02	0.61	0.27	0.60	BDL	0.04	0.14	BDL	1.73	0.14	0.35	0.45	0.01	0.06	0.06	0.86	0.13	0.67	0.2
S7	BDL	0.12	0.04	1.19	0.21	0.82	0.03	0.05	0.11	0.04	1.86	0.07	0.65	0.16	0.04	0.03	0.03	0.52	0.19	0.78	0.2
S8	0.01	0.06	0.04	1.01	0.25	0.89	0.03	0.07	0.12	BDL	1.72	0.24	0.81	0.04	BDL	0.04	0.09	0.71	0.21	0.68	0.1
S9	BDL	0.1	0.06	0.18	0.29	0.91	0.05	0.07	0.08	BDL	1.87	0.38	0.15	0.15	0.03	0.03	0.08	0.66	0.27	0.76	0.2
S10	BDL	0.11	0.06	1.98	0.21	0.93	0.30	0.06	0.062	0.02	1.65	0.24	0.55	0.12	0.02	0.05	0.10	0.45	0.34	0.72	0.2
S11	BDL	0.07	0.02	0.37	0.27	1.03	BDL	0.06	0.13	0.02	2.13	0.31	0.35	0.29	0.02	BDL	0.07	0.74	0.40	0.81	0.2
S12	0.02	0.06	0.03	0.89	0.28	3.09	0.02	0.08	0.21	BDL	1.92	0.24	0.29	0.24	0.02	0.02	0.15	0.71	0.03	0.68	0.2
S13	BDL	0.14	0.02	1.82	0.31	0.97	0.01	0.05	0.11	0.02	1.04	0.14	0.25	0.20	BDL	0.14	0.07	0.91	0.11	0.84	0.3
S14	BDL	0.14	0.02	0.38	0.34	1.19	0.05	0.04	0.12	0.02	1.73	0.24	0.25	0.17	BDL	0.06	0.03	0.45	0.16	0.88	0.1
S15	BDL	0.13	0.08	0.47	0.36	1.20	0.01	0.07	0.03	BDL	1.82	0.10	0.65	0.13	0.04	0.04	0.04	0.62	0.19	0.73	0.1
S16	0.03	0.13	0.02	0.68	0.31	1.41	BDL	0.09	0.04	0.04	2.13	0.31	0.25	0.11	0.06	0.02	0.06	0.40	0.21	0.83	0.2
S17	BDL	0.15	0.07	0.62	0.27	1.40	BDL	0.06	0.091	0.07	1.77	0.31	0.55	0.14	0.05	0.06	0.12	0.82	0.21	0.73	0.2
S18	BDL	0.05	0.07	0.59	0.31	1.30	BDL	0.05	0.21	BDL	2.14	0.34	0.35	0.16	BDL	0.05	0.09	0.76	0.19	0.83	0.2
S19	BDL	0.03	0.05	0.81	0.18	0.40	0.04	0.05	0.14	0.04	1.89	0.03	0.65	0.27	0.01	0.04	0.14	0.88	0.19	0.82	0.2
S20	BDL	0.03	0.08	0.73	0.26	0.30	0.02	0.06	0.172	0.04	1.95	0.07	0.75	0.19	0.01	0.03	0.09	0.66	0.21	0.78	0.1
Range	BDL-0.03	0.03-0.15	BDL-0.12	0.18-1.98	0.18-0.36	0.20-3.09	BDL-0.30	0.04-0.09	0.03-0.21	BDL-0.14	1.04-2.14	BDL-0.38	0.15-0.81	0.03-0.45	BDL-0.06	BDL-14	0.03-0.15	0.39-0.91	BDL-0.40	0.08-0.88	0.1-0.3
Mean ±SD	0.004 ±0.01	0.09 ±0.04	0.04 ±0.03	0.76 ±0.45	0.27 ±0.05	0.97 ±0.60	0.02 ±0.02	0.06 ±0.01	0.13 ±0.05	0.03 ±0.03	1.72 ±0.30	0.17 ±0.12	0.47 ±0.22	0.19 ±0.10	0.02 ±0.02	0.04 ±0.03	0.09 ±0.03	0.66 ±0.17	0.16 ±0.11	0.73 ±0.17	0.16 ±0.04

Note: The mean and (±SD) was carried out from sampling sites (S1-S20), and BDL represents Below Ddetection Limit.

4.2.3 Water Quality Indices

Classification of water quality in Bhindawas wetland was carried out based on, Heavy Metal Pollution Index (HPI), Heavy Metal Evaluation Index (HEI), Degree of Contamination (Cd) and Water Quality Index (WQI). Further the water quality based upon HPI, HEI, Cd and WQI is evaluated according to the International Standards (CCME, 2007 and FAO, 1994) for its suitability in irrigation and aquatic use .

4.2.3.1 Water Quality Indices for Aquatic Life

Classification of water quality in Bhindawas wetland was carried out based on HPI, HEI, Cd and WQI for aquatic life for two years (September, 2015 to May, 2017; monsoon, post-monsoon and pre-monsoon) is shown in Table 4.10 and Table 4.15.

Heavy Metal Pollution Index (HPI)

HPI is based on the weight (Wi) of the metals analysed in a study. The weight or rating varies between 0 and 1, which indicates the relative significance of an individual metal and it is evaluated by inverse proportion of the standard/normative value (Si) of that metal. The normative value used for calculated HPI value to assess its suitability for aquatic use (CCME, 2007). In the present study, the degree of pollution was observed to be low for 65%; medium for 30% and high for only 5% of samples for aquatic life in monsoon. The observed values of HPI for aquatic life varied from 25 to 161 (monsoon), 11 to 36 (post -monsoon) and 26 to 41 (pre-monsoon).

Relatively higher values were observed at locations S12 for monsoon; medium at locations S2 for post-monsoon; and S8 for pre-monsoon. The reason may be excess uptake of heavy metal by plants. Higher levels of heavy metals in that particular region may be ascribed to pumping of domestic sewage from the adjoining village. This indicates that the water quality is questionable for aquatic life. It becomes a cause of concern since Bhindawas wetland is a temporary nesting ground for the migratory birds during the winter season. The classification of degree of pollution for aquatic use is given in Table 4.10 to Table 4.15.

For the second year the observed values of HPI for aquatic life varied from 25 to 143 (Monsoon), 8 to 53 (Post-monsoon) and 16 to 57 (Pre-monsoon). Relatively higher values were observed at location S10 for monsoon; S4 for post-monsoon and medium HPI values for pre-monsoon sampling locations indicating moderate pollution. The classification of degree of pollution for aquatic use is given in Table 4.13 to 4.15.

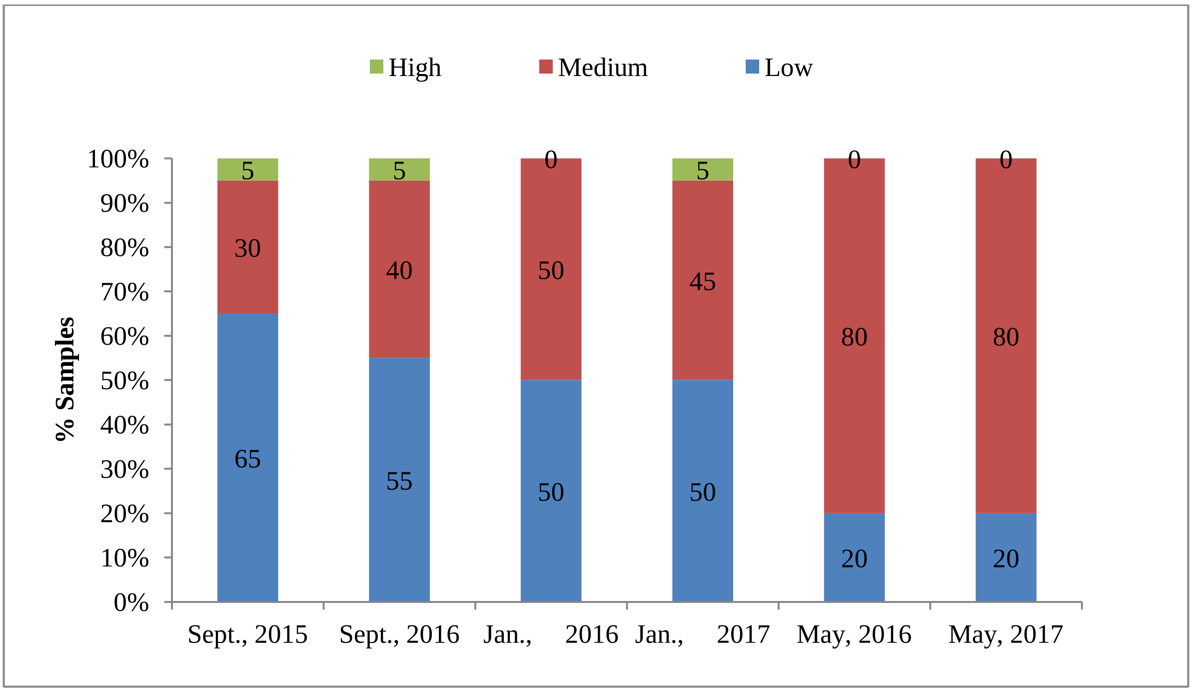

Figure 4.29 Heavy metal pollution index (HPI) in surface water of Bhindawas Wetland (September, 2015 - May, 2017) for aquatic use.

Heavy Metal Evaluation Index (HEI)

HEI is an indication of aggregated quality of water with respect to the analysed heavy metals. It is used for a clear understanding and validation of other pollution indices by synchronising the classification criteria of the other indices. Based on the values of HEI, 65% of the samples add low degree of pollution; 30% had medium; and 5% of the sample had the high degree of the pollution in monsoon was observed in case of HPI. The samples having maximum HEI value was observed at sampling location S12 for monsoon and in post-monsoon and pre-monsoon, 50% and 35% sampling locations were found with low HEI values along with medium degree of pollution with 50% and 65% sampling locations during post-monsoon and pre-monsoon respectively. The classification of water based on HEI is given in Table 4.10 to Table.4.15.

For the second year the samples having maximum HEI value was observed again at S12 with low degree of pollution by 55%, 50% and 25% sampling sites in monsoon, post-monsoon and pre-monsoon respectively. About 40%, 50% and 75% sampling sites indicated medium pollution during monsoon, post-monsoon and pre-monsoon. The classification of water based on HEI is given in Table 4.13 to Table 4.15.

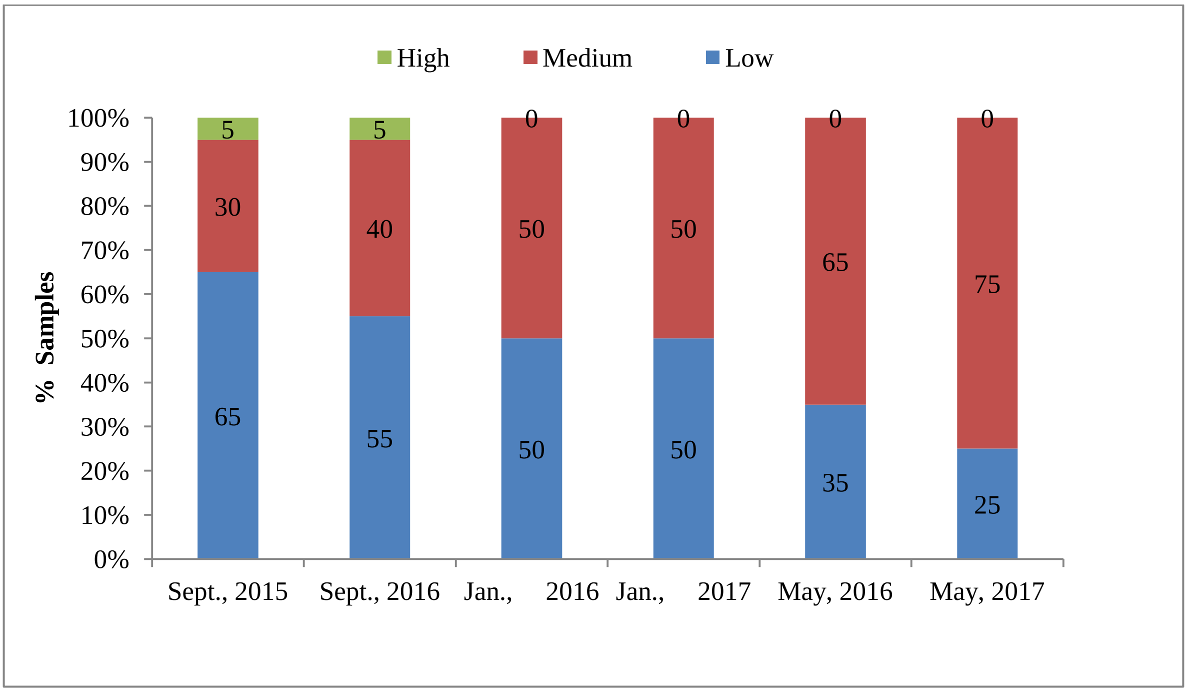

Figure 4.30 Heavy metal evaluation index (HEI) in surface water of Bhindawas Wetland (September, 2015 - May, 2017) for aquatic use.

Degree of Contamination (C_d)

The degree of contamination/contamination index (C_d) is another representation of the quality of water with respect to the heavy metal concentration. Based on the values of C_d, 65% samples during monsoon, 50% during post-monsoon and 30% in pre-monsoon had low; 30%, 50% and 70% samples had medium degree of pollution during monsoon, post-monsoon and pre-monsoon respectively and 5% samples having high degree of pollution during monsoon only confirming to the classification as observed for HPI and HEI of water for aquatic life. The details of C_d are given in Table 4.10 to 4.15.

For the second year of study, 55%, 65% and 40% samples indicated low degree of pollution and 45%, 30% and 60% samples contributed medium degree of pollution in monsoon, post-monsoon and pre-monsoon respectively. Only a single sampling location, S12 was observed with highest degree of pollution.

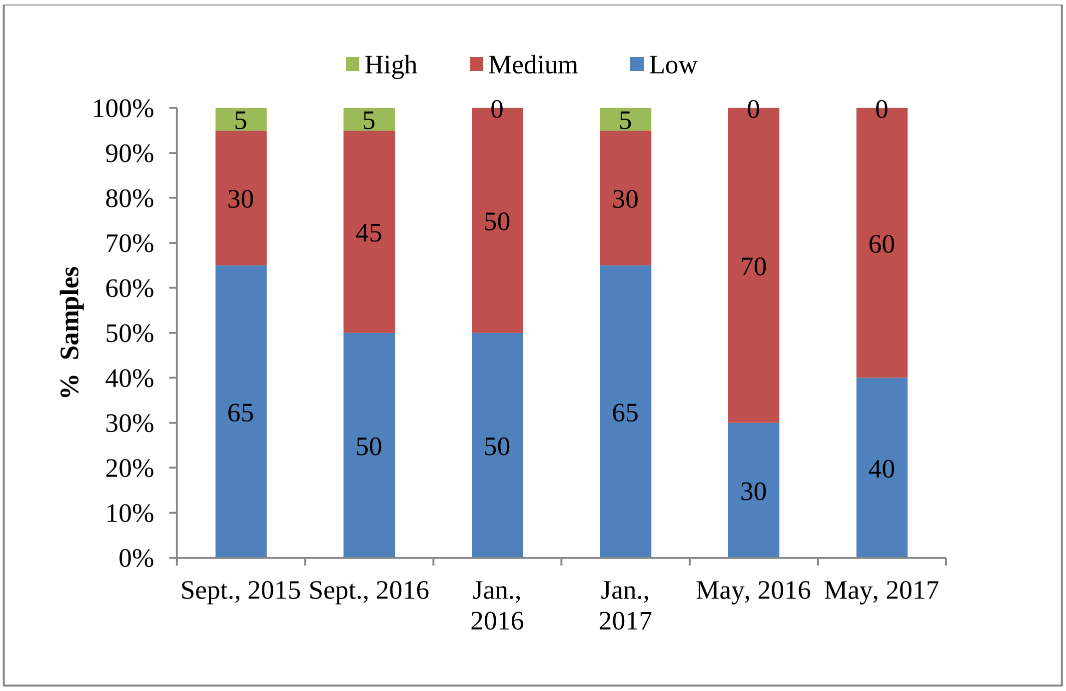

Figure 4.31 Degree of contamination (C_d) in surface water of Bhindawas Wetland (September, 2015 - May, 2017) for aquatic use.

Based on various indices (HPI, HEI, C_d), for degree of pollution most of the locations were having good quality of water for irrigation and aquatic life with the only exception of region adjoining rural habitation in north east region of the wetland. For aquatic life all three indices had similar classification for quality and validated each other. For agricultural quality C_d and HEI had similar values and were 85% in conformance with HPI.

Water Quality Index (WQI)

The Water Quality Index (WQI) is another representation of the quality of water with respect to physico-chemical parameters. Based on the values of WQI 100% samples are found unsuitable for monsoon and pre-monsoon, 85% samples are unsuitable in post-monsoon. But during the study of second year,100% of samples in all the seasons are found unsuitable indicating high degree of pollution respectively. The details of WQI are given in Table 4.10 to 4.15 (September, 2015- May, 2016) and Table 4.13 to 4.15 (September, 2016- May, 2017).

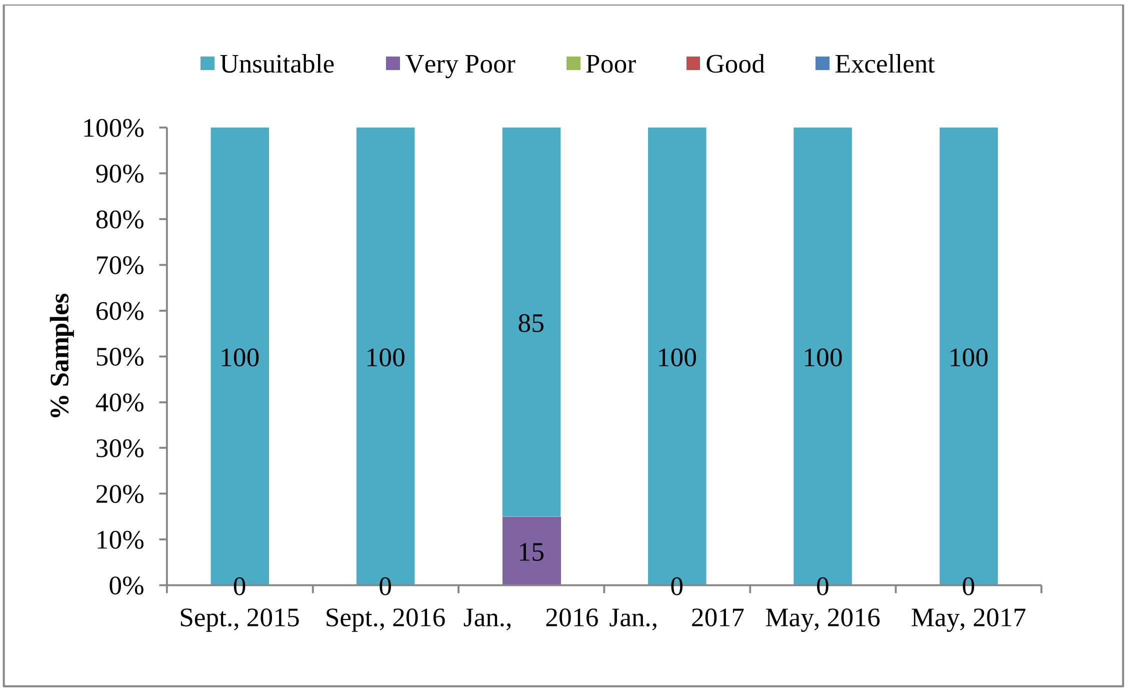

Figure 4. 32 Water quality index (WQI) of surface water of Bhindawas Wetland (September, 2015 - May, 2017) for aquatic use.

4.2.3.2 Water Quality Indices for Irrigation

Classification of water quality in Bhindawas wetland was carried out based on HPI, HEI, Cd and WQI for irrigation for two years (September, 2015 to May, 2017; monsoon, post-monsoon and pre-monsoon) is shown in Table 4.10 and Table 4.15.

Heavy Metal Pollution Index (HPI)

The normative value used for calculated HPI value to assess its suitability for irrigational use is based on FAO, 1994. In the present study, the degree of pollution was observed to be low for 95% for samples; medium for 5% samples for irrigation use. The observed values of HPI for irrigation use varied from 0.5 to 1.3 (monsoon), 0.03 to 0.89 (post -monsoon) and 0.004 to 0.75 (pre-monsoon). In the second year of the study the values varied from 0.5 to 1.3; 0.01 to 0.92; and 0.15 to 1.13 for monsoon, post-monsoon and pre-monsoon respectively.

Relatively lower values < 1 has been observed from sites S2 to S20, indicating low degree of pollution for monsoon; relatively all sites (S1 to S20) falls < 2 category indicating low degree of pollution in post-monsoon; and 45% sites <0.5 indicating low degree of pollution for pre-monsoon and 45% with medium degree of pollution and sampling sites S13 and S18 having high values indicating highest pollution at these sites. Low degree of pollution for monsoon and post-monsoon was observed indicating that heavy metals were in the permissible limits for use in irrigation. Since the heavy metals uptake by the plants is selective and restrictive, relatively smaller fractions are assimilated in the plant tissues. Therefore the standard limits for use in irrigation are relaxed /higher which results in low values of HPI for agricultural use. The classification of degree of pollution for irrigation use is given in Table 4.10. to 4.15. For the second year the observed values of HPI for irrigation varied from 0.5 to 1.3 (monsoon), 0.01 to 0.92 (post -monsoon) and 0.15 to 1.13 (pre-monsoon). During the study period of second year, 30% sampling sites in monsoon, 50% in post-monsoon and 55% in pre-monsoon have low degree of pollution whereas 70%, 50% and 45% locations were observed with medium degree of pollution (Table 4.13 to Table 4.15).

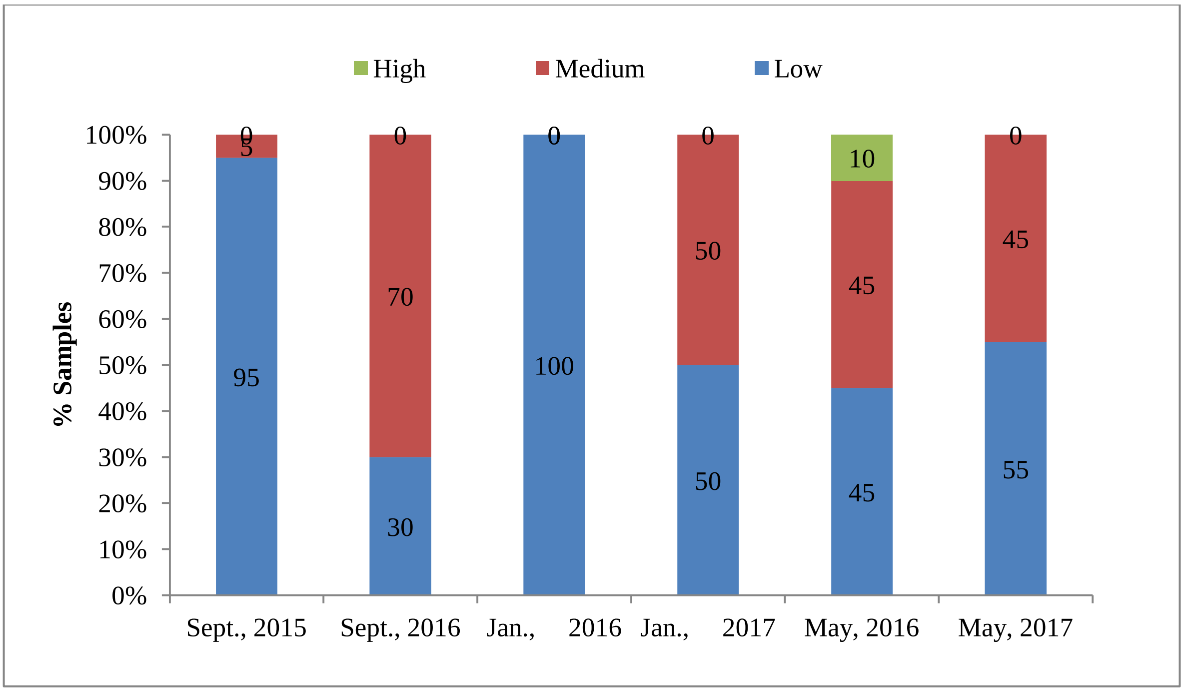

Figure 4.33 Heavy metal pollution index (HPI) in surface water of Bhindawas Wetland (September, 2015 - May, 2017) for irrigation use.

Heavy Metal Evaluation Index (HEI)

Based on the values of HEI, 85%, 65% and 45% of the samples add low degree of pollution and 15%, 35% and 55% of samples for medium degree of the pollution in monsoon, post-monsoon and pre-monsoon respectively. The samples having HEI value was observed in range from 1.1 to 2.2 in monsoon, 0.57 to 2.40 in post-monsoon and 0.05 to 0.37 in pre-monsoon. Similarly for the second year, 95%, 75% and 55% samples representing low degree of pollution and 5%, 25% and 45% of samples contributed medium degree of pollution in monsoon, post-monsoon and pre-monsoon respectively. The classification of water based on HEI is given in Table .4.13 to 4.15.

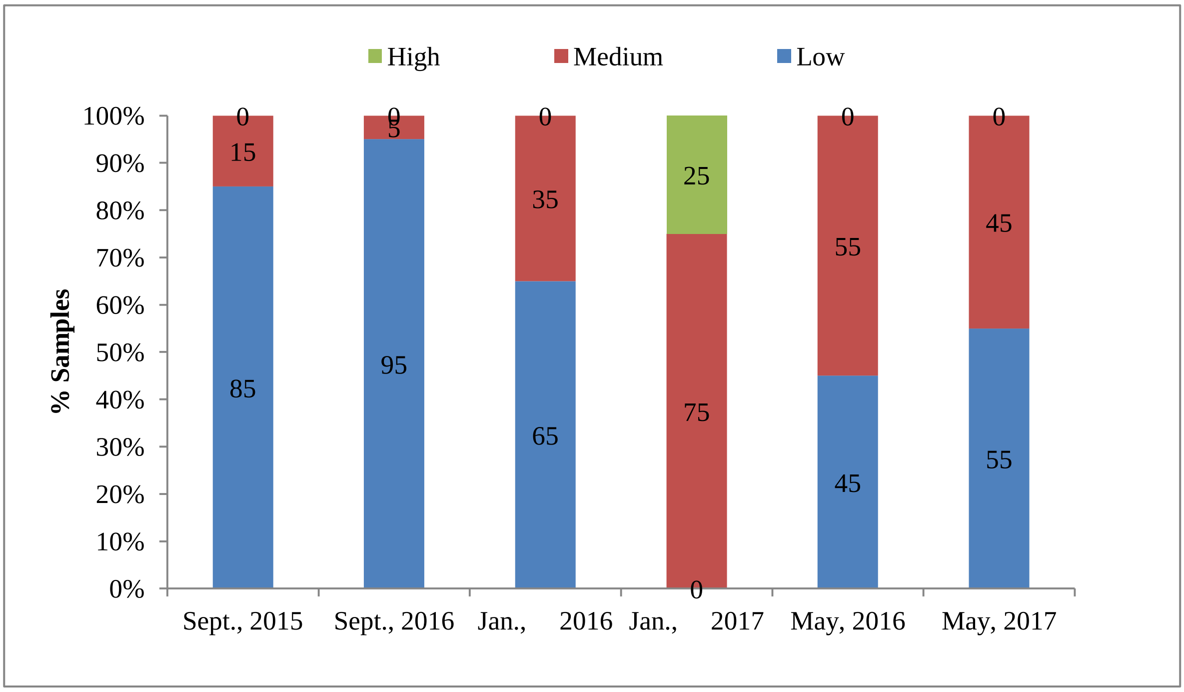

Figure 4.34 Heavy metal evaluation index (HEI) in surface water of Bhindawas Wetland (September, 2015 - May, 2017) for irrigation use.

Degree of Contamination (C_d)

Based on the values of C_d, 85% samples had low and 15% samples having high degree of pollution in monsoon and in post-monsoon and pre-monsoon 30% and 50% samples with low and 70% and 50% samples with medium degree of pollution confirming to the classification as observed in present water study for irrigation. The Cd values ranged from -3.9 to -2.8 in monsoon,-4.43 to -2.60 in post-monsoon and -4.75 to -3.15 in pre-monsoon during study of first year. The details of C_d are given in Table 4.10 to 4.12.

For the second year Cd values for monsoon, post-monsoon and pre-monsoon is -3.86 to -2.46, -4.5 to -2.6 and -4.36 to -2.24 respectively. Similarly low degree of pollution with 55%, 75% and 75% sampling sites and medium degree of pollution with 45%, 25% and 25% of samples in monsoon, post-monsoon and pre-monsoon was observed during the study of second year. The details of C_d are given in Table 4.13 to 4.15.

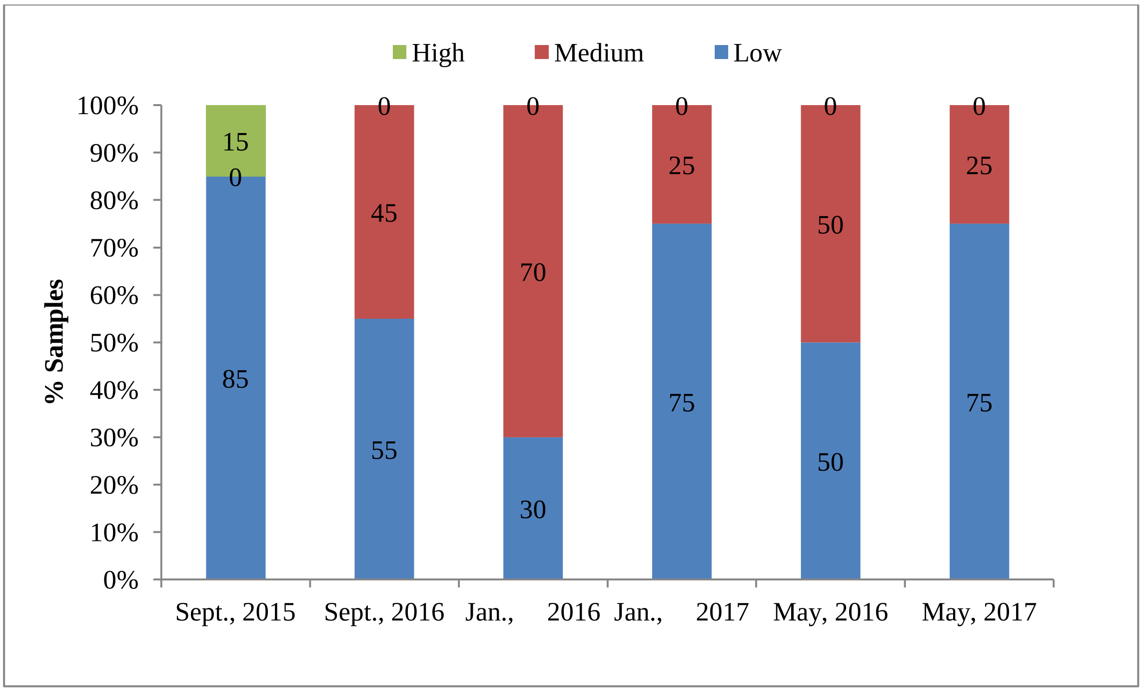

Figure 4.35. Degree of contamination (C_d) in surface water of Bhindawas Wetland (September, 2015 - May, 2017) for irrigation use.

Water Quality Index (WQI)

The Water Quality Index (WQI) is another representation of the quality of water with respect to physico-chemical parameters.WQI values for monsoon, post-monsoon and pre-monsoon is 53 to 257, 37 to 151 and 141 to 289 respectively. Based on the values of WQI 70% samples in monsoon, 10% in post-monsoon and 100% samples in pre-monsoon were found unsuitable whereas 20%, 30% samples were found in very poor category in monsoon, post-monsoon respectively. 10% sampling sites in monsoon, 30% in post-monsoon falls under poor category. Only 30% samples falls under good category during post-monsoon and no single site was observed under range of good category in monsoon and pre-monsoon.

During second year of study the range of WQI was observed 79 to 269 in monsoon, 63 to 100 in post-monsoon and 103 to 295 in pre-monsoon with 25% and 50% samples under very poor category in monsoon and post-monsoon whereas 85% and 100% samples fall under unsuitable category in monsoon and pre-monsoon. 50% samples during post monsoon were found under poor category only with not a single site with unsuitable category.

The details of WQI for irrigation use are given in Table 4.10 to Table 4.12 (September, 2015-May, 2016) and Table 4.13 to 4.15 (September, 2016- May, 2017).

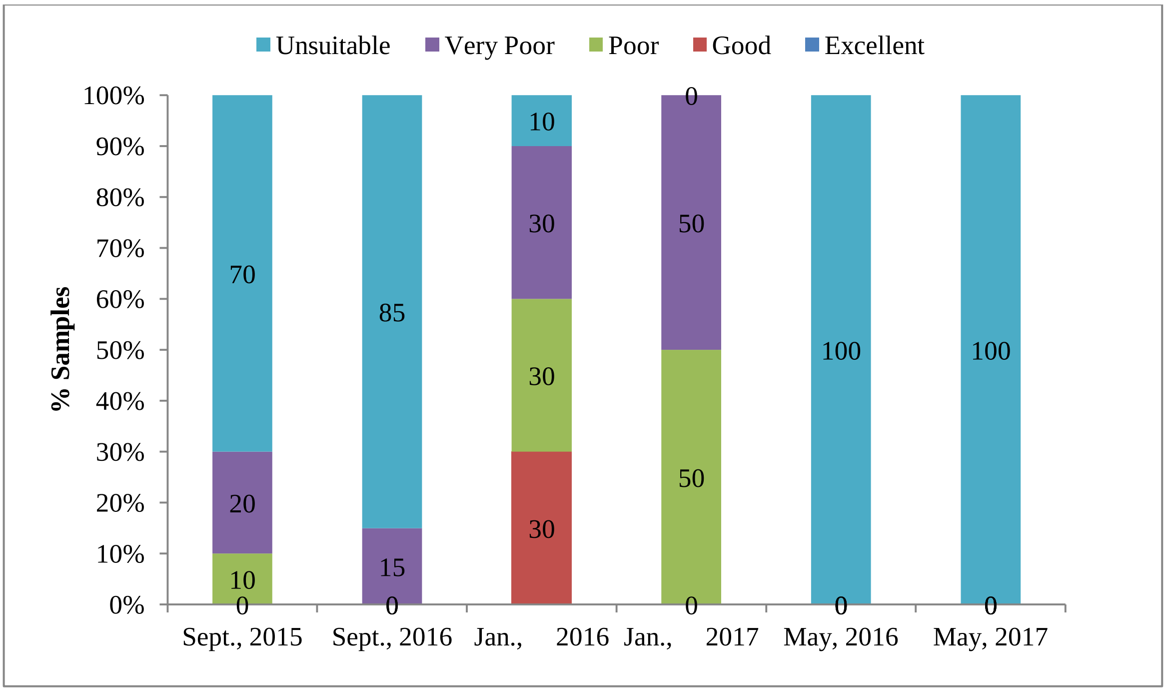

Figure 4.36 Water quality index (WQI) of surface water of Bhindawas Wetland (September, 2015 - May, 2017) for irrigation use.

Table 4.10. Classification of water in Bhindawas wetland based on HPI, HEI, Degree of Contamination and WQI in Monsoon (September, 2015).

	Aquatic Life				**Irrigation**			
Index	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.-Max.)**	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.-Max.)**
HPI	< 50 50 – 100 > 100	Low Medium High	13(65) 06 (30) 01 (05)	48 (25 - 161)	< 1 1– 2 > 2	Low Medium High	19 (95) 1 (5) -	0.7 (0.5 - 1.3)
HEI	< 160 160–320 >320	Low Medium High	13 (65) 06 (30) 01(05)	160 (68 - 519)	< 2 2 – 4 >4	Low Medium High	17 (85) 03(15) -	1.7 (1.1 - 2.2)
C_d	< 150 150 –320 > 320	Low Medium High	13 (65) 06 (30) 01 (05)	152 (63 - 514)	< -3 -3 – 0 > 0.0	Low Medium High	17(85) - 03(15)	-3.3 (-3.9 to - 2.8)
WQI	0-25 25-50 51-75 76-100 >100	Excellent Good Poor Very Poor Unsuitable	Nil Nil Nil Nil 20(100)	194 (101-384)	0 -25 26-50 51-75 76-100 >100	Excellent Good Poor V. Poor Unsuitable	Nil Nil 2 (10) 4 (20) 14(70)	143 (53-257)

Table 4.11. Classification of water in Bhindawas wetland based on HPI, HEI, Degree of Contamination and WQI in Post-monsoon (January, 2016).

	Aquatic Life				Irrigation			
Index	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.-Max.)**	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.-Max.)**
HPI	< 25	Low	10(50)	23 (11 - 36)	< 1	Low	20(100)	0.4 (0.03 – 0.89)
	25 – 50	Medium	10(50)		1– 2	Medium	Nil	
	> 50	High	Nil		> 2	High	Nil	
HEI	< 80	Low	10(50)	81 (42 - 123)	< 1.5	Low	13(65)	1.4 (0.57 - 2.40)
	80–160	Medium	10(50)		1.5 – 3	Medium	07(35)	
	>160	High	Nil		>3	High	Nil	
C_d	< 75	Low	10(50)	76 (37 - 118)	< -4	Low	06(30)	-3.6 (-4.43 to - 2.60)
	75 - 150	Medium	10(50)		-4 – 0	Medium	14(70)	
	> 150	High	Nil		> 0.0	High	Nil	
WQI	0-25	Excellent	Nil	151 (84 - 234)	0 -25	Excellent	Nil	70 (37-151)
	25-50	Good	Nil		26-50	Good	06(30)	
	51-75	Poor	Nil		51-75	Poor	06(30)	
	76-100	Very Poor	03(15)		76-100	V. Poor	06(30)	
	>100	Unsuitable	17(85)		>100	Unsuitable	02(10)	

Table 4.12 Classification of water in Bhindawas wetland based on HPI, HEI, Degree of Contamination and WQI in Pre-monsoon (May, 2016).

	Aquatic Life				Irrigation			
Index	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.-Max.)**	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.- Max.)**
HPI	< 30	Low	04(20)	33 (26 - 41)	< 0.3	Low	09(45)	0.3 (0.004 - 0.75)
	30 – 60	Medium	16(80)		0.3 – 0.6	Medium	09(45)	
	> 60	High	Nil		> 0.6	High	02(10)	
HEI	< 110	Low	07(35)	112 (85 - 127)	< 0.2	Low	09(45)	0.2 (0.05 - 0.37)
	110–220	Medium	13(65)		0.2– 0.4	Medium	11(55)	
	>220	High	Nil		>0.4	High	Nil	
C_d	< 100	Low	06(30)	107 (80 - 122)	< -4	Low	10(50)	-4 (-4.75 to - 3.15)
	100 - 200	Medium	14(70)		-4 – 0	Medium	1(50)	
	> 200	High	Nil		> 0.0	High	Nil	

WQI	0-25 25-50 51-75 76-100 >100	Excellent Good Poor Very Poor Unsuitable	Nil Nil Nil Nil 20(100)	236 (152-343)	0 -25 26-50 51-75 76-100 >100	Excellent Good Poor V. Poor Unsuitable	Nil Nil Nil Nil 20(100)	185 (141-289)

Table 4.13 Classification of water in Bhindawas wetland based on HPI, HEI, Degree of Contamination and WQI in Monsoon (September, 2016)

	Aquatic Life				**Irrigation**			
Index	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.- Max.)**	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.- Max.)**
HPI	< 50 50 – 100 > 100	Low Medium High	11(55) 08(40) 01(05)	51 (25 - 143)	< 0.7 0.7 – 1.4 > 1.4	Low Medium High	06(30) 14(70) Nil	0.7 (0.5 - 1.3)
HEI	< 160 160–320 >320	Low Medium High	11(55) 08(40) 01(05)	164 (72 - 463)	< 0.5 0.5– 1 >1	Low Medium High	19(95) 01(05) Nil	0.4 (0.2 – 0.5)
C_d	< 150 150 - 300 > 300	Low Medium High	10(50) 09(45) 01(05)	159 (67 - 458)	< -3 -3 – 0 > 0.0	Low Medium High	11(55) 09(45) Nil	-3.1 (-3.86 to - 2.46)
WQI	0-25 25-50 51-75 76-100 >100	Excellent Good Poor Very Poor Unsuitable	Nil Nil Nil Nil 20(100)	256 (192-348)	0 -25 26-50 51-75 76-100 >100	Excellent Good Poor V. Poor Unsuitable	Nil Nil Nil 03(15) 17(85)	128 (79-269)

Table 4.14. Classification of water in Bhindawas wetland based on HPI, HEI, Degree of Contamination and WQI in Post-monsoon (January, 2017).

	Aquatic Life				**Irrigation**			
Index	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.- Max.)**	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.- Max.)**
HPI	< 25 25 – 50 > 50	Low Medium High	10(50) 09(45) 01(05)	26 (8 - 53)	< 0.5 0.5 – 1 > 1	Low Medium High	10(50) 10(50) Nil	0.5 (0.01 – 0.92)
HEI	< 90 90–180 >180	Low Medium High	10(50) 10(50) Nil	92 (46 - 151)	< 2 2– 4 >4	Low Medium High	15(75) 05(25) Nil	2 (0.5 - 2.4)

C_d	< 80 80 - 160 > 160	Low Medium High	13(65) 06(30) 01(05)	87 (41 - 146)	< -3 -3 – 0 > 0.0	Low Medium High	15(75) 05(25) Nil	-3.4 (-4.5 to - 2.6)
WQI	0-25 25-50 51-75 76-100 >100	Excellent Good Poor Very Poor Unsuitable	Nil Nil Nil Nil 20(100)	224 (100-332)	0 -25 26-50 51-75 76-100 >100	Excellent Good Poor V. Poor Unsuitable	Nil Nil 10(50) 10(50) Nil	79 (63-100)

Table 4.15. Classification of water in Bhindawas wetland based on HPI, HEI, Degree of Contamination and WQI in Premonsoon (May, 2017).

	Aquatic Life				**Irrigation**			
Index	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.-Max.)**	**Modified Category**	**Degree of pollution**	**No. of samples (%)**	**Mean (Range) (Min.-Max.)**
HPI	< 40 40 – 80 > 80	Low Medium High	04(20) 16(80) Nil	45 (16 - 57)	< 0.6 0.6 – 1.2 > 1.2	Low Medium High	11(55) 09(45) Nil	0.6 (0.15 - 1.13)
HEI	< 130 130–260 >260	Low Medium High	05(25) 15(75) Nil	137 (39 - 167)	< 0.3 0.3 – 0.6 >0.6	Low Medium High	11(55) 09(45) Nil	0.3 (0.13 - 0.55)
C_d	< 130 130 - 260 > 260	Low Medium High	08(40) 12(60) Nil	132 (34 - 162)	< -3 -3 – 0 > 0.0	Low Medium High	15(75) 05(25) Nil	-3.4 (-4.36 to - 2.24)
WQI	0-25 25-50 51-75 76-100 >100	Excellent Good Poor Very Poor Unsuitable	Nil Nil Nil Nil 20(100)	224 (126-367)	0 -25 26-50 51-75 76-100 >100	Excellent Good Poor V. Poor Unsuitable	Nil Nil Nil Nil 20(100)	161 (103-295)

4.3 Sediment Quality of Bhindawas Wetland

4.3.1 Physico-chemical Parameters

Sediment quality assessment of Bhindawas wetland was performed with the help of detail study of the various physico-chemical parameters *viz*. moisture content, pH, EC, Na^+, K^+, Ca^{2+}, TP, AP, TKN, TOC % and Organic matter % during the study period.

Spatial and Seasonal variations (September, 2015 to May, 2017)

In the present study physical and chemical characteristics of sediment samples were studied spatially and seasonally for the time period of two years, September, 2015 to May, 2016 (1st Year) and September, 2016 to May, 2017 (2nd Year) respectively, covering three major seasons i.e. monsoon, post-monsoon and pre-monsoon. The study for monsoon, post-monsoon and pre-monsoon season was carried out during September, 2015; January, 2016; and May, 2016 of 1st Year and September, 2016; January, 2017; and May, 2017 of 2nd Year, respectively. Analytical results of sediment quality with respect to various parameters with mean values and inlet and outlet concentrations were shown in Table 4.16 to 4.21 to highlight the difference in their concentrations at different locations during study period and Fig. 4.37 to 4.47 represented the comparision between various physicochemical parameters seasonally.

Moisture Content

Water content in wetland sediments was investigated from 11% to 95% at sampling sites S18 and S16 during May, 2016 and September, 2016.Whereas maximum (41%) as well as minimum (23%) moisture content was recorded in Sept,15 in inlet and outlet respectively.

The mean value of water content in wetland sediments during the study period varied from 47.54% to 83.84% (Fig. 4.37). Maximum mean water content value for all the sites were observed for the monsoon 81.42 ± 4.53 (2015-16); 83.84 ± 7.23 (2016-17) followed by post-monsoon 54.56 ±26.12 (2015-16); 63.1± 6.65 (2016-17) and pre-monsoon 47.54 ± 16.26 (2015-16); 55 ± 26.1 (2016-17). Water content generally defined as water held in spaces present between sediment particles which are highly required by organisms to maintain their osmotic balance and to facilitate oxygen adsorption through the integument (Gardner et al., 1972). Percentage of high organic matter during monsoon could be the reason for maximum water content as increases organic matter leads to increased water holding capacity of sediments (DeLaune and Reddy, 2008).

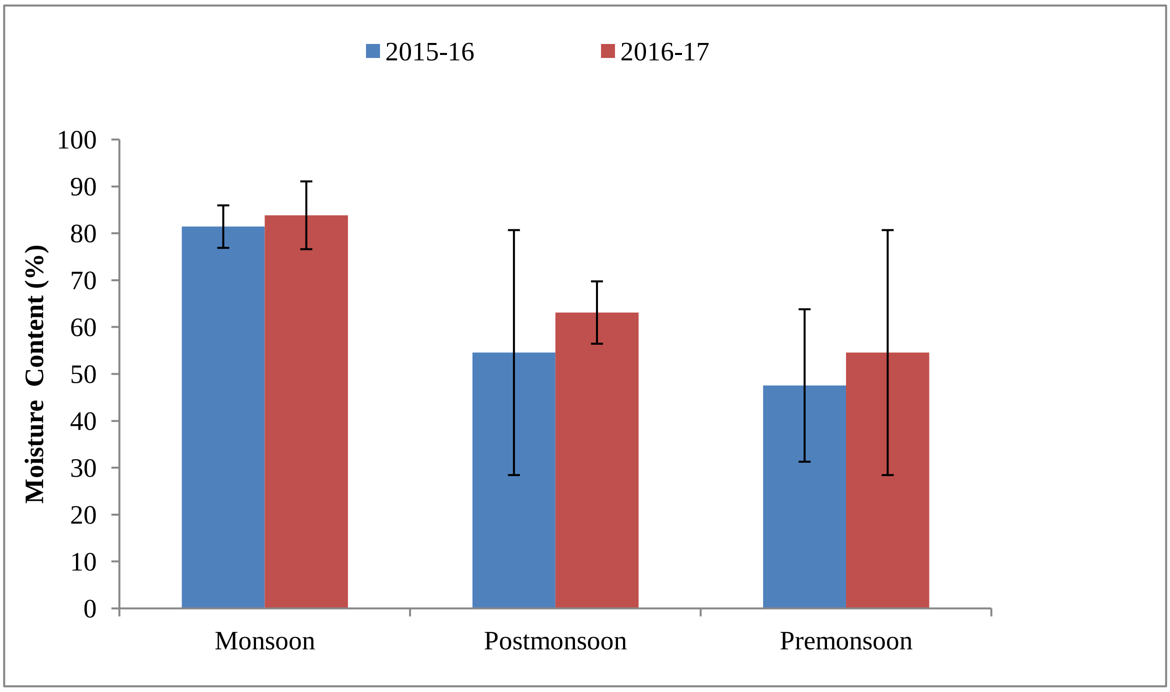

Figure 4.37 Seasonal variations in mean value of percentage Moisture content of sediments in Bhindawas wetland in different seasons for two successive years.

pH

pH value in Bhindawas wetland varied between 6 to 7.6 with minimum at sampling location, S14 and maximum at S16 during January, 2017 and May, 2017 respectively. Inlet and outlet possess significant difference in pH values with maximum (7.1) in inlet (September, 2016) and minimum (6.2) in outlet (January, 2016). The mean pH value of sediments during the study period varied from 6.4 to 6.6 (Fig.4.38) which indicate slightly acidic nature of wetland sediments as compare to wetland water, which may be due to organic matter decomposition (humus) resulting in formation of organic acid into these sediments (Chandrakiran and Kuldeep, 2013). pH is majorly known as important parameter affecting physical characteristics of soil, release of nutrients and reflects potency of toxic substances (Wondim and Mosa, 2015). Saravanakumar et al. (2008) stated that acidic condition in wetland sediments may be due to oxidation of ferrous sulphate ($FeSO_4$ into FeS and H_2SO_4. Maximum mean pH value for all the sites was observed for the monsoon season 6.6 ± 0.2 (2015-16); 6.6 ± 0.3 (2016-17) followed by pre-monsoon 6.5 ± 0.2 (2015-16); 6.6 ± 0.3 (2016-17) and post-monsoon 6.4±0.2 (2015-16), 6.4 ± 0.2 (2016-17).

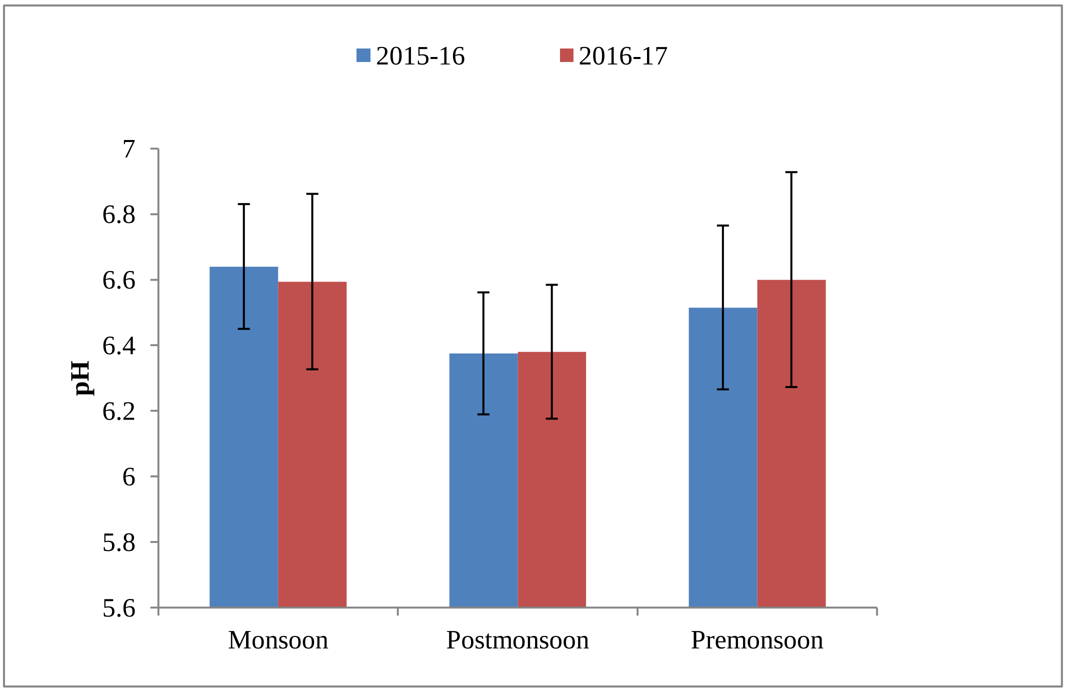

Figure 4.38. Seasonal variations in mean pH value of sediments in Bhindawas wetland in different seasons for two successive years.

Electrical Conductivity

Minimum value of conductivity, 68μS/cm was observed at sampling locations S15, S17 (May, 2017) and maximum, 1029 μS/cm at S16 (September, 2016). Maximum (311 μS/cm) and minimum (116 μS/cm) conductivity was found in outlet during September, 2015; September, 2016 and May, 2017 respectively .

The mean EC value in sediments during the study period varied from 170μS/cm to 603 μS/cm (Fig. 4.39). The maximum value was observed to be high in monsoon 534 ±159 (2015-16); 603 ± 183 (2016-17) followed by post-monsoon 355 ± 45 (2015-16); 348 ± 46 (2016-17) and pre-monsoon 170 ± 83 (2015-16); 217 ± 107.7 (2016-17) during the study period. High EC value during monsoon may be due contamination of wetland sediment with agricultural residue and sewage waste through catchment area and low conductivity in pre-monsoon may be observed due to utilization of minerals and nutrients by living organisms, plants and animals (Mondal et al., 2016). EC is positively correlated with TOC and OM.

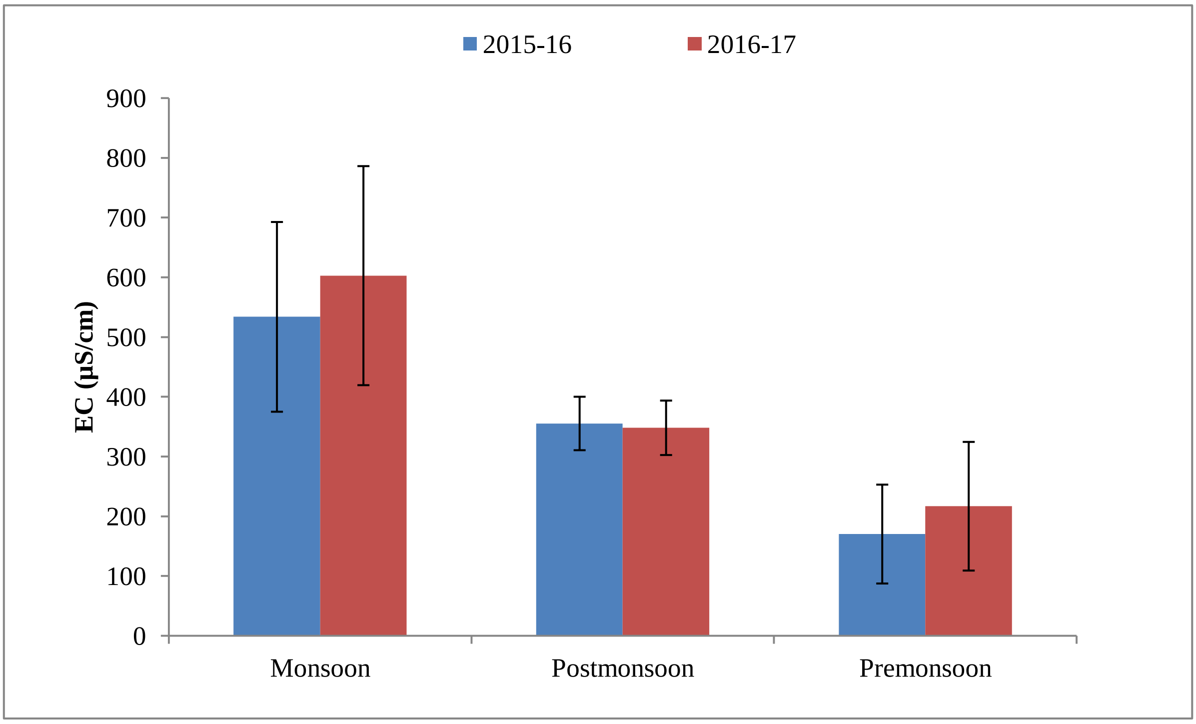

Figure 4.39 Seasonal variation in mean value (µS/cm) of Electrical Conductivity of sediments in Bhindawas wetland in different seasons for two successive years.

Sodium (Na^+)

Major cation Na^+ in Bhindawas wetland was found with minimum value, 0.04 mg/kg and maximum value, 0.29 mg/kg at sampling locations, S10; S18; S19 (September, 2015) and at S7; S8 ; S16 (May, 2017) respectively. Outlet was found with maximum (0.34 mg/kg) in May, 2017 and minimum (0.02 mg/kg) in outlet (September, 2016).

The mean Na^+ ions value of wetland sediments during the study period varied from 0.08 mg/kg to 0.21 mg/kg (Fig.4.40). Maximum mean value for Na^+ ion concentration in sediments was detected for the pre-monsoon season 0.18 ± 0.05 (2015-16); 0.21 ± 0.06 (2016-17) followed by post-monsoon 0.10 ± 0.03 (2015-16); 0.09 ± 0.01 (2016-17) and monsoon 0.08±0.03 (2015-16); 0.09± 0.03 (2016-17).

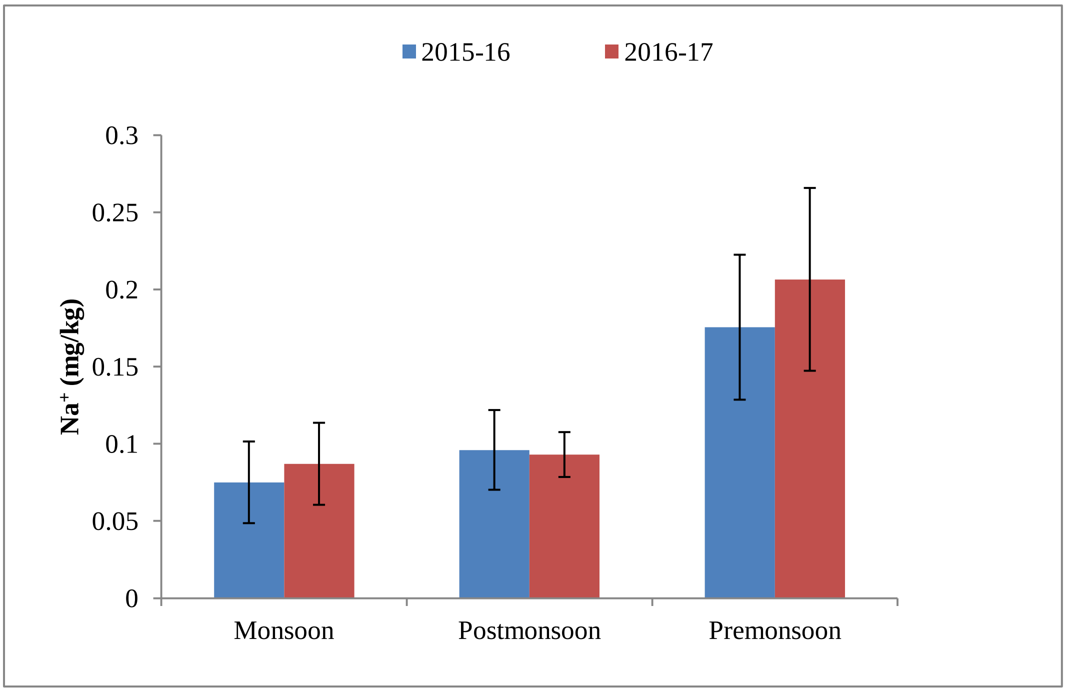

Figure 4.40 Seasonal variations in mean concentration (mg/kg) of Na^+ ion in sediments of Bhindawas wetland in different seasons for two successive years.

Potasium (K^+)

K^+ concentration in study area was investigated with mimimum concentration, 0.2 mg/kg at location S7 and maximum, 2.4 mg/kg at S15 during September, 2015. Minimum

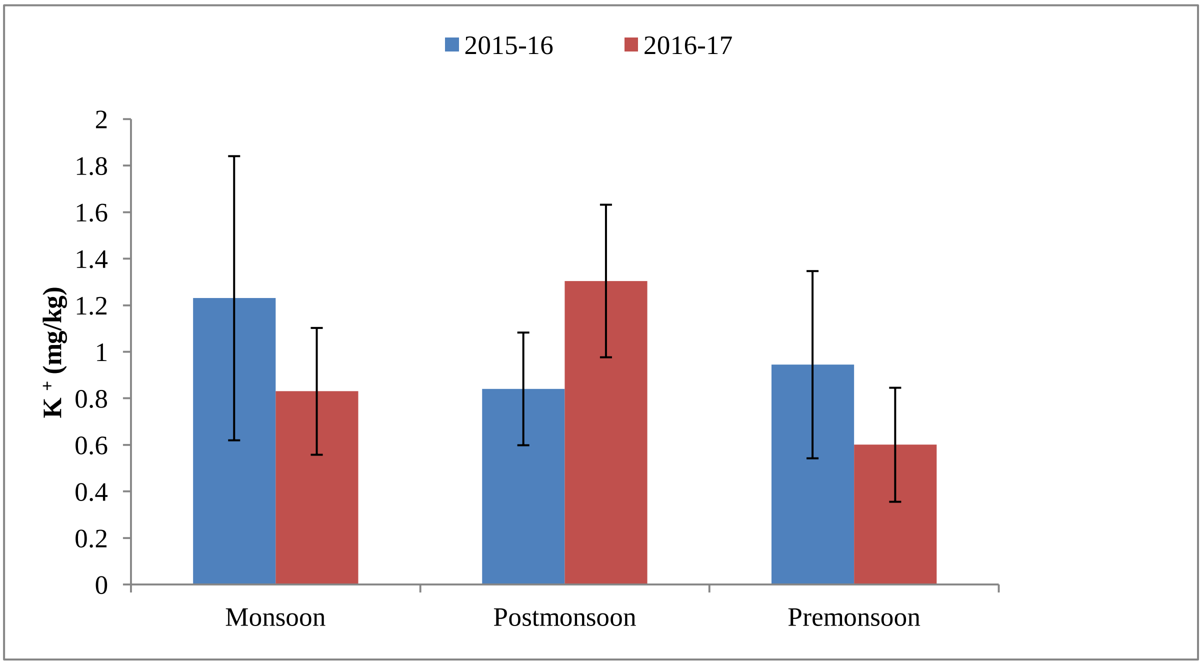

Figure 4.41 Seasonal variations in mean concentration (mg/kg) of K^+ ion in sediments of Bhindawas wetland in different seasons for two successive year.

concentration (0.15 mg/kg) of potassium ion was detected in outlet during September, 2016 and maximum (0.92 mg/kg) was observed in both outlet and inlet in Jan., 2016 and May, 2016 respectively. The mean K^+ ions value of wetland sediments during the study period varied from 0.6 mg/kg to 1.3 mg/kg (Fig. 4.41). Maximum mean value for K^+ ion concentration in sediments was detected for the post-monsoon season 0.84 ± 0.24 (2015-16); 1.3 ± 0.33 (2016-17) followed by monsoon 1.23 ± 0.61 (2015-16); 0.83 ± 0.27(2016-17) and pre-monsoon 0.95 ± 0.4 (2015-16); 0.60 ± 0.24 (2016-17). The increased concentration during post monsoon is due to the disposal of waste from surrounding area and also due to the after effects of monsoon. Similar observations were also found by Nair et al. (1984) with a high concentration of potassium during post- monsoon

Calcium (Ca^{2+})

The maximum value (0.30 mg/kg) for Ca^{2+} was observed in January, 2016 at location S5 whereas minimum value (0.01 mg/kg) was recorded at locations S6, S18 in September, 2015. Outlet with minimum Ca^{2+} value (0.01 mg/kg) was detected in September, 2016 whereas inlet was found with maximum value, 0.20 mg/kg in May, 2017.

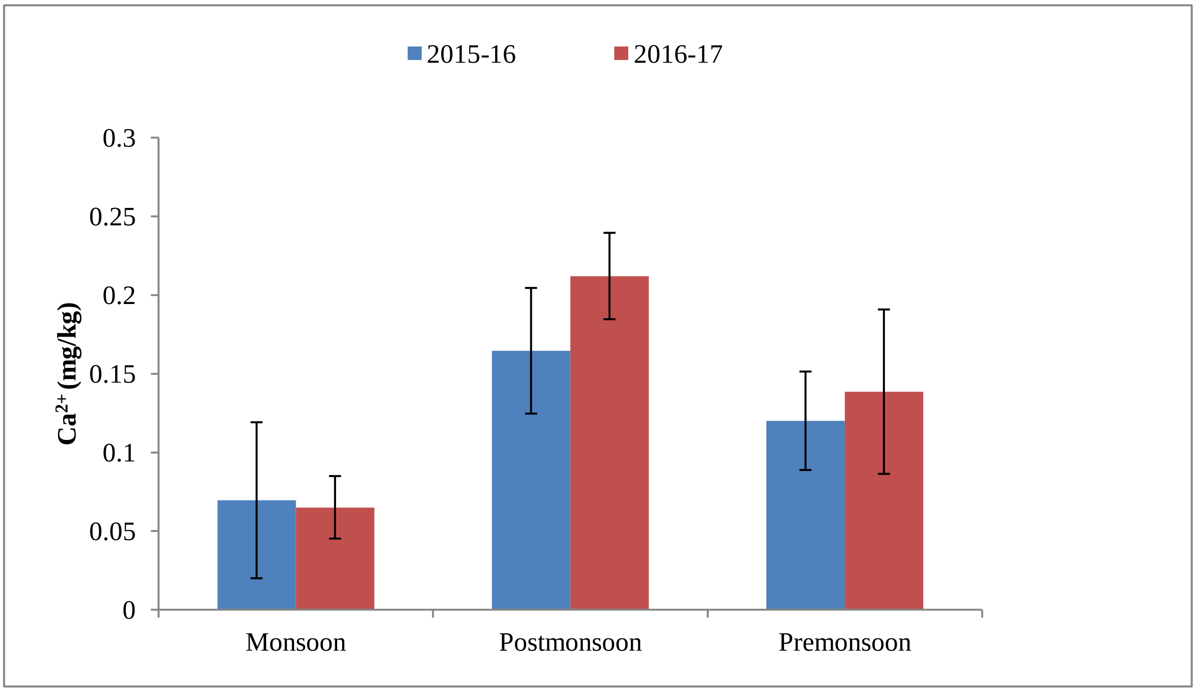

Figure 4.42 Seasonal variations in mean concentration (mg/kg) of Ca^{2+} ion in sediments of Bhindawas wetland in different seasons for two successive years

The mean Ca^{2+} ions value of wetland sediments during the study period varied from 0.06 mg/kg to 0.2 mg/kg (Fig. 4.42). Maximum mean value for Ca^{2+} ion concentration in sediments was detected for the post-monsoon season 0.16 ± 0.04 (2015-16); 0.21 ± 0.03 (2016-17) followed by pre-monsoon 0.12 ± 0.03 (2015-16); 0.14 ± 0.05 (2016-17) and monsoon 0.07 ± 0.05 (2015-16); 0.07 ± 0.02 (2016-17).

Total Phosphate (TP)

Maximum concentration of total phosphate (0.60 mg/kg) was found at sampling sites S12 during September, 2016 and minimum value, 0.03 mg/kg was observed at sampling sites S15 during May, 2016. Increased concentration of total phosphorous was observed in outlet in. January, 2017 and minimum value was found May, 2016.

The mean total phosphate (TP) value of wetland sediments during the study period varied from 0.15 mg/kg to 0.41 mg/kg (Fig. 4.43). Maximum mean value for TP in sediments was detected for the post-monsoon 0.30 ± 0.10 (2015-16); 0.4 1± 0.07 (2016-17) followed by monsoon 0.16 ± 0.08 (2015-16); 0.39 ± 0.1 (2016-17) and pre-monsoon 0.15 ± 0.04 (2015-16); 0.32 ± 0.06 (2016-17). A positive correlation was found between TP, AP, TKN and K^+. A number of abiotic and biotic processes govern the transport of phosphorus between soil and overlying water column. Maximum available phosphorus level in monsoon period may be due to the runoff from the nearby areas cantaining organic waste (Saravanakumar et al., 2008), which is agreeing with the findings of Walls et al. (2005), which further increased concentration of soil nutrients (P and N) by sedimentation process. During post-monsoon, low temperature and less macrophytes growth supports the higher concentration of phosphorous in sediments as the macrophytes help in removal of nutrients from sediments and return them to water column after their decomposition (Barrow and Shaw, 1980). Monsoon season is characterized by more number of aquatic macrophytes than post-monsoon. So removal of phosphorus from the sediments through the macrophytes could have resulted in a lesser phosphorus levels in this season. In pre-monsoon, contradictory results were obtained with respect to phosphorous sorption characteristics and dry soil (anaerobic) as various study showed that drying soils support increased phosphate adsorption (Barrow and Shaw, 1980; Haynes and Swift, 1989). Also in post-monsoon season the numerous avian fauna migrated to Bhindawas wetland. The input of nutrients (phosphorus and nitrogen) resulting from avian excrement could have contributed in increased concentration of phosphate in sediments. In lake Grand-Lieu, France, the avian excrement contributed 95% of phosphorus annually.

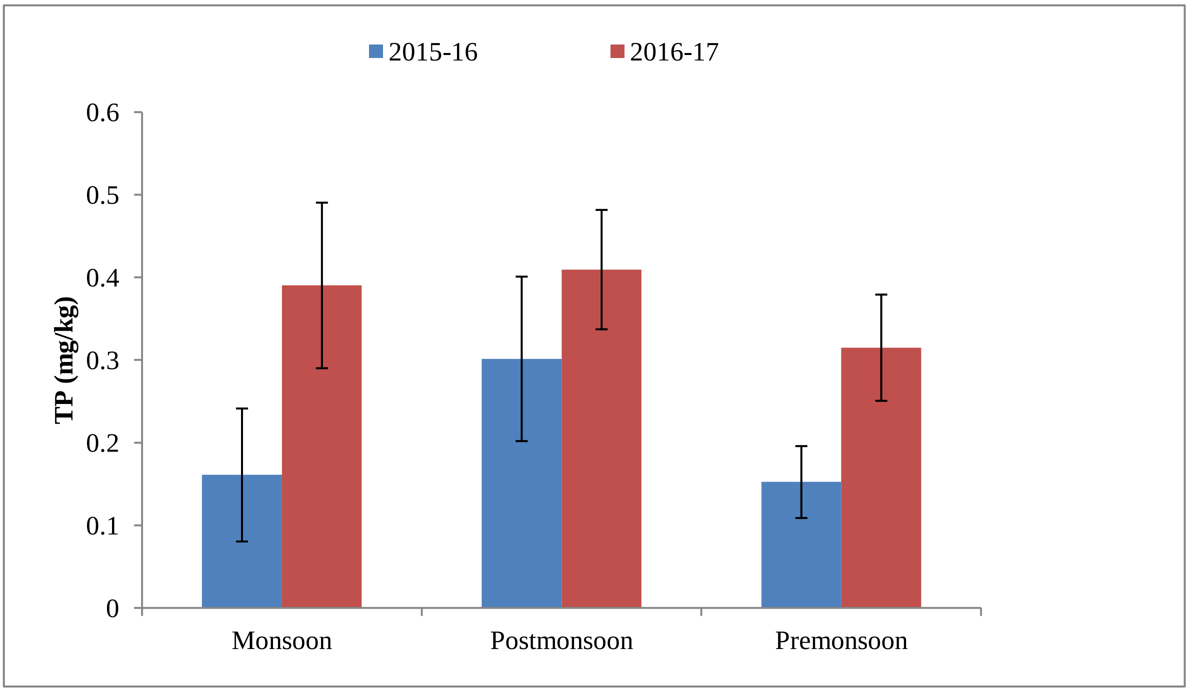

Figure 4.43 Seasonal variations in mean concentration (mg/kg) of Total Phosphorous (TP) in sediments of Bhindawas wetland in different seasons for two successive years

Previous studies have proved that avian fauna have significant increased in nutrient content in water bodies (Hobara et al., 2005; Takeda, 1999).

Available Phosphate (AP)

AP was reported with maximum concentration (0.23 mg/kg) at sampling location S2 during January, 2016 whereas minimum concentration (0.01 mg/kg) was observed at S5, S6 (May, 2016) and S7, S10, S12 (May, 2017) sites. Maximum AP value (0.14 mg/kg) was reported in outlet during January, 2017 whereas minimum (0.02 mg/kg) was investigated in outlet in January, 2016.

The mean available phosphate (AP) value of wetland sediments during the study period varied from 0.03 mg/kg to 0.1 mg/kg (Fig. 4.44.). Maximum mean value for AP in sediments was detected in the post-monsoon 0.07 ± 0.06 (2015-16); 0.10 ± 0.05 (2016-17) followed by monsoon 0.06 ± 0.02 (2015-16); 0.09 ± 0.04 (2016-17) and pre-monsoon 0.03 ± 0.03 (2015-16); 0.05± 0.04 (2016-17). High values during monsoon seasons were reported by Nair et al. (1984) and Chandran and Ramamoorthy (1984).

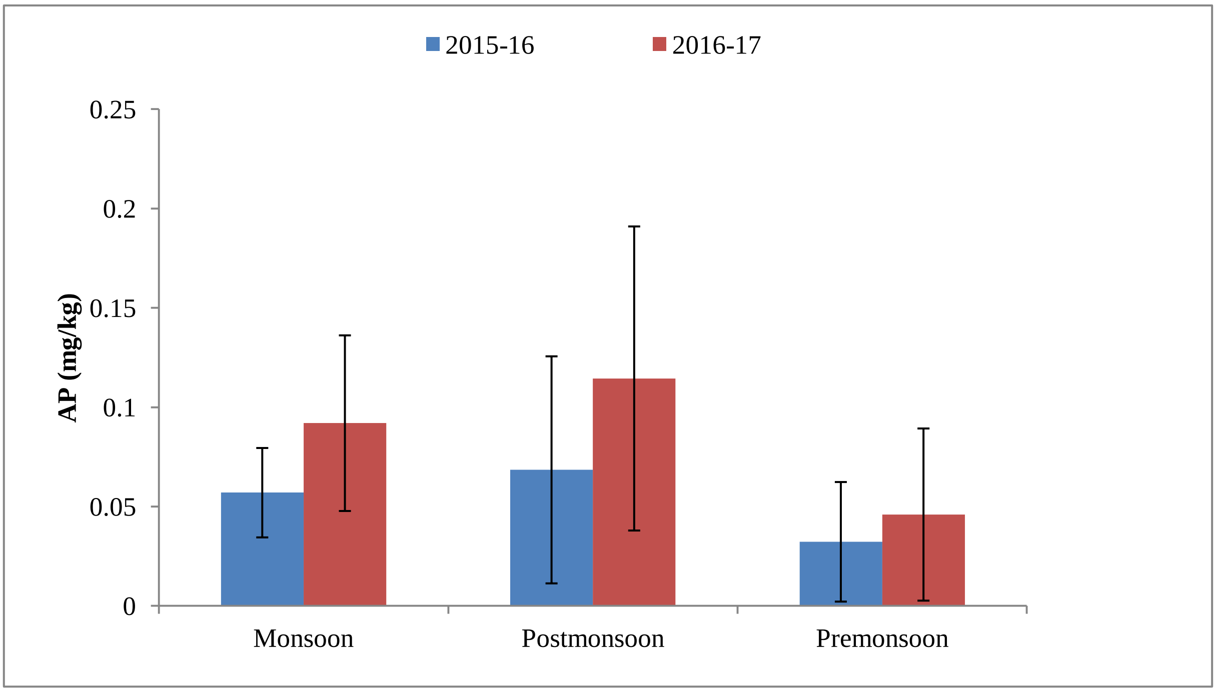

Figure 4.44 Seasonal variations in mean concentration (mg/kg) of Available Phosphorous (AP) of sediments in Bhindawas wetland in different seasons for two successive years

Total Kjehldhal Nitrogen (TKN)

Maximum TKN value (0.15 mg/kg) was detected at sampling site S3 in January, 2017 whereas minimum (0.01 mg/kg) was observed in S9, in January, 2017, S8 in September, 2015 and most of the sampling sites in May, 2016 and May, 2017. Maximum value (0.13 mg/kg) was detected in outlet and minimum (0.01 mg/kg) was also detected in outlet during January, 2017 and May, 2016 respectively.

The mean TKN value of wetland sediments during the study period varied from 0.02 mg/kg to 0.08 mg/kg (Fig. 4.45). Maximum mean value for TKN in sediments was detected for the post-monsoon 0.07 ± 0.03 (2015-16); 0.08 ± 0.03 (2016-17) followed by monsoon 0.03 ± 0.01 (2015-16); 0.06 ± 0.02 (2016-17) and pre-monsoon 0.02 ±0.01 (2015-16); 0.04 ± 0.02 (2016-17). Similar results were found in by George (2011) during study of sediments in Vembanadu Lake. Low nitrate concentration in wetland sediments during pre-monsoon was observed may be due to presence of low organic waste. Also increased denitrification and inhibited nitrification rate by organic matter especially lignin could be major reason for lower NO_3-N concentration (Eriksson, 2001 and Wetzel, 2001). Increased nitrate content could be due to leaching and surface runoff of nitro-phosphate fertilizers from agricultural land nearby wetland as well as domestic sewage from villages. Jeelani and Shah, 2006 also reported high concentration of NO_3-N in Dal lake, Srinagar.

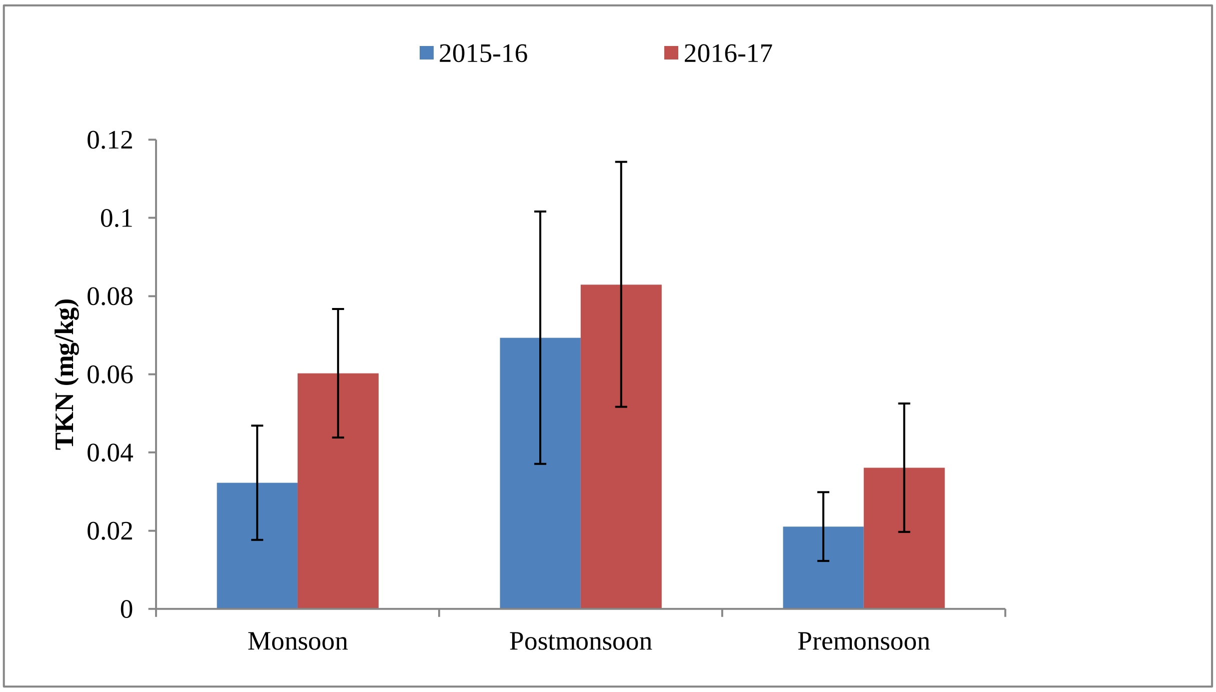

Figure 4.45 Seasonal variations in mean concentration (mg/kg) of Total Kjeldhal Nitrogen (TKN) of sediments in Bhindawas wetland in different seasons for two successive years

% Total Organic Carbon (TOC)

Maximum (17) and minimum (3) TOC % was observed during September, 2016 and May, 2017 at sampling sites S3 and S16;S20 respectively.Whereas maximum percentage (13) of TOC was detected in outlet during September, 2015 and minimum was depicted in May, 2016 and 2017.

Maximum TKN value (0.15 mg/kg) was detected at sampling site S3 in January, 2017 whereas minimum (0.01 mg/kg) was observed in S9, in January, 2017, S8 in September, 2015 and most of the sampling sites in May, 2016 and May, 2017. Maximum value (0.13 mg/kg) was detected in outlet and minimum (0.01mg/kgl) was also detected in outlet during January, 2017 and May, 2016 respectively

The mean TOC percentage value of wetland sediments during the study period varied from 6 % to 11% (Fig. 4.46). Maximum mean percentage for TOC in sediments was detected for the monsoon 9.67 ± 2.25 (2015-16); 10.90 ± 3 (2016-17) followed by post-monsoon 8.31 ± 2.30 (2015-16); 8.98 ± 1.89 (2016-17) and pre-monsoon 7.05 ± 2.26 (2015-16); 5.69 ± 2.1 (2016-

17). The highest concentrations of organic carbon were found in wetland sediments; which could be attributed to the mixing of pollutants (sewage waste, agrochemicals, plant residue) coming from catchment area and further their accumulation in sediments by various physicochemical processes (Du Laing et al., 2006 and El-Serehy et al., 2012).

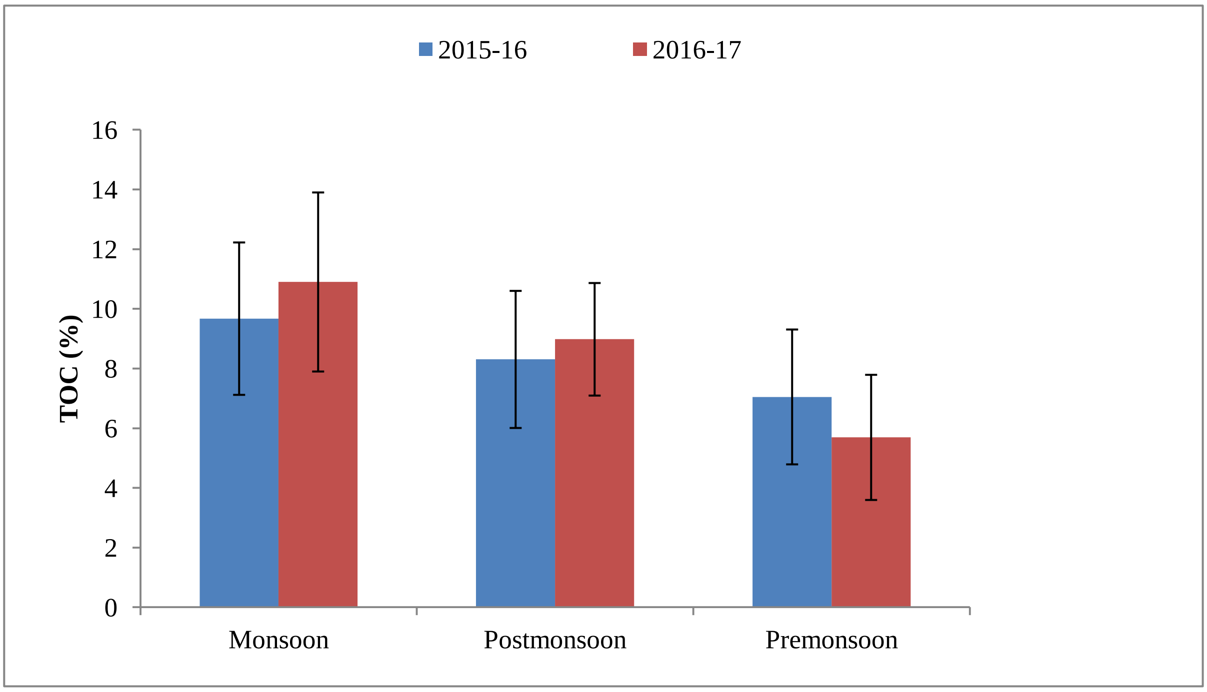

Figure 4.46 Seasonal variations in % Total Organic Carbon (TOC) in sediments of Bhindawas wetland in different seasons for two successive years

% Organic Matter (OM)

Organic matter percentage in wetland sediments was detected maximum (29) in September, 2016 and minimum (5) in May, 2017 at sampling sites, S3 and S16 respectively. Maximum organic matter percentage was found in September, 2015 in outlet whereas minimum was also observed in May, 2016 and 2017.

The organic carbon content in the lake sediment is derived from the primary production within the water body (autochthonous sources) and also from terrestrial runoff (allochthonous sources). The mean organic matter (OM) percentage value of wetland sediments during the study period varied from 10 % to 19% (Fig. 4.47). Maximum mean percentage for OM in sediments was detected for the monsoon 16.48 ± 4.4 (2015-16); 18.79 ± 5.17 (2016-17) followed by post-monsoon 14.32 ± 3.96 (2015-16); 15.48 ± 3.25 (2016-17) and pre-monsoon 12.15 ± 3.89 (2015-16); 9.82 ± 3.61 (2016-17). Excessive runoff of agrochemicals from agricultural land and untreated sewage from residential zone and plant litter during monsoon give substantial flux of organic content/waste to the wetland sediments by various decomposition processes. Influx of organic waste during monsoon and decay of aquatic macrophytes could be the main reason for the high organic matter in monsoon and during pre-monsoon, reduced water level increased the concentration of organic matter further and hence resulted in increased organic matter overall (Lobinske et al., 1996), (Real et al., 2000). It was observed that increase in water levels may dilute the amount of organic matter (Ali et al., 2002; Walker et al., 2003).

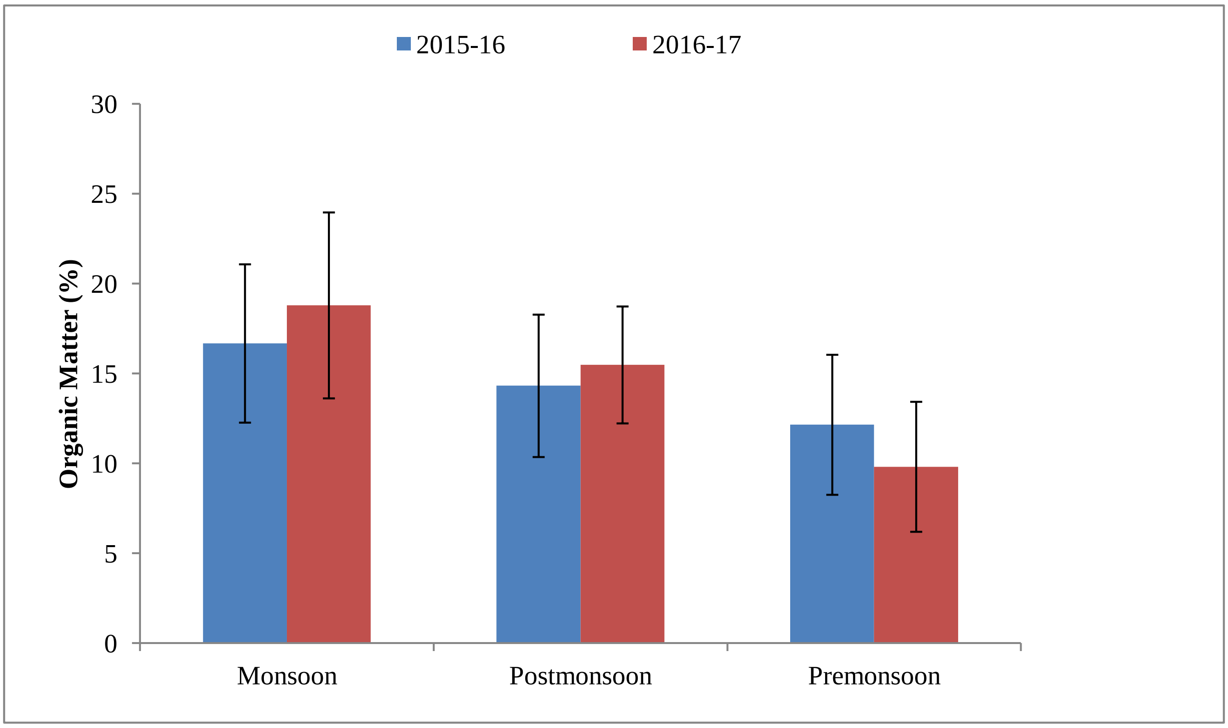

Figure 4.47 Seasonal variation in % Organic Matter (OM) in sediments of Bhindawas wetland in different seasons for two successive years.

Similar trend for OM % value was observed in monsoon for first year (17%) and second year (19%).

Table 4.16 Physico-chemical characteristics of sediment in Bhindawas Wetland for Monsoon (September, 2015)

Sites	Moisture	pH	EC	Na^+	K^+	Ca^{2+}	TP	AP	TKN	TOC	OM
Inlet	41	7.3	267	0.06	0.8	0.19	0.21	0.03	0.02	10	17
Outlet	23	6.3	311	0.04	0.12	0.05	0.31	0.09	0.04	13	23
S1	81	6.7	549	0.08	1.1	0.06	0.31	0.09	0.03	11	19
S2	82	6.5	607	0.11	1.6	0.02	0.13	0.03	0.02	13	23
S3	71	6.7	573	0.11	1.9	0.09	0.11	0.02	0.08	10	17
S4	78	6.6	537	0.1	1.2	0.03	0.09	0.06	0.02	13	23
S5	73	6.9	707	0.1	1.8	0.02	0.07	0.09	0.04	10	17
S6	84	7.1	328	0.12	1.9	0.01	0.06	0.08	0.04	6	11
S7	80	6.8	769	0.11	2.4	0.04	0.24	0.03	0.03	9	15
S8	81	6.6	581	0.08	2.1	0.08	0.32	0.06	0.01	10	17
S9	82	6.5	546	0.07	1.7	0.09	0.13	0.04	0.03	11	19
S10	91	6.7	348	0.04	1.4	0.14	0.18	0.09	0.04	9	16
S11	86	6.4	421	0.06	0.6	0.07	0.22	0.05	0.03	10	17
S12	82	6.7	716	0.07	1.3	0.03	0.22	0.08	0.04	6	11
S13	87	6.5	454	0.09	1.1	0.08	0.28	0.04	0.05	8	15
S14	79	6.3	332	0.07	0.9	0.09	0.17	0.05	0.02	14	25
S15	80	6.6	292	0.06	0.2	0.1	0.11	0.06	0.02	12	20
S16	83	6.8	314	0.05	0.4	0.06	0.1	0.05	0.04	4	7
S17	83	6.8	807	0.05	0.7	0.06	0.14	0.04	0.03	11	19
S18	86	6.5	647	0.04	0.8	0.01	0.11	0.04	0.03	10	18
S19	79	6.7	666	0.04	0.5	0.22	0.17	0.09	0.03	10	17
S20	79	6.4	482	0.05	1.01	0.09	0.06	0.05	0.04	6	11
Range	71-91	6.3-7.1	292-807	0.04-0.12	0.2-2.4	0.01-0.22	0.06-0.32	0.02-0.09	0.01-0.08	4 -14	7- 25
Mean(±SD)	81.42(±4.53)	6.6(±0.2)	534(±159)	0.08(±0.03)	1.23(±0.61)	0.07(±0.05)	0.16(±0.08)	0.06(±0.02)	0.03(±0.01)	9.67(±2.25)	16.48(±4.4)

Note: The values for Na^+, K^+, Ca^{2+}, TP, AP and TKN are in mg/kg and Moisture , TOC and OM in %.

Table 4.17 Physico-chemical characteristics of sediment in Bhindawas Wetland for Post-monsoon (January, 2016).

Sites	Moisture	pH	EC	Na^+	K^+	Ca^{2+}	TP	AP	TKN	TOC	OM
Inlet	34	6.9	217	0.09	0.14	0.03	0.3	0.03	0.11	4	7
Outlet	27	6.2	274	0.04	0.92	0.14	0.26	0.02	0.11	9	16
S1	85	6.4	461	0.1	1.04	0.16	0.26	0.02	0.05	8	13
S2	80	6.3	357	0.1	0.98	0.16	0.33	0.23	0.06	13	22
S3	83	6.3	311	0.08	0.83	0.15	0.32	0.15	0.11	9	16
S4	72	6.2	349	0.1	0.63	0.14	0.26	0.03	0.07	12	21
S5	82	6.6	352	0.11	0.44	0.3	0.35	0.04	0.04	9	15
S6	80	6.8	412	0.06	0.73	0.14	0.35	0.04	0.04	10	18
S7	81	6.6	382	0.12	0.87	0.17	0.23	0.06	0.04	5	8
S8	84	6.4	345	0.1	0.92	0.17	0.41	0.03	0.04	7	13
S9	21	6.2	364	0.08	0.4	0.15	0.16	0.04	0.04	4	8
S10	45	6.2	333	0.08	0.82	0.16	0.44	0.1	0.06	8	13
S11	39	6.3	317	0.11	0.87	0.15	0.26	0.15	0.06	7	12
S12	29	6.6	362	0.16	1.05	0.15	0.26	0.02	0.11	9	15
S13	81	6.3	335	0.11	1.06	0.15	0.28	0.02	0.10	11	18
S14	24	6.2	318	0.13	0.94	0.15	0.26	0.12	0.04	5	8
S15	27	6.1	423	0.11	0.7	0.15	0.26	0.02	0.05	8	14
S16	33	6.5	376	0.1	1.25	0.16	0.24	0.03	0.11	7	13
S17	19	6.2	362	0.08	1.24	0.16	0.38	0.03	0.09	10	17
S18	22	6.3	247	0.06	0.46	0.13	0.26	0.08	0.05	11	18
S19	49	6.4	345	0.05	0.93	0.25	0.14	0.06	0.13	6	11
S20	55	6.6	356	0.08	0.66	0.14	0.58	0.1	0.13	7	13
Range	19-85	6.1-6.8	247-461	0.05-0.16	0.40-1.25	0.13-0.30	0.14-0.58	0.02-0.23	0.04-0.13	4-13	8- 22
Mean(±SD)	54.56(±26.12)	6.4(±0.2)	355(±45)	0.10(±0.03)	0.84(±0.24)	0.16(±0.04)	0.30(±0.10)	0.07(±0.06)	0.07(±0.03)	8.31(±2.30)	14.32(±3.96)

Note: The values for Na^+, K^+, Ca^{2+}, TP, AP and TKN are in mg/kg and Moisture , TOC and OM in %.

Table 4.18 Physico-chemical characteristics of sediment in Bhindawas Wetland for Pre-monsoon (May, 2016)

Sites	Moisture	pH	EC	Na+	K+	Ca2+	TP	AP	TKN	TOC	OM
Inlet	37	7.1	158	0.14	0.92	0.12	0.16	0.04	0.04	4.0	7
Outlet	40	7.6	126	0.21	0.14	0.04	0.16	0.03	0.01	3.0	5
S1	60	6.5	318	0.14	0.99	0.13	0.14	0.03	0.02	9.0	16
S2	27	6.4	310	0.18	0.92	0.13	0.18	0.02	0.01	8.0	14
S3	54	6.6	104	0.25	0.78	0.11	0.11	0.02	0.05	7.0	12
S4	58	6.2	272	0.19	0.99	0.13	0.22	0.02	0.01	4.0	7
S5	58	6.3	308	0.23	1.18	0.14	0.19	0.01	0.03	4.0	7
S6	59	6.7	131	0.2	0.51	0.06	0.14	0.01	0.02	6.0	10
S7	54	6.6	164	0.17	1.63	0.17	0.16	0.02	0.01	8.0	14
S8	61	6.5	95	0.15	1.23	0.14	0.23	0.02	0.01	12.0	21
S9	44	6.6	79	0.15	0.68	0.1	0.10	0.04	0.01	10.0	17
S10	43	6.3	186	0.17	0.8	0.11	0.14	0.02	0.02	9.0	16
S11	60	6.6	119	0.07	0.99	0.13	0.17	0.04	0.02	8.0	14
S12	61	6.4	138	0.27	1.86	0.19	0.14	0.02	0.03	5.0	9
S13	62	6.2	210	0.25	1.31	0.13	0.19	0.01	0.03	6.0	10
S14	58	6.8	105	0.17	1.08	0.13	0.14	0.07	0.01	6.0	10
S15	59	6.6	78	0.15	1.07	0.12	0.03	0.02	0.01	10.0	17
S16	51	6.9	214	0.14	1.05	0.13	0.12	0.05	0.03	5.0	9
S17	21	6.9	77	0.13	0.31	0.11	0.19	0.03	0.02	8.0	14
S18	11	6.9	94	0.16	0.42	0.07	0.15	0.02	0.02	7.0	12
S19	23	6.2	239	0.17	0.28	0.07	0.16	0.14	0.02	5.0	9
S20	29	6.1	164	0.17	0.82	0.1	0.13	0.05	0.02	4.0	7
Range	11-62	6.1-6.9	77-318	0.07-0.27	0.28-1.86	0.06-0.19	0.03-0.23	0.01-0.14	0.01-0.05	4-12	7- 21
Mean(±SD)	47.54(±16.26)	6.5(±0.2)	170(±83)	0.18(±0.05)	0.95(±0.4)	0.12(±0.03)	0.15(±0.04)	0.03(±0.03)	0.02(±0.01)	7.05(±2.26)	12.15(±3.89)

Note: The values for Na^+, K^+, Ca^{2+}, TP, AP and TKN are in mg/kg and Moisture , TOC and OM in %.

Table 4.19 Physico-chemical characteristics of sediment in Bhindawas Wetland for Monsoon (September, 2016).

Sites	Moisture	pH	EC	Na^+	K^+	Ca^{2+}	TP	AP	TKN	TOC	OM
Inlet	37	7.3	267	0.09	1.2	0.08	0.28	0.04	0.06	10	17
Outlet	25	7.3	311	0.02	0.15	0.01	0.20	0.08	0.11	9	16
S1	84	6.3	352	0.1	0.99	0.08	0.59	0.06	0.04	11	19
S2	84	6.6	452	0.12	0.92	0.08	0.36	0.04	0.04	12	21
S3	89	6.7	704	0.1	1.06	0.08	0.41	0.03	0.04	17	29
S4	87	6.6	687	0.11	1.22	0.08	0.48	0.08	0.04	9	16
S5	85	7.1	705	0.09	1.12	0.08	0.32	0.08	0.06	11	18
S6	82	7.0	678	0.08	1.06	0.08	0.43	0.09	0.06	12	20
S7	89	6.9	729	0.11	1.3	0.09	0.47	0.05	0.05	11	19
S8	82	6.7	511	0.12	1.05	0.09	0.32	0.1	0.06	13	23
S9	79	6.6	606	0.07	0.69	0.05	0.34	0.09	0.05	9	16
S10	88	6.6	632	0.1	0.95	0.08	0.42	0.06	0.04	16	27
S11	77	6.8	330	0.07	0.41	0.04	0.37	0.19	0.06	6	10
S12	85	6.3	770	0.07	0.6	0.05	0.60	0.06	0.08	11	18
S13	65	6.4	276	0.06	0.67	0.05	0.34	0.07	0.06	6	11
S14	85	6.6	418	0.07	0.79	0.05	0.40	0.16	0.06	9	16
S15	92	6.4	599	0.14	0.7	0.08	0.49	0.08	0.08	14	24
S16	95	6.3	1029	0.07	0.41	0.05	0.24	0.17	0.08	15	25
S17	77	6.1	508	0.05	0.56	0.04	0.24	0.12	0.07	9	16
S18	92	6.9	837	0.05	0.55	0.04	0.25	0.15	0.05	7	11
S19	72	6.8	667	0.05	0.53	0.03	0.38	0.08	0.08	9	15
S20	88	6.5	566	0.11	1.03	0.08	0.36	0.08	0.09	12	20
Range	65-95	6.1-7.1	276-1029	0.05-0.14	0.41-1.30	0.03-0.09	0.24-0.6	0.03-0.19	0.04-0.09	6-17	10- 29
Mean(±SD)	83.84(±7.23)	6.6(±0.3)	603(±183)	0.09(±0.03)	0.83(±0.27)	0.07(±0.02)	0.39(±0.1))	0.09(±0.04)	0.06(±0.02)	10.90(±3)	18.79(±5.17)

Note: The values for Na^+, K^+, Ca^{2+}, TP, AP and TKN are in mg/kg and Moisture , TOC and OM in %.

Table 4.20 Physico-chemical characteristics of sediment in Bhindawas Wetland for Post-monsoon (January, 2017)

Sites	Moisture	pH	EC	Na^+	K^+	Ca^{2+}	TP	AP	TKN	TOC	OM
Inlet	32	7.8	198	0.05	0.89	0.21	0.31	0.05	0.06	9	16
Outlet	24	8	200	0.03	0.29	0.12	0.32	0.14	0.13	8	14
S1	71	6.3	392	0.10	1.36	0.19	0.41	0.12	0.06	8	14
S2	69	6.4	457	0.100	1.29	0.2	0.42	0.17	0.06	7	12
S3	71	6.2	321	0.11	1.35	0.22	0.45	0.2	0.15	9	16
S4	52	6.2	374	0.10	1.31	0.2	0.41	0.09	0.09	10	16
S5	61	6.5	321	0.10	1.66	0.23	0.41	0.07	0.04	7	12
S6	61	6.9	322	0.10	1.55	0.23	0.46	0.07	0.08	9	16
S7	63	6.4	352	0.11	1.78	0.25	0.39	0.05	0.06	11	18
S8	60	6.3	331	0.08	1.21	0.21	0.49	0.09	0.06	8	14
S9	69	6.3	354	0.08	1.13	0.21	0.4	0.12	0.01	8	13
S10	79	6.2	347	0.11	1.04	0.22	0.46	0.18	0.07	12	21
S11	60	6.8	312	0.08	1.12	0.19	0.36	0.06	0.08	7	12
S12	61	6.5	365	0.11	1.89	0.28	0.14	0.04	0.13	11	19
S13	69	6.4	338	0.12	2.06	0.26	0.45	0.03	0.09	6	11
S14	63	6	453	0.08	1.28	0.2	0.44	0.07	0.06	8	13
S15	55	6.4	306	0.08	0.92	0.18	0.47	0.09	0.11	10	18
S16	63	6.3	262	0.07	0.96	0.18	0.46	0.14	0.11	10	17
S17	61	6.4	347	0.08	1.08	0.19	0.4	0.1	0.07	13	22
S18	52	6.4	325	0.09	0.9	0.18	0.39	0.11	0.11	8	14
S19	61	6.5	340	0.08	1.09	0.2	0.38	0.14	0.11	12	20
S20	61	6.2	343	0.08	1.11	0.22	0.4	0.15	0.11	7	12
Range	52-79	6-6.9	262-457	0.07-0.12	0.9-2.06	0.18-0.28	0.14-0.49	0.03-0.20	0.01-0.15	6-13	11-22
Mean(±SD)	63.1(±6.65)	6.4(±0.2)	348(±46)	0.09(±0.01)	1.3(±0.33)	0.21(±0.03)	0.41(±0.07))	0.10(±0.05)	0.08(±0.03)	8.98(±1.89)	15.48(±3.25)

Note: The values for Na^+, K^+, Ca^{2+}, TP, AP and TKN are in mg/kg and Moisture , TOC and OM in %.

Table 4.21 Physico-chemical characteristics of sediment in Bhindawas Wetland for Pre-monsoon (May, 2017)

Sites	Moisture	pH	EC	Na^+	K^+	Ca^{2+}	TP	AP	TKN	TOC	OM
Inlet	34	7.5	258	0.11	0.73	0.2	0.31	0.05	0.05	5	9
Outlet	27	7.8	116	0.34	0.37	0.13	0.17	0.07	0.06	3	5
S1	85	6.4	338	0.16	0.8	0.17	0.41	0.03	0.04	11	19
S2	80	6.5	290	0.17	0.75	0.19	0.31	0.04	0.04	7	11
S3	83	6.5	323	0.26	0.88	0.22	0.29	0.04	0.08	6	10
S4	72	6.3	290	0.22	0.81	0.18	0.37	0.02	0.02	6	11
S5	82	6.4	328	0.25	0.81	0.17	0.33	0.02	0.06	7	12
S6	80	6.7	331	0.13	1.12	0.23	0.24	0.03	0.02	8	13
S7	81	6.5	364	0.29	0.76	0.16	0.32	0.01	0.03	6	11
S8	84	6.4	295	0.29	0.71	0.16	0.31	0.03	0.01	5	8
S9	21	6.8	72	0.12	0.49	0.1	0.28	0.03	0.02	7	11
S10	45	6.2	178	0.17	0.35	0.1	0.42	0.01	0.04	4	7
S11	39	6.7	109	0.16	0.52	0.11	0.25	0.04	0.04	4	7
S12	29	6.5	148	0.15	0.47	0.15	0.42	0.01	0.05	4	6
S13	81	6.3	310	0.16	0.93	0.18	0.2	0.05	0.03	5	8
S14	24	6.9	96	0.26	0.36	0.17	0.41	0.07	0.04	5	9
S15	27	6.7	68	0.16	0.31	0.08	0.27	0.07	0.04	10	17
S16	33	7.6	220	0.29	0.45	0.08	0.34	0.2	0.05	3	5
S17	19	7	68	0.26	0.44	0.08	0.32	0.03	0.02	4	7
S18	22	6.9	85	0.21	0.26	0.04	0.29	0.02	0.04	5	9
S19	49	6.3	269	0.27	0.47	0.1	0.24	0.07	0.03	5	8
S20	55	6.4	155	0.15	0.33	0.1	0.28	0.1	0.04	3	6
Range	19-85	6.2-7.6	68-364	0.12-0.29	0.26-1.12	0.04-0.23	0.20-0.42	0.01-0.20	0.01-0.08	3-11	5-19
Mean(±SD)	55(±26.1)	6.6(±0.3)	217(±107.7)	0.21(±0.06)	0.60(±0.24)	0.14(±0.05)	0.32(±0.06)	0.05(±0.04)	0.04(±0.02)	5.69(±2.1)	9.82(±3.61)

Note: The values for Na^+, K^+, Ca^{2+}, TP, AP and TKN are in mg/kg and Moisture , TOC and OM in %.

4.3.2. Heavy metals

Spatial and seasonal variations *(September, 2015 to May, 2017)*

Sediment quality assessment of Bhindawas wetland based on Heavy Metal (Cd, Cr, Cu, Pb, Ni, Fe, Zn) concentrations is carried out for twenty sites (S1 to S20) along with inlet (JLN Canal) and outlet (Drain no.8) for two years (September, 2015 to May, 2017; monsoon, post-monsoon, pre-monsoon). The mean (±SD) value of heavy metal concentrations are shown in Table 4.22 (September, 2015- May, 2016) and Table 4.23 (September, 2016- May, 2017). Heavy metal concentrations in the sediment reflect the overall health and pollution status of wetland ecosystem. During first year (2015-16), the value of chromium (Cr) in the sediment samples ranged from 0.62 (S11) to 1.08 (S6) with the mean value of 0.91 (±0.14) in monsoon; 15.42 (S4) to 25.19 (S19) with the mean value of 19.19 (±2.83) in post-monsoon; and 8.80 (S2) to 51.32 (S18) with the mean value of 29.51 (±11.81) in pre-monsoon (Table 4.22). Cadmium (Cd) in the sediment sample was observed only two sampling sites, S9 and S18 in monsoon with the mean value of 0.17 (±0.55) and the values of cd in pre-monsoon ranged from 0.91 (S2) to 1.76 (S20) with the mean value of 1.34 (±0.23). Whereas, all the sampling sites in post-monsoon and monsoon (except S9, S18) were observed to be BDL. The range and the mean (±SD) value for copper (Cu), for monsoon, post-monsoon and pre-monsoon was observed to be 9.73 (S11) to 36.08 (S6) and 19.36 (±6.31); 8.61 (S5) to 11.02 (S8) and 9.49 (±0.63); 27 (S20) to 35.96 (S4) and 30.71 (±2.64) respectively. Similarly the range and the mean (±SD) value for iron (Fe) in monsoon, post-monsoon and pre-monsoon was observed to be 1988 (S11) to 9804 (S6) and 5121 (±1928); 2700 (S9) to 8265 (S15) and 5453 (±1461); 1936 (S18) to 6244 (S11) and 4379 (±1270) respectively. The range and the mean (±SD) value for nickel (Ni) in monsoon, post-monsoon was observed to be 9.74 (S1) to 23.8 (S6) and 16.49 (±3.2); 4.68 (S4) to 14.50 (S19) and 9.36 (±2.41) BDL was observed for the pre-monsoon. The range and the mean (±SD) value for lead (Pb) in monsoon, post-monsoon and pre-monsoon was observed to be 0.35 (S4) to 20.98 (S20) and 9.41 (±5.34); 4.29 (S9) to 11.29 (S20) and 7.27 (±1.79); 14.38 (S4) to 28.29 (S16) and 19.65 (±4.45) respectively. Lastly the range and mean (±SD) value for zinc (Zn) in monsoon, post-monsoon and pre-monsoon was observed to be 7.15 (S11) to 67.25 (S6) and 27.11 (±15.27); 2.30 (S9) to 18.40 (S14) and 20.04 (±4.57); 47 (S18) to 110.3 (S5) and 61.24 (±15.1) respectively.

Table 4.22 Heavy Metal concentration (mg/kg) in sediments of Bhindawas Wetland (September, 2015 - May, 2016)

	Monsoon							Post-monsoon							Pre-monsoon						
Sites	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**
Inlet	0.14	0.76	13.96	3849	14.08	12.99	12.37	0.21	8.92	22.90	6711	7.90	7.84	6.34	0.46	38.80	30.20	4690	2.14	27.61	61.24
Outlet	0.09	0.91	17.33	5132	18.76	25.66	26.64	0.16	8.79	17.30	5910	13.20	5.52	13.29	0.33	50.48	26.92	1197	1.03	25.23	46.20
S1	BDL	0.63	11.85	3528	9.74	2.77	15.15	BDL	16.84	10.32	7024	11.52	7.83	15.02	1.21	14.60	33.72	5097	BDL	14.71	54.60
S2	BDL	0.73	15.01	4928	13.21	8.38	19.71	BDL	16.45	9.92	5801	10.62	5.83	13.22	0.91	8.80	31.00	4530	BDL	16.55	52.28
S3	BDL	0.90	19.08	6384	15.40	10.21	30.44	BDL	16.84	9.82	5655	9.42	6.13	8.90	0.98	20.68	35.28	4339	BDL	19.10	52.76
S4	BDL	0.88	19.71	7556	16.60	0.35	58.25	BDL	15.42	8.99	4133	4.68	8.67	6.38	1.19	25.64	35.96	5125	BDL	14.38	54.16
S5	BDL	0.93	29.62	9168	21.47	6.20	46.49	BDL	16.57	8.61	2886	9.00	6.02	10.72	1.10	19.28	32.20	5352	BDL	17.68	110.32
S6	BDL	1.08	36.08	9804	23.80	7.00	67.25	BDL	17.59	9.85	4798	6.58	7.52	6.82	1.16	13.88	30.76	2582	BDL	16.34	69.12
S7	BDL	1.00	25.91	3382	17.91	1.95	39.93	BDL	17.38	8.97	5455	10.50	6.02	15.74	1.16	24.80	29.84	5862	BDL	18.20	84.00
S8	BDL	0.76	15.40	3712	13.49	5.74	22.26	BDL	17.04	11.02	5738	8.76	4.30	14.54	1.23	20.80	28.56	5222	BDL	19.23	74.00
S9	1.09	0.77	24.14	4688	14.99	7.90	21.01	BDL	17.91	9.04	2701	8.40	4.29	2.30	1.28	30.84	28.88	3462	BDL	19.77	67.20
S10	BDL	0.90	14.75	6108	15.76	12.25	22.10	BDL	19.17	9.81	5478	7.74	6.71	13.04	1.31	28.84	29.00	4762	BDL	16.44	72.48
S11	BDL	0.62	9.73	1988	11.12	2.89	7.15	BDL	18.24	10.03	6700	7.26	10.74	14.18	1.37	25.72	35.08	6244	BDL	18.19	60.52
S12	BDL	1.04	24.44	3733	18.61	7.46	33.89	BDL	18.95	8.95	5991	8.58	7.26	13.66	1.34	33.52	31.40	5630	BDL	15.43	55.68
S13	BDL	0.97	18.99	3821	19.43	12.54	26.40	BDL	19.27	9.31	4863	7.88	6.92	10.12	1.34	31.72	32.08	4726	BDL	18.18	56.60
S14	BDL	1.02	18.20	5448	17.45	11.43	17.25	BDL	20.81	9.65	7309	6.16	9.33	18.40	1.49	26.20	31.00	5060	BDL	18.57	57.28
S15	BDL	0.89	15.78	4224	16.08	14.71	18.42	BDL	20.24	8.90	8266	8.94	7.26	18.26	1.53	36.88	28.00	5036	BDL	16.93	54.24
S16	BDL	1.06	16.74	5200	16.36	16.29	24.55	BDL	19.20	9.08	2988	11.54	6.22	3.74	1.53	42.56	29.04	1947	BDL	28.29	47.80
S17	BDL	0.94	15.96	4492	17.41	10.62	17.11	BDL	24.68	10.20	6126	10.42	7.86	15.42	1.61	43.68	28.56	2551	BDL	27.91	49.92
S18	2.25	1.00	23.60	5084	17.70	15.04	24.63	BDL	22.40	9.61	4825	13.22	7.78	9.58	1.61	51.32	27.96	1936	BDL	26.75	47.00
S19	BDL	0.97	14.63	3956	16.50	13.49	15.01	BDL	25.19	8.67	6018	14.50	7.56	14.50	1.67	48.00	28.88	4115	BDL	25.34	49.96
S20	BDL	1.03	17.71	5228	16.72	20.98	15.30	BDL	23.63	9.08	6317	11.44	11.29	16.28	1.76	42.48	27.00	4010	BDL	25.10	54.92
Range	BDL-2.25	0.62-1.08	9.73-36.08	1988-9804	9.74-23.8	0.35-20.98	7.15-67.25	-	15.42-25.19	8.61-11.02	2700-8265	4.68-14.50	4.29-11.29	2.30-18.40	0.91-1.76	8.80-51.32	27-35.96	1936-6244	-	14.38-28.29	47-110.32
Mean ±SD	0.17 ±0.55	0.91 ±0.4	19.36 ±6.1	5121 ±198	16.49 ±3.2	9.41 ±5.3	27.11 ±15.27	0.00	19.19 ±2.83	9.49 ±0.63	5453 ±1461	9.36 ±2.41	7.27 ±1.79	20.04 ±4.57	1.34 ±0.23	29.51 ±11.81	30.71 ±2.64	4379 ±1270	-	19.65 ±4.45	61.24 ±15.14

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites). All the Heavy metals have concentration in mg/kg. BDL represents Below detection limit.

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Similarly for the second year (2016-17) the value of Cd in the sediment samples was observed in range of 0 (S2, S4, S5, S7, S11, S12, S14-S17, S20) to 1.92 (S18) mg/kg with mean value of 0.23 (±0.48) mg/kg in monsoon, whereas in post-monsoon and pre-monsoon values were in range of 0 (S1, S3, S6, S13, S14, S17, S20) to 0.06 (S9) mg/kg and 0.58 (S2) to 1.33 (S11) mg/kg with the mean values of 0.02 (±0.02) mg/kg and 0.39 (±0.10) mg/kg respectively (Table 4.22). Range and the mean (±SD) value for Chromium (Cr) for monsoon, post-monsoon and pre-monsoon was observed to be 0.10 (S2) to 2.34 (S20) and 1.27 (±0.61); 13.7 (S12) to 21.70 (S14) and 18.22 (± 2.08); 14.50 (S3) to 50 (S7) and 27.94 (± 9.75) respectively. Copper (Cu) was found with range and mean (±SD) values to be 13.30 (S1) to 26.20 (S3) and 20.01 (±4.07); 6.35 (S14) to 19.95 (S16) and 11.21 (±4.45); 22.70 (S1) to 39.45 (S16) and 31.89 (±4.75) in monsoon, post-monsoon and pre-monsoon respectively. Similarly the range and the mean (±SD) value for iron (Fe) in monsoon, post-monsoon was observed to be 2236 (S17) to 9924 (S20) and 6834 (±1909); 7205 (S18) to 8377 (S9) and 7718 (±361); and 3165 (S17) to 6705 (S6) and 5338 (±993) respectively. The range and the mean (±SD) value for nickel (Ni) was observed to be 1.25 (S14) to 24.45 (S10) and 14.24 (±7.02); 5.85 (S5) to 18.15 (S13) and 11.02 (±4.02); and 0 (S14, S20) to 6.25 (S11) and 1.71 (±3.39) in monsoon, post-monsoon and pre-monsoon respectively.

The range and the mean (±SD) value for lead (Pb) in monsoon, post-monsoon and pre-monsoon was observed to be 0 (S9) to 21.25 (S5) and 11.45 (±5.04); 4.43 (S10) to 18.75 (S8) and 9.72 (±3.54); 1.25(S7) to 20.32 (S20) and 14.26 (±4.45) respectively. Lastly the range and mean (±SD) value for zinc (Zn) in monsoon, post-monsoon and pre-monsoon was observed to be 16.70 (S11, S15) to 63.20 (S4) and 31.22 (±13.58), 5.75 (S18) to 15.85 (S12) and 12 (±2.47) and 43.10 (S5) to 81.15 (S6) and 55.8 (±9.26) respectively.

Table 4.23 Heavy Metal concentration (mg/kg) in sediments of Bhindawas Wetland (September, 2016 - May, 2017).

	Monsoon							Post-monsoon							Pre-monsoon						
Sites	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**	**Cd**	**Cr**	**Cu**	**Fe**	**Ni**	**Pb**	**Zn**
Inlet	0.18	BDL	BDL	7034	17.64	14.56	9.23	0.20	15.60	4.90	7478	12.70	13.95	9.25	0.51	8.50	1.95	6138	3.35	16.20	59.60
Outlet	0.10	4.50	6.60	6775	14.50	32.15	18.39	0.11	12.60	3.40	4861	40.00	18.95	3.55	0.27	3.00	BDL	4722	1.57	5.90	44.50
S1	0.02	1.50	13.30	6561	12.30	10.30	22.40	BDL	16.70	8.35	8084	6.65	8.90	11.05	1.18	21.50	22.70	5997	3.30	14.20	60.65
S2	BDL	0.10	17.75	8892	14.50	10.30	26.70	0.01	18.70	7.60	7498	8.90	7.40	10.15	0.58	23.34	31.95	5997	1.65	10.75	54.15
S3	0.75	0.88	26.20	7271	17.80	10.30	42.75	BDL	19.60	16.15	8084	7.85	8.95	10.60	0.62	14.50	35.65	6138	3.55	15.90	46.65
S4	BDL	0.95	16.60	6239	22.25	12.15	63.20	0.01	17.60	9.10	7791	6.40	7.75	14.55	0.61	38.50	24.90	6138	3.20	10.75	49.60
S5	0.00	2.08	17.30	7418	9.00	21.25	49.95	0.02	20.50	8.65	7938	5.85	6.85	13.65	1.16	18.50	28.76	6138	2.65	7.53	43.10
S6	0.61	1.50	19.35	7247	22.25	13.10	45.10	BDL	15.60	9.65	8084	6.75	13.95	15.00	1.08	26.50	30.10	6705	1.65	15.90	81.15
S7	BDL	0.92	15.20	8661	18.95	11.25	55.10	0.01	18.70	10.05	7791	12.15	11.85	13.65	1.23	50.00	26.56	6280	4.02	1.25	61.15
S8	0.02	0.73	18.70	8745	14.50	11.25	23.20	0.05	17.30	14.90	7645	17.75	18.75	11.90	0.89	23.00	37.32	6280	3.13	11.75	49.60
S9	0.78	0.64	13.85	4470	11.20	BDL	28.55	0.06	18.60	13.85	8377	7.95	8.10	8.85	1.06	26.50	35.65	5147	5.30	15.90	57.55
S10	0.01	0.83	23.85	8132	24.45	13.10	18.70	0.01	19.85	9.10	7498	10.60	4.43	10.15	1.11	20.50	32.70	5430	3.89	11.75	46.05
S11	BDL	0.65	22.45	6195	20.05	4.85	16.70	0.05	15.85	8.15	7352	11.80	13.85	10.60	1.33	26.50	25.65	5006	6.25	16.43	66.55
S12	BDL	1.84	23.85	5773	9.00	17.65	38.10	0.03	13.70	18.55	8231	12.45	8.70	15.85	0.99	38.50	36.40	6563	5.00	12.75	53.15
S13	0.01	0.83	19.55	5122	11.20	12.15	29.95	BDL	18.70	7.32	8084	18.15	13.80	15.00	1.01	20.50	33.20	4297	3.34	16.31	65.32
S14	BDL	1.93	18.70	4912	1.25	15.75	19.50	BDL	21.70	6.35	7791	17.20	8.85	14.55	1.23	24.50	31.20	4156	BDL	15.90	55.53
S15	BDL	2.01	16.60	9311	5.70	16.70	16.70	0.01	18.60	8.15	7205	16.15	5.90	11.05	1.32	44.00	34.70	4864	5.30	16.04	46.05
S16	BDL	1.73	23.85	8080	5.70	10.30	34.80	0.01	19.60	19.95	7352	13.80	7.70	12.80	0.85	26.50	39.45	5147	5.00	17.65	58.50
S17	BDL	0.74	18.05	2236	5.70	4.85	25.75	BDL	17.90	6.90	7352	9.85	9.85	10.60	0.87	26.50	36.54	3165	2.12	15.90	53.45
S18	1.92	1.64	25.20	6363	12.30	4.85	25.30	0.04	14.75	15.64	7205	8.50	6.05	5.75	1.03	44.00	36.95	5147	3.46	19.75	46.05
S19	0.51	1.54	23.85	5135	23.35	12.15	23.20	0.02	19.75	7.40	7352	13.80	13.80	12.35	0.87	18.50	28.15	4014	5.00	18.45	65.65
S20	BDL	2.34	25.90	9924	23.35	16.70	18.70	BDL	20.70	18.35	7645	7.95	8.95	11.90	0.96	26.50	29.20	4156	BDL	20.32	56.05
Range	BDL - 1.92	1.10-2.34	13.30-26.20	2236-9924	1.25-24.45	BDL-21.25	16.70-63.20	BDL -0.06	13.7-21.7	6.35-19.95	7205 - 8377	5.85-18.15	4.43-18.75	5.75-15.85	0.58-1.33	14.5-50	22.7-39.45	3165 - 6705	BDL -6.25	1.25-20.32	43.10 - 81.15
Mean ±SD	0.23 ±0.5	1.27± 0.61	20.01 ±4.07	6834 ±1909	14.24 ±7.02	11.45 ±5.04	31.22 ±13.58	0.02 ±0.02	18.22 ±2.08	11.21 ±4.45	7718 ±361	11.02 ±4.02	9.72 ±3.54	12 ±2.47	0.39 ±0.10	27.94 ±9.75	31.89 ±4.75	5338 ±993	1.71 ±3.39	14.26 ±4.45	55.8 ±9.26

Note: The mean (±SD) & Range were carried out for S1 to S20 (20sites). All the Heavy metals have concentration in mg/kg. BDL represents Below detection limit.

Cadmium (Cd)

The mean value of Cadmium (Cd) in sediments varied from 0 mg/kg to 1.34 mg/kg (Fig. 4.48). The maximum value was observed to be high in pre-monsoon 1.34 ± 0.23 (2015-16); 0.39 ± 0.10 (2016-17) followed by monsoon 0.17 ± 0.55 (2015-16); 0.23 ± 0.48 (2016-17) and post-monsoon 0 ± 0 (2015-16); 0.02 ± 0.02 (2016-17) during the study of two years.

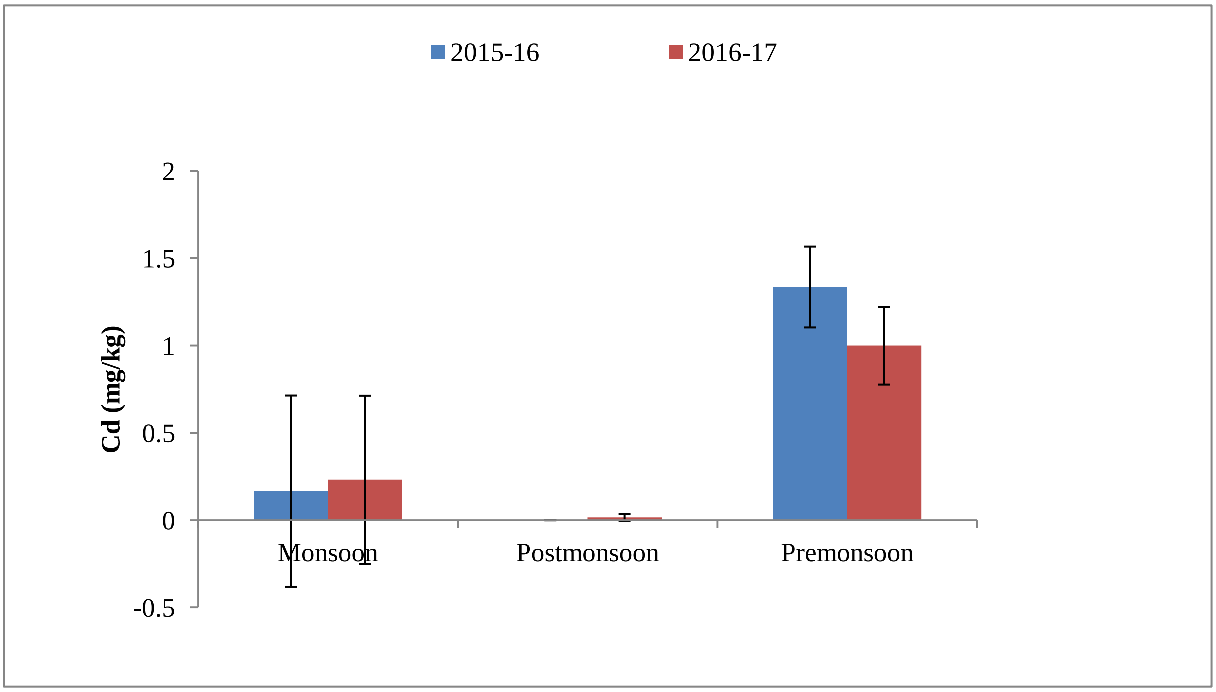

Figure 4.48. Seasonal variation in mean concentration (mg/kg) of Cd in sediments of Bhindawas wetland in different seasons for two successive years.

Chromium (Cr)

The mean value of Chromium (Cr) in sediments during the study period varied from 0.91 mg/kg to 29.51 mg/kg (Fig. 4.49). The maximum value was observed to be high in pre-monsoon 29.51 ± 11.81 (2015-16); 27.94 ± 9.75 (2016-17) followed by post-monsoon 19.19 ± 2.83 (2015-16); 18.22 ± 2.08 (2016-17) and monsoon 0.91 ± 0.14 (2015-16); 1.27 ± 0.61 (2016-17) during the study of two years.

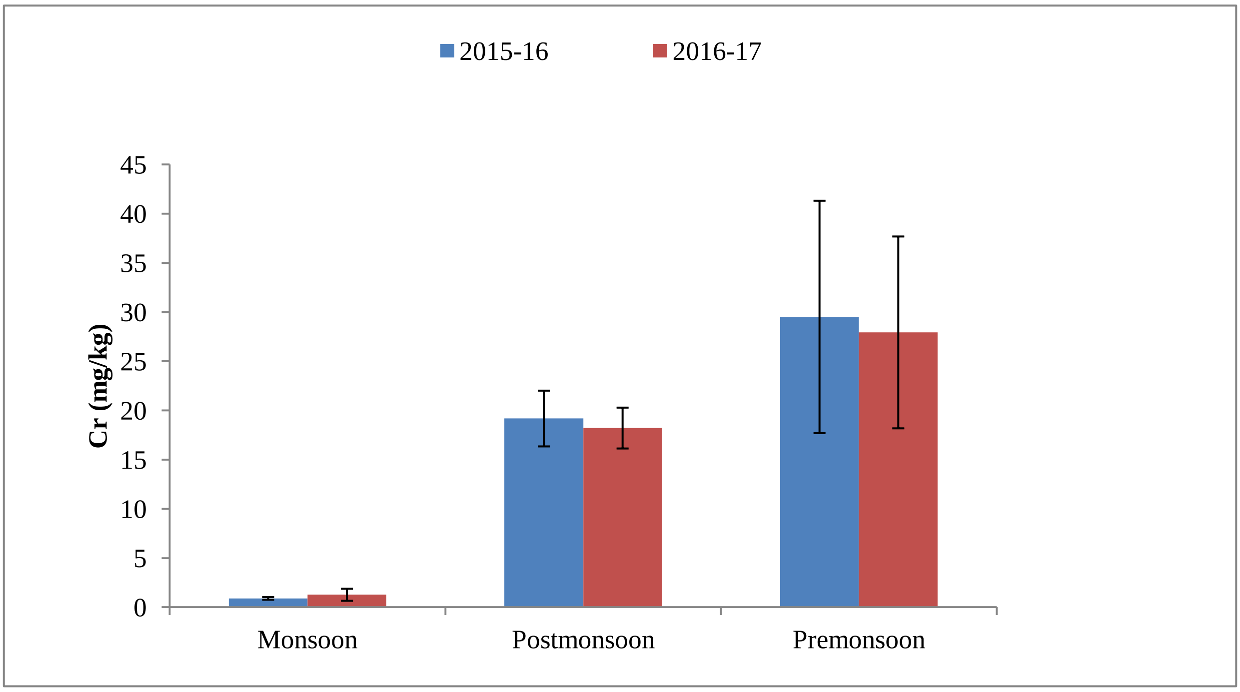

Figure 4.49 Seasonal variations in mean concentration (mg/kg) of Cr in sediments of Bhindawas wetland in different seasons for two successive years.

Copper (Cu)

The mean value of Copper (Cu) in sediments during the study period varied from 9.49 mg/kg to 32.05 mg/kg (Fig.4.50). The maximum value was observed to be high in pre-monsoon

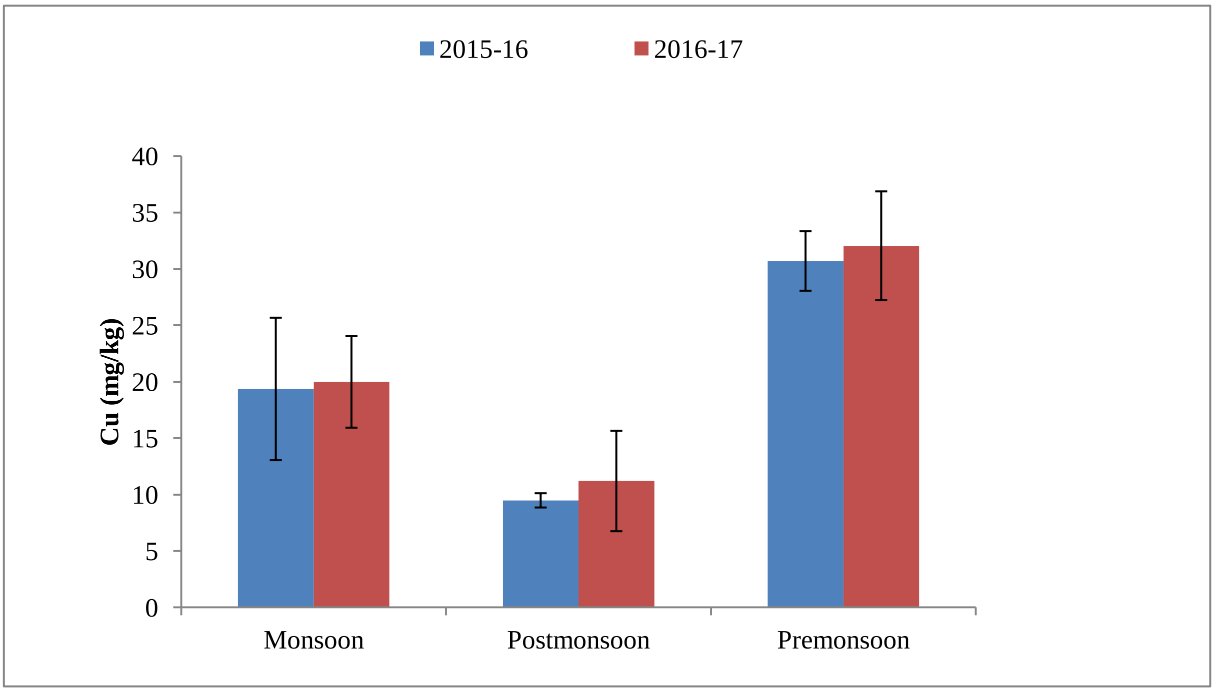

Figure 4.50 Seasonal variations in mean concentration (mg/kg) of Cu in sediments of Bhindawas wetland in different seasons for two successive years.

30.71 ±2.64 (2015-16); 31.89 ± 4.75 (2016-17) followed by monsoon 19.36 ± 6.31 (2015-16); 20.01 ± 4.07 (2016-17) and post-monsoon 9.49 ± 0.63 (2015-16); 11.21 ± 4.45 (2016-17) during the study of two years.

Iron (Fe)

The mean value of iron (Fe) in sediments during the study period varied from 4380 mg/kg to 7717 mg/kg (Fig. 4.51). The maximum value was observed to be high in post-monsoon 5453 ± 1461 (2015-16); 7718 ± 361 (2016-17) followed by monsoon 5121 ± 1928 (2015-16); 6834 ± 1909 (2016-17) and pre-monsoon 4379 ± 1270 (2015-16); 5338 ± 993 (2016-17) during the study of two years.

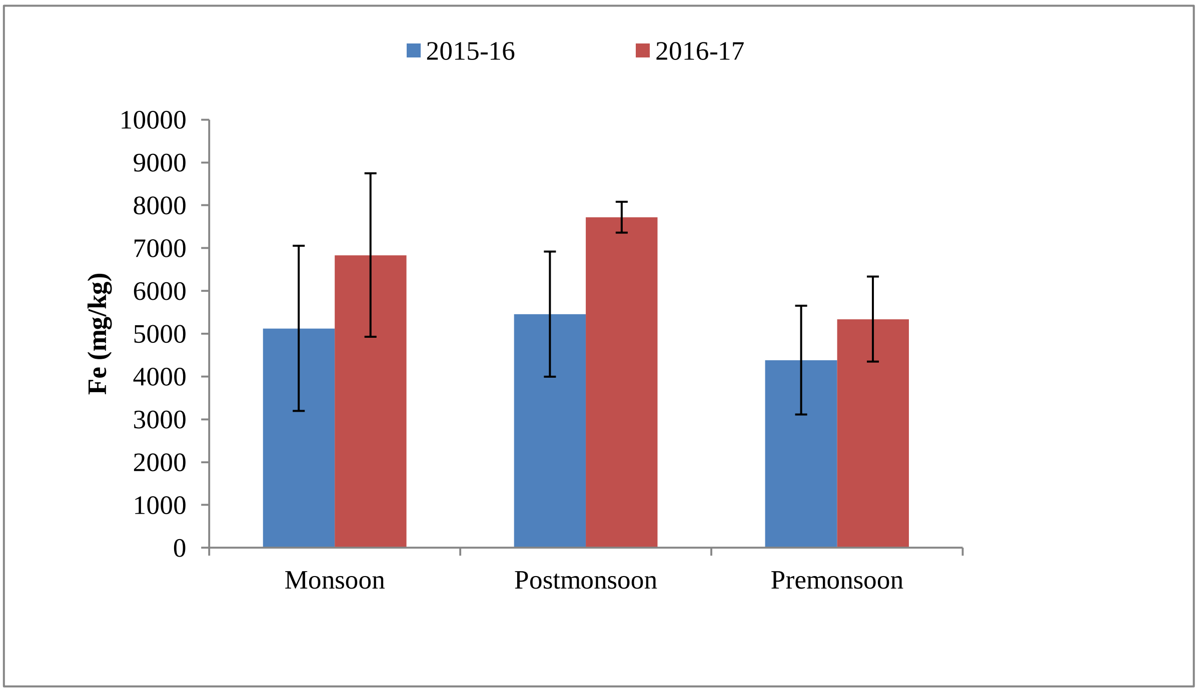

Figure 4.51 Seasonal variations in mean concentration (mg/kg) of Fe in sediments of Bhindawas wetland in different seasons for two successive years.

Nickel (Ni)

The mean value of nickel (Ni) in sediments during the study period varied from 0 mg/kg to 16.49 mg/kg (Fig.4.52). The maximum value was observed to be high in monsoon 16.49 ± 3.2 (2015-16); 14.24 ± 7.02 (2016-17) followed by post-monsoon 9.36 ± 2.41 (2015-16); 11.02 ± 4.02 (2016-17) and pre-monsoon 0 ± 0 (2015-16); 1.71 ± 3.39 (2016-17) during the study of two years.

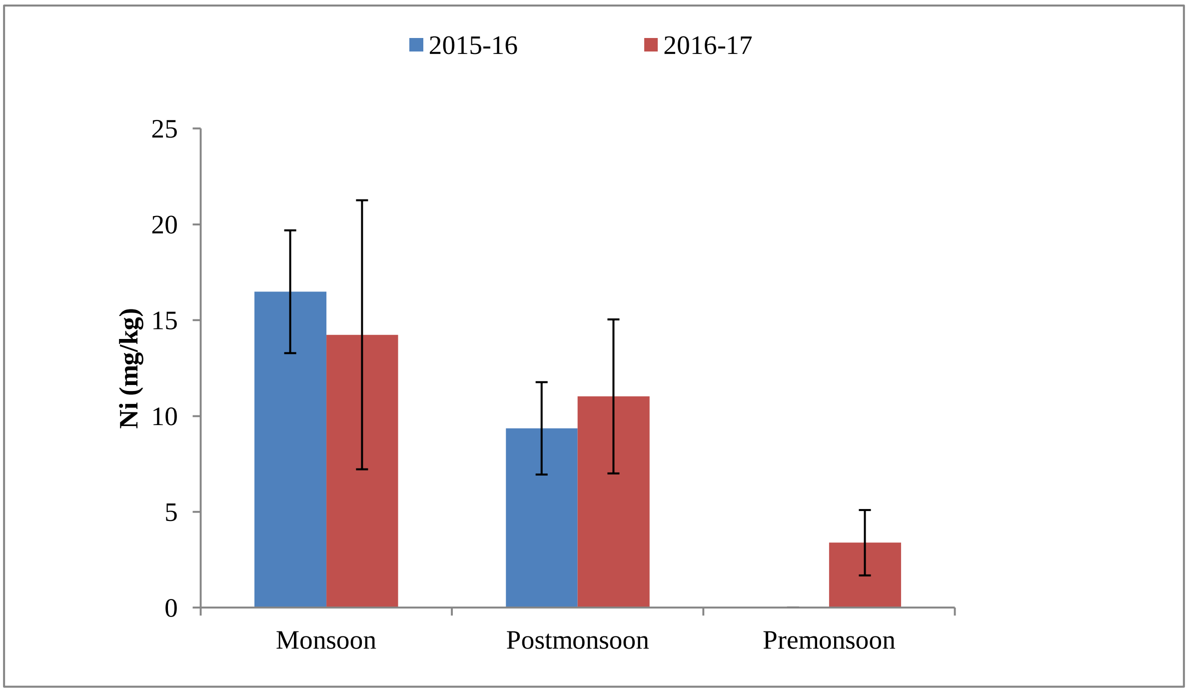

Figure 4.52 Seasonal variations in mean concentration (mg/kg) of Ni in sediments of Bhindawas wetland in different seasons for two successive years.

Lead (Pb)

The mean value of Lead (Pb) in sediments during the study period varied from 7.27 mg/kg to 19.65 mg/kg (Fig.4.53). The maximum value was observed to be high in pre-monsoon

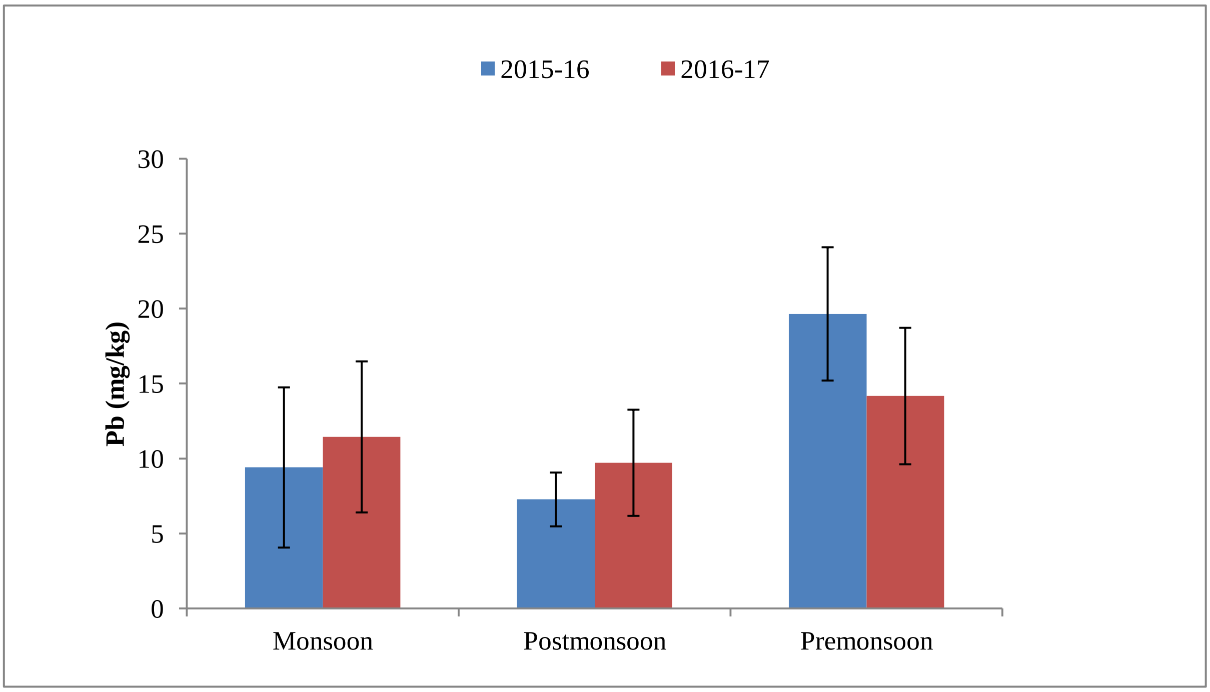

Figure 4.53 Seasonal variations in mean concentration (mg/kg) of Pb in sediments of Bhindawas wetland in different seasons for two successive years.

19.65 ± 4.45 (2015-16); 14.26 ± 4.45 (2016-17) followed by monsoon 9.41 ± 34.60 (2015-16); 11.45 ± 5.04 (2016-17) and post-monsoon 7.27 ± 1.79 (2015-16); 9.72 ± 3.54 (2016-17) during the study of two years.

Zinc (Zn)

The mean value of zinc (Zn) in sediments during the study period varied from 12 mg/kg to 61.24 mg/kg (Fig.4.54). The maximum value was observed to be high in pre-monsoon 61.24 ± 15.1 (2015-16); 55.8 ± 9.26 (2016-17) followed by monsoon 27.11 ± 15.27 (2015-16); 31.22 ± 13.58 (2016-17) and post-monsoon 20.04 ± 4.57 (2015-16); 12 ± 2.47 (2016-17) during the study of two years.

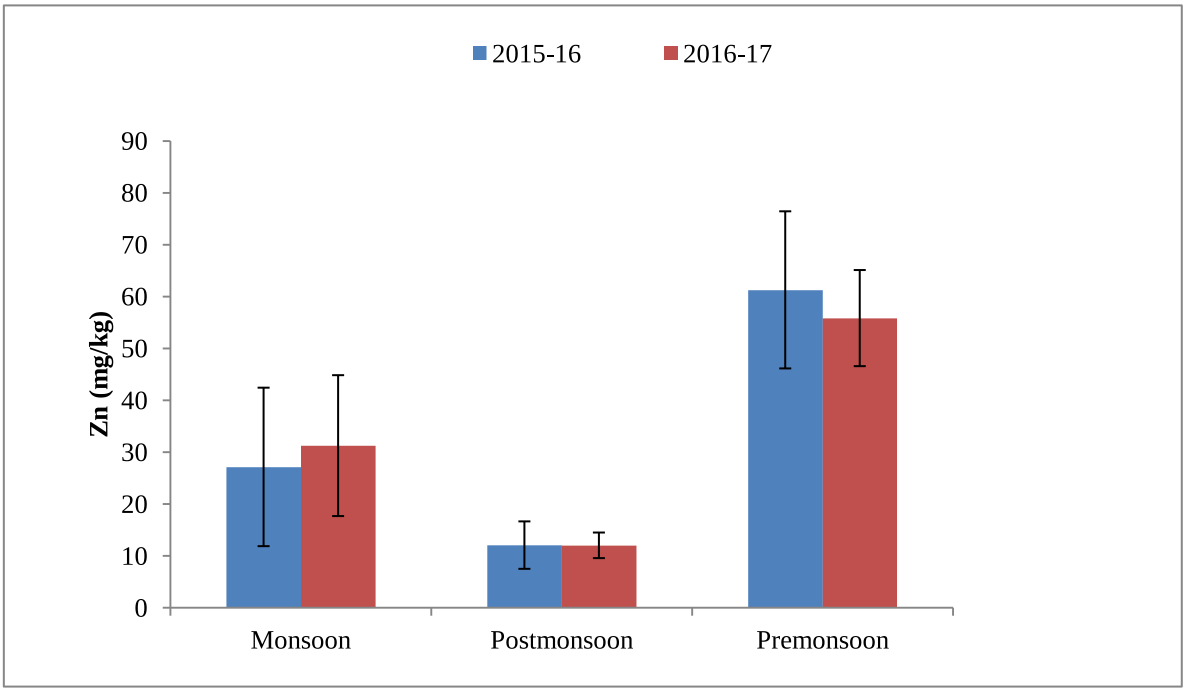

Figure 4.54 Seasonal variations in mean concentration (mg/kg) of Zn in sediments of Bhindawas wetland in different seasons for two successive years.

4.3.3 Sediment Quality Indices

The classification of sediment quality in Bhindawas wetland was carried out using various standard indices *viz*. Enrichment Factor (EF) (Saken et al., 2009); Contamination Factor (CF); Pollution Load Index (PLI) (Tomlinson et al., 1980); Degree of Contamination (DC) (Hokanson, 1980); Geo-accumulation Index (Igeo) (Muller, 1969); and sediment pollution index (SPI) (Singh et al., 2002).

4.3.3.1. Enrichment Factor (EF)

EF in all the heavy metals in Bhindawas wetland sediments is shown in Table 4.24 (September, 2015 – May, 2016) and Table 4.25 (September, 2016 – May, 2017). It indicates that the EF of Cadmium (Cd) varied from 0 (category: background concentration; source: natural) to 69.65 (extremely high enrichment; anthropogenic source) in monsoon and 31.13 (very high enrichment; anthropogenic source) to 130.84 (extremely high enrichment; anthropogenic source) in pre-monsoon respectively. EF of Chromium (Cr) varied from 0.05 to 0.16 (background concentration; natural source) in monsoon, 1.26 (indicates minimal enrichment; natural source) to 3.48 (indicate moderate enrichment; anthropogenic source) in post-monsoon and 1.02 (minimal enrichment; natural source) to 13.90 (significant enrichment; anthropogenic source) in pre-monsoon respectively. Similarly copper ranged from 2.53 (moderate enrichment; anthropogenic source) to 8.04 (significant enrichment; anthropogenic source) in monsoon, 1.13 (minimal enrichment; natural source) to 3.51 (moderate enrichment; anthropogenic source) in post-monsoon and 5.34 to 15.65 in pre-monsoon showing significant enrichment with anthropogenic source respectively. The details of EF for Ni, Pb and Zn for monsoon, post-monsoon and pre-monsoon have been shown in Table 4.24 during first year. EF of heavy metals in the sediment samples of Bhindawas wetland are shown in Table 4.25 for the second year of study (September, 2016 – May, 2017). Nickel (Ni) varied from 0.18 (background concentration, natural source) to 3.16 (moderate enrichment and anthropogenic source) in monsoon, 0.51(background concentration; natural source) to 1.61 (minimum enrichment; natural source) in post-monsoon and 0 (background concentration; natural source) to 0.87 (background concentration; natural source) in pre-monsoon respectively. EF of lead (Pb) varied from 0 to 7.57 (background concentration; natural source to significant enrichment) in monsoon, 1.39 (minimal enrichment) to 5.79 (significant enrichment) in post-monsoon and 0.47 to 11.86 (background concentration; natural source to significant enrichment) in pre-monsoon respectively. Similarly Zinc (Zn) ranged from 0.89 (background concentration; natural source) to 5.72 (significant enrichment; anthropogenic source) in monsoon, 0.40 (background concentration; natural source) to 0.96 (background concentration; natural source) in post-monsoon and 3.49 (moderate enrichment; anthropogenic source) to 8.39 (significant enrichment; anthropogenic source) in pre-monsoon respectively. The EF values for Cd, Cr and Cu for monsoon, post-monsoon and pre-monsoon are shown in Table 4.25.

Table 4.24 The Enrichment Factor (EF) of heavy metals in the sediment samples of Bhindawas Weland (September, 2015 - May, 2016).

	Monsoon						Post-monsoon						Pre-monsoon					
Sites	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**
Inlet	7.96	5.72	3.81	0.10	1.60	2.54	2.76	4.92	3.58	0.70	0.47	0.82	13.89	0.05	6.76	4.34	6.49	0.32
Outlet	11.80	2.76	3.54	0.09	2.58	2.54	2.20	4.26	3.07	0.78	1.12	1.55	49.76	0.19	23.60	22.12	19.18	0.60
S1	1.85	0.00	3.53	0.09	2.13	1.92	2.63	0.00	1.54	1.26	1.06	1.14	6.81	37.20	6.94	1.50	5.32	0.00
S2	4.01	0.00	3.20	0.08	1.99	1.86	2.37	0.00	1.79	1.49	1.13	1.27	8.62	31.43	7.18	1.02	5.73	0.00
S3	3.77	0.00	3.14	0.07	2.37	1.67	2.56	0.00	1.82	1.56	0.78	1.16	10.39	35.35	8.53	2.50	6.04	0.00
S4	0.11	0.00	2.74	0.06	3.83	1.52	4.95	0.00	2.28	1.96	0.77	0.79	6.62	36.53	7.36	2.62	5.25	0.00
S5	1.60	0.00	3.39	0.05	2.52	1.62	4.92	0.00	3.13	3.01	1.85	2.16	7.79	32.19	6.31	1.89	10.24	0.00
S6	1.69	0.00	3.86	0.06	3.41	1.68	3.70	0.00	2.15	1.92	0.71	0.95	14.93	70.67	12.50	2.82	13.30	0.00
S7	1.36	0.00	8.04	0.15	5.87	3.67	2.60	0.00	1.73	1.67	1.43	1.34	7.33	31.13	5.34	2.22	7.12	0.00
S8	3.65	0.00	4.35	0.11	2.98	2.52	1.77	0.00	2.01	1.56	1.26	1.06	8.69	37.06	5.74	2.09	7.04	0.00
S9	3.98	36.56	5.40	0.09	2.23	2.22	3.75	0.00	3.51	3.48	0.42	2.16	13.48	57.94	8.75	4.67	9.64	0.00
S10	4.73	0.00	2.53	0.08	1.80	1.79	2.89	0.00	1.88	1.83	1.18	0.98	8.15	43.29	6.39	3.18	7.56	0.00
S11	3.42	0.00	5.13	0.16	1.79	3.88	3.78	0.00	1.57	1.43	1.05	0.75	6.87	34.52	5.90	2.16	4.81	0.00
S12	4.72	0.00	6.87	0.15	4.51	3.46	2.86	0.00	1.57	1.66	1.13	0.99	6.47	37.30	5.85	3.12	4.91	0.00
S13	7.74	0.00	5.22	0.13	3.43	3.53	3.36	0.00	2.01	2.08	1.03	1.12	9.08	44.61	7.12	3.52	5.95	0.00
S14	4.95	0.00	3.51	0.10	1.57	2.22	3.01	0.00	1.39	1.49	1.25	0.58	8.66	46.17	6.43	2.72	5.62	0.00
S15	8.22	0.00	3.92	0.11	2.17	2.64	2.07	0.00	1.13	1.28	1.10	0.75	7.93	47.64	5.83	3.84	5.35	0.00
S16	7.39	0.00	3.38	0.11	2.35	2.18	4.91	0.00	3.19	3.37	0.62	2.68	34.29	123.22	15.65	11.46	12.19	0.00
S17	5.58	0.00	3.73	0.11	1.89	2.69	3.03	0.00	1.75	2.11	1.25	1.18	25.82	99.29	11.75	8.98	9.72	0.00
S18	6.98	69.65	4.87	0.10	2.41	2.42	3.81	0.00	2.09	2.43	0.99	1.90	32.60	130.84	15.15	13.90	12.06	0.00
S19	8.05	0.00	3.88	0.13	1.88	2.89	2.96	0.00	1.51	2.19	1.20	1.67	14.53	63.66	7.36	6.12	6.03	0.00
S20	9.47	0.00	3.55	0.10	1.45	2.22	4.22	0.00	1.51	1.96	1.28	1.26	14.77	68.85	7.06	5.55	6.80	0.00
Range	0.11-9.47	0-69.65	2.53-8.04	0.05-0.16	1.45-5.87	1.52-3.88	1.77-4.95	0-0	1.13-3.51	1.26-3.48	0.42-1.85	0.58-2.68	6.47-34.29	31.13-130.84	5.34-15.65	1.02-13.90	4.81-13.30	0-0
Mean ±SD	4.66 ±2.64	5.31 ±17.2	4.21 ±1.38	0.10 ±0.03	2.63 ±1.10	2.43 ±0.73	3.31 ±0.93	-	1.98 ±0.63	1.99 ±0.64	1.07 ±0.31	1.29 ±0.55	12.69 ±8.45	55.44 ±29.92	8.16 ±3.10	4.29 ±3.42	7.54 ±2.67	-

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites).

Table 4.25 The Enrichment Factor (EF) of heavy metals in the sediment samples of Bhindawas Weland (September, 2016 - May, 2017).

	Monsoon						Post-monsoon						Pre-monsoon					
Sites	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**
Inlet	4.89	4.02	0.00	0.00	0.65	1.74	4.40	4.21	0.69	1.09	0.61	1.18	6.23	13.06	0.33	0.73	4.82	0.38
Outlet	11.20	2.32	1.02	0.35	1.35	1.49	9.20	3.56	0.73	1.36	0.36	5.71	2.95	8.99	0.00	0.33	4.68	0.23
S1	3.71	0.48	2.13	0.12	1.70	1.30	2.60	0.00	1.08	1.08	0.68	0.57	5.59	30.94	3.97	1.88	5.02	0.38
S2	2.73	0.00	2.09	0.01	1.49	1.13	2.33	0.21	1.06	1.31	0.67	0.82	4.23	15.21	5.59	2.04	4.49	0.19
S3	3.34	16.22	3.78	0.06	2.92	1.70	2.61	0.00	2.10	1.27	0.65	0.67	6.11	15.88	6.09	1.24	3.78	0.40
S4	4.60	0.00	2.79	0.08	5.03	2.48	2.35	0.24	1.23	1.18	0.93	0.57	4.13	15.63	4.26	3.29	4.01	0.36
S5	6.76	0.00	2.45	0.15	3.35	0.84	2.04	0.40	1.14	1.35	0.85	0.51	2.90	29.71	4.92	1.58	3.49	0.30
S6	4.27	13.23	2.80	0.11	3.09	2.13	4.07	0.00	1.25	1.01	0.92	0.58	5.60	25.33	4.71	2.07	6.01	0.17
S7	3.07	0.00	1.84	0.06	3.16	1.52	3.59	0.20	1.35	1.26	0.87	1.08	0.47	30.80	4.44	4.18	4.84	0.44
S8	3.04	0.36	2.24	0.04	1.32	1.15	5.79	1.03	2.05	1.19	0.77	1.61	4.42	22.28	6.24	1.92	3.92	0.35
S9	0.00	27.44	3.25	0.08	3.17	1.74	2.28	1.13	1.73	1.16	0.52	0.66	7.29	32.38	7.27	2.70	5.55	0.71
S10	3.80	0.19	3.08	0.05	1.14	2.09	1.39	0.21	1.27	1.39	0.67	0.98	5.11	32.14	6.32	1.98	4.21	0.50
S11	1.85	0.00	3.80	0.06	1.34	2.25	4.45	1.07	1.16	1.13	0.72	1.11	7.75	41.78	5.38	2.78	6.60	0.87
S12	7.22	0.00	4.34	0.17	3.28	1.08	2.49	0.48	2.36	0.87	0.96	1.05	4.58	23.72	5.82	3.08	4.02	0.53
S13	5.60	0.31	4.01	0.08	2.91	1.52	4.03	0.00	0.95	1.21	0.92	1.56	8.96	36.96	8.11	2.50	7.55	0.54
S14	7.57	0.00	3.99	0.21	1.97	0.18	2.68	0.00	0.86	1.46	0.93	1.53	9.03	46.54	7.88	3.09	6.64	0.00
S15	4.23	0.00	1.87	0.11	0.89	0.42	1.93	0.26	1.19	1.35	0.76	1.56	7.78	42.67	7.49	4.74	4.70	0.76
S16	3.01	0.00	3.10	0.11	2.14	0.49	2.47	0.26	2.85	1.40	0.86	1.30	8.09	25.97	8.04	2.70	5.65	0.67
S17	5.12	0.00	8.47	0.17	5.72	1.77	3.16	0.00	0.98	1.28	0.72	0.93	11.86	43.23	12.12	4.39	8.39	0.46
S18	1.80	47.45	4.16	0.14	1.98	1.34	1.98	0.87	2.28	1.07	0.40	0.82	9.06	31.46	7.53	4.48	4.44	0.47
S19	5.58	15.62	4.87	0.16	2.24	3.16	4.43	0.40	1.06	1.41	0.83	1.30	10.85	34.08	7.36	2.42	8.12	0.86
S20	3.97	0.00	2.74	0.12	0.94	1.63	2.76	0.00	2.52	1.42	0.77	0.72	11.54	36.32	7.37	3.34	6.70	0.00
Range	0-7.57	0-47.45	1.84-8.47	0.01-0.21	0.89-5.72	0.18-3.16	1.39-5.79	0-1.13	0.86-2.85	0.87-1.46	0.40-0.96	0.51-1.61	0.47-11.86	15.21-46.54	3.97-12.12	1.24-4.74	3.49-8.39	0-0.87
Mean ±SD	4 ±1.89	6.06 ±12.46	3.39 ±1.5	0.10 ±0.05	2.49 ±1.29	1.50 ±0.73	2.97 ±1.09	0.34 ±0.39	1.52 ±0.61	1.24 ±0.15	0.77 ±0.15	1±0.37	6.77 ±2.98	30.65 ±9.23	6.54 ±1.87	2.82 ±1.01	5.41 ±1.50	0.45 ±0.25

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites).

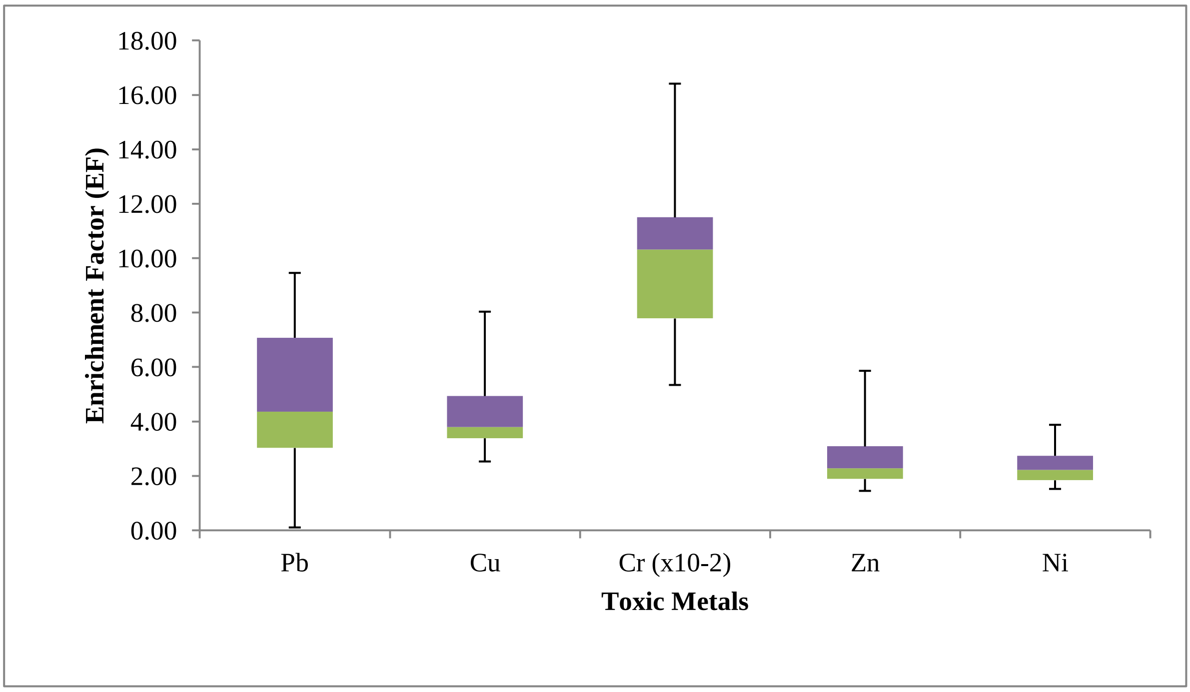

Figure. 4.55 Enrichment Factor (EF) of heavy metals in sediment of Bhindawas Wetland during monsoon (September, 2015)

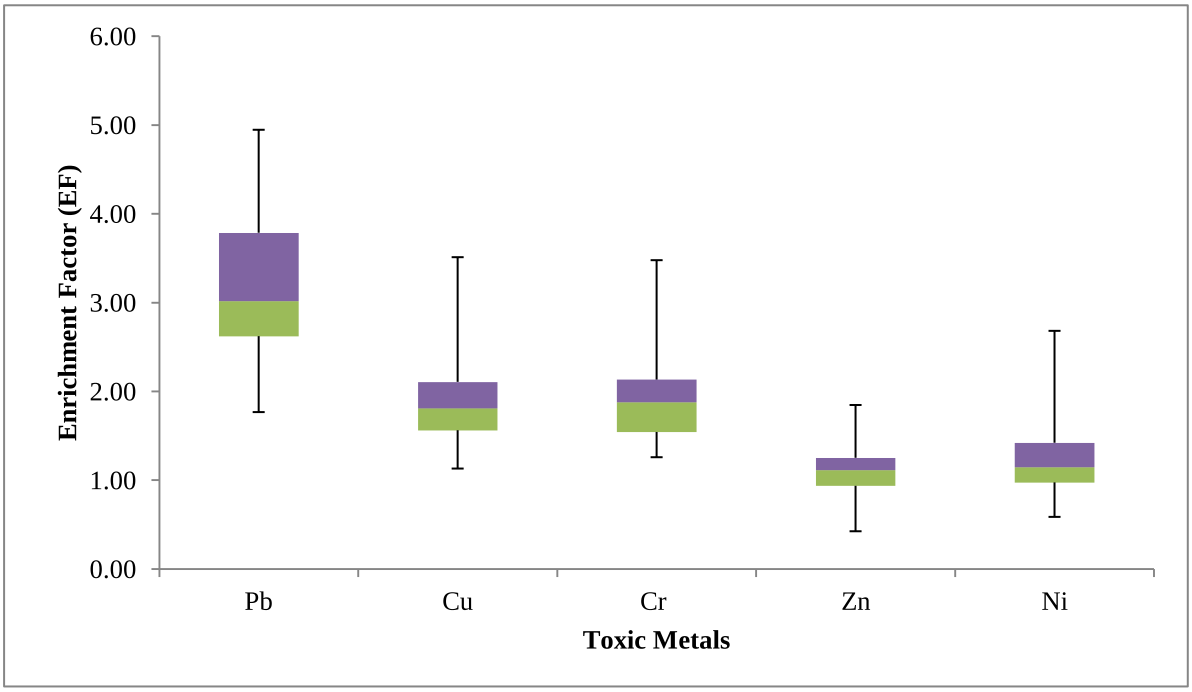

Figure 4.56 Enrichment Factor (EF) of heavy metals in sediment of Bhindawas Wetland during post-monsoon (January, 2016)

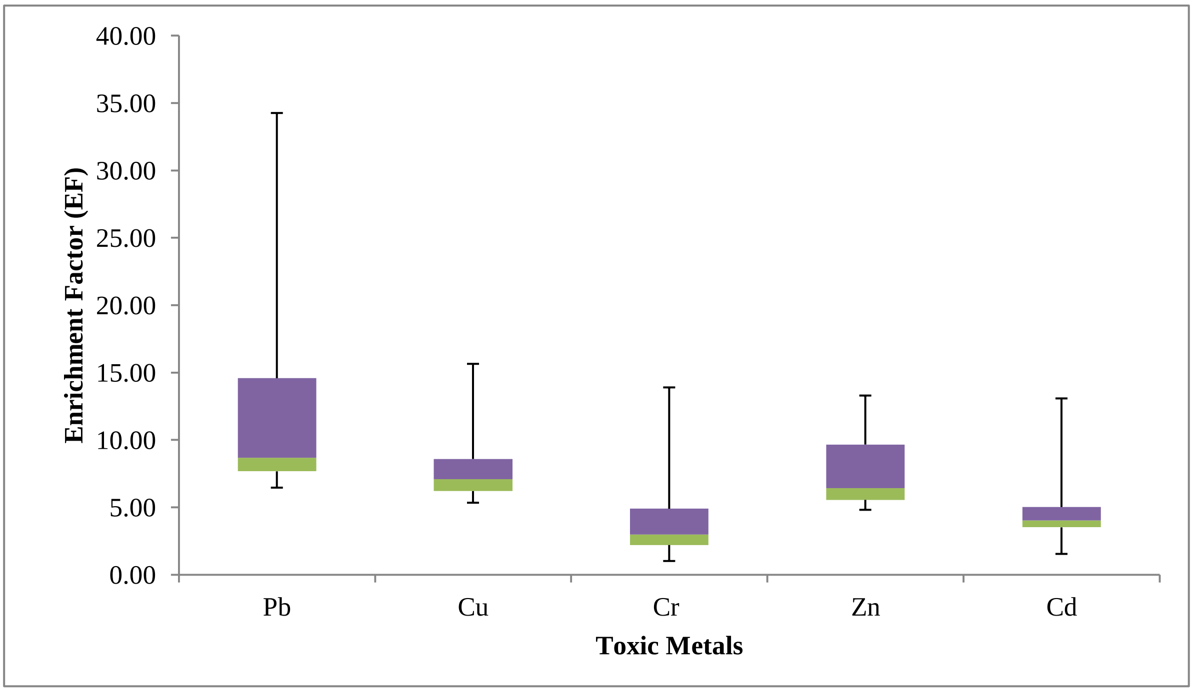

Figure 4.57 Enrichment Factor (EF) of heavy metals in sediment of Bhindawas Wetland during pre-monsoon (May, 2016)

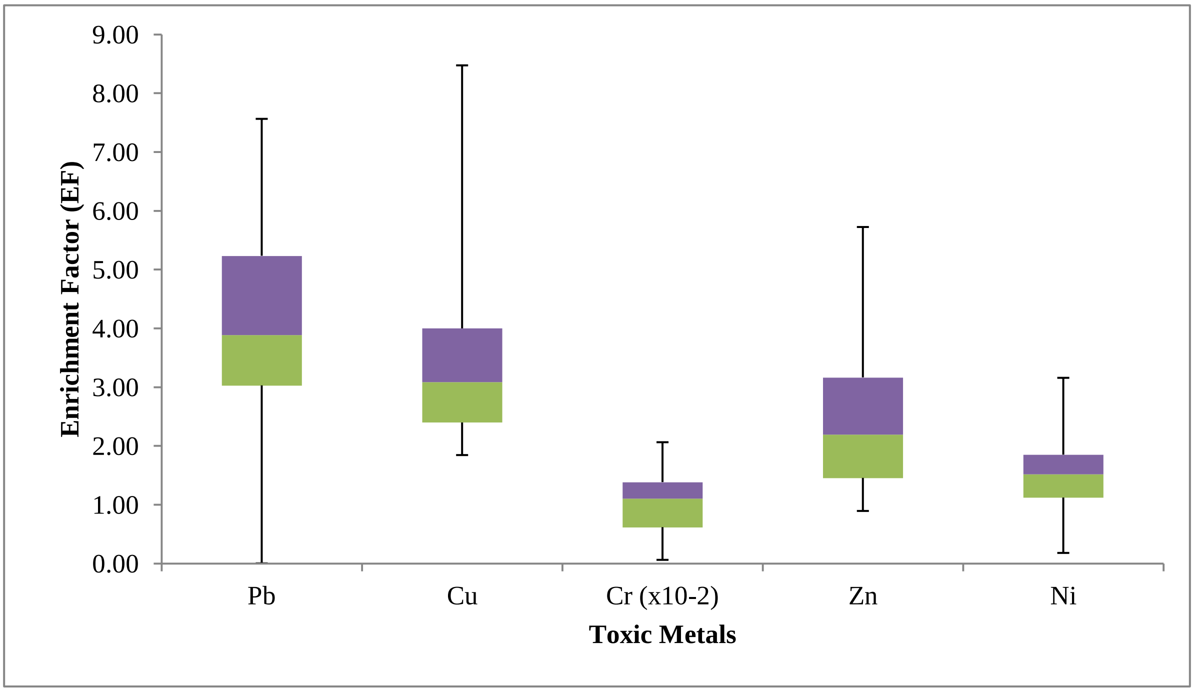

Figure 4.58 Enrichment Factor (EF) of heavy metals in sediment of Bhindawas Wetland during monsoon (September, 2016)

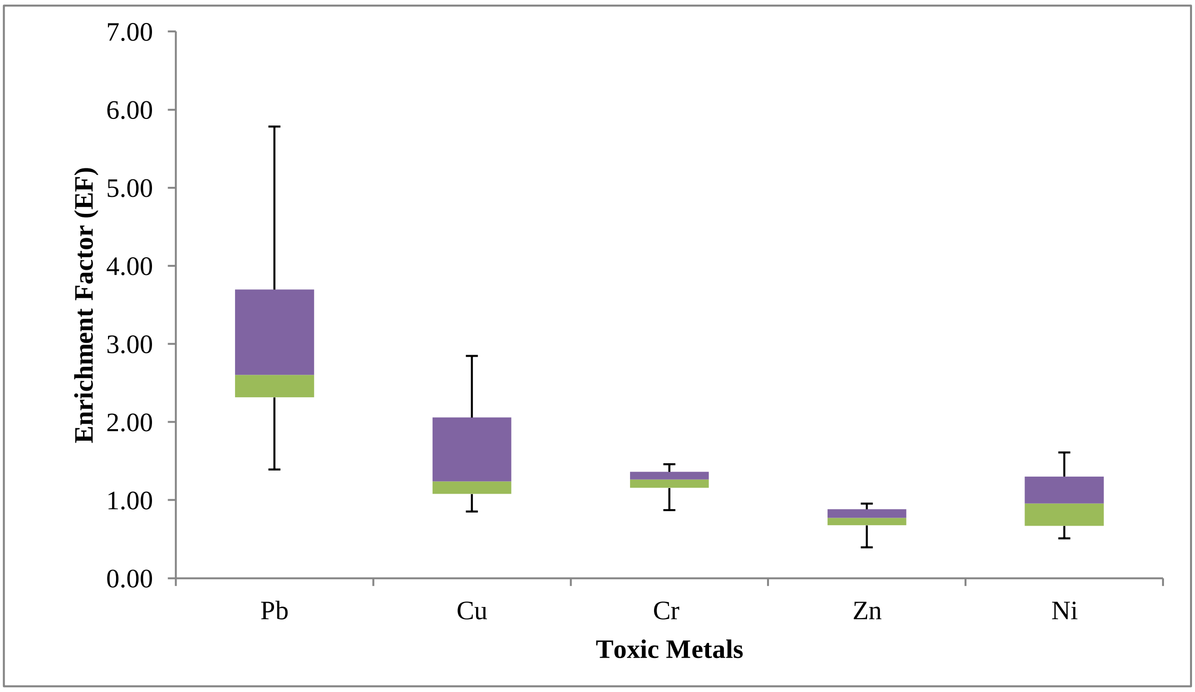

Figure 4.59 Enrichment Factor (EF) of heavy metals in sediment of Bhindawas Wetland during post-monsoon (January, 2017)

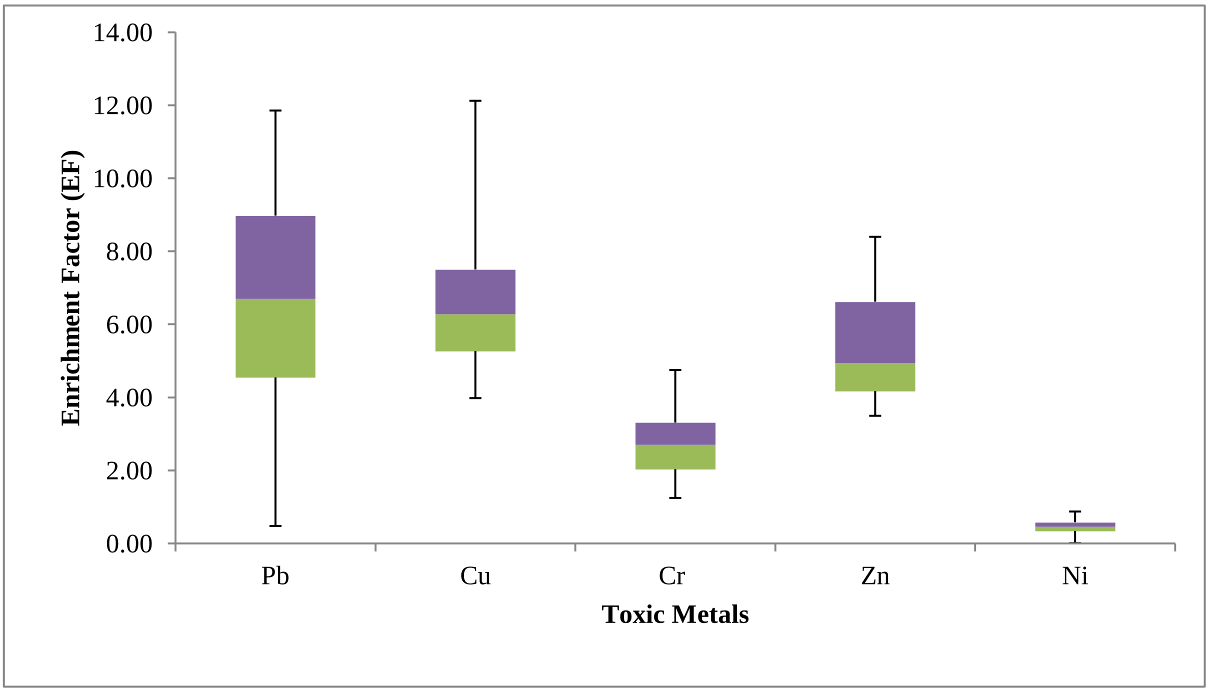

Figure 4.60 Enrichment Factor (EF) of heavy metals in sediment of Bhindawas Wetland during pre-monsoon (May, 2017)

Table 4.26 Description of Enrichment Factor of heavy metals along with sampling locations and percentage of samples in Bhindawas wetland in monsoon (September, 2015 and September, 2016)

Classification		September, 2015		Sept, 2016	
Value	**Inference**	**Sampling Location**	**(%) Samples**	**Sampling Location**	**(%) Samples**
EF < 1	Back ground Concentration	Pb(S4) Cr (S1-S20)	5 100	Cd (S1,S8,S10,S13) Cr (S1-S20) Zn (S15,S20) Ni (S5,S14-S16)	20 100 10 20
1 < EF <2	Minimal Enrichment	Pb (S1, S5, S6, S7) Zn (S2, S10, S11, S14, S17, S19, S20) Ni (S1-S6,S10)	20 35 35	Pb (S11,S18) Cu (S7,S15) Zn (S1, S2, S8, S10, S11, S14, S18) Ni (S1-S3, S7-S9, S12, S13, S17, S18, S20)	10 10 35 55
2 < EF < 5	Moderate Enrichment	Pb (S2, S3, S8-S12, S14) Cu (S1-S6, S8, S10, S14-S20) Zn (S1, S3, S6, S8, S9, S12, S13, S15, S16, S18) Ni (S7-S9,S11-S20)	40 75 60 65	Pb (S1-S4, S6-S8, S10, S15, S16, S20) Cu (S1-S6, S8-S14, S16, S18-S20) Zn (S3, S5-S7, S9, S12, S13, S16, S19) Ni (S4,S6,S10,S11,S19)	55 85 45 25
5 < EF <20	Significant Enrichment	Pb(S13,S15-S20) Cu (S7 ,S9, S11-S13) Zn (S7)	35 25 5	Pb (S5, S12-S14, S17, S19) Cd (S3,S6,S19) Cu (S17) Zn (S4, S17)	30 15 5 10
20 < EF < 40	High Enrichment	Cd (S9)	50	Cd (S9)	50
EF > 40	Extremely high Enrichment	Cd (S11)	50	Cd (S18)	50

Table 4.27 Description of Enrichment Factor of heavy metals along with sampling locations and percentage of samples in Bhindawas wetland in post-monsoon (January, 2016 and January, 2017)

Classification		Jan., 2016		Jan., 2017	
Value	**Inference**	**Sampling Location**	**(%) Samples**	**Sampling Location**	**(%) Samples**
EF < 1	Back ground Concentration	Zn(S3,S4,S6,S9,S16,S18) Ni (S4 ,S6, S10-S12, S14, S15)	30 35	Cd (S2, S4, S5, S7, S10, S12, S15, S16, S18, S19) Cu (S13, S14, S17) Cr (S12) Zn (S1-S20) Ni (S1-S6, S9, S10, S17, S18, S20)	50 15 5 100 55

1 < EF <2	Minimal Enrichment	Pb (S8) Cu (S1-S3, S7, S10-S12, S14, S15, S17, S19, S20) Cr (S1-S4, S6-S8, S10-S12,S14, S15, S20) Zn (S1, S2, S5, S7, S8, S10-S15,S17,S19, S20) Ni (S1-S3, S7, S8, S13, S17-S20)	5 60 65 70 50	Pb (S10, S15, S18) Cd (S8, S9, S11) Cu (S1, S2, S4-S7, S9-S11, S15, S19) Cr (S1-S11, S13-S20) Ni (S7, S8, S11-S16, S19)	15 15 55 95 45
2 < EF < 5	Moderate Enrichment	Pb (S1-S7, S9-S20) Cu (S4-S6, S8, S9, S13, S16, S18) Cr (S5, S9, S13, S16-S19) Ni (S5, S9,S16)	95 40 35 15	Pb (S1-S7, S9, S11-S14, S16, S17, S19, S20) Cu (S3, S8, S12, S16, S18, S20)	80 30
5 < EF <20	Significant Enrichment	NIL	NIL	Pb (S8)	5
20 < EF < 40	High Enrichment	NIL	NIL	NIL	NIL
EF > 40	Extremely high Enrichment	NIL	NIL	NIL	NIL

Table 4.28 Description of Enrichment Factor of heavy metals along with sampling locations and percentage of samples in Bhindawas wetland in pre-monsoon (May, 2016 and May, 2017)

Classification		**May, 2016**		**May, 2017**	
Value	**Inference**	**Sampling Location**	**(%) Samples**	**Sampling Location**	**(%) Samples**
EF < 1	Back ground Concentration	NIL	NIL	Pb(S7) Ni(S1-S19)	5 95
1 < EF <2 2 < EF < 5	Minimal Enrichment Moderate Enrichment	Cr (S1, S2, S5) Cr (S3, S4, S6-S15) Zn (S11, S12)	15 60 10	Cr (S1, S3, S5, S8, S10) Pb (S2, S4, S5, S8, S12) Cu (S1, S4-S7) Cr (S2, S4, S6, S7, S9, S11-S20) Zn (S2-S5, S7, S8, S10, S12, S15, S18)	25 25 25 75 50
5 < EF <20	Significant Enrichment	Pb (S1-S15, S19, S20) Cu (S1-S20) Cr (S16-S20) Zn (S1-S10, S13-S20)	85 100 25 90	Pb (S1, S3, S6, S9-S11, S13-S20) Cd (S2, S3, S4) Cu (S2, S3 ,S8-S20) Zn (S1, S6, S9, S11, S13, S14, S16, S17, S19, S20)	70 15 75 50
20 < EF < 40	High Enrichment	Pb (S16, S17, S18) Cd (S1, S5, S7, S8, S11, S12)	15 45	Cd (S1, S5-S10, S12, S13, S16, S18-S20)	65
EF > 40	Extremely high Enrichment	Cd (S6, S9, S10, S13-S20)	55	Cd (S11, S14, S15, S17)	20

4.3.3.2 Contamination Factor (CF), Pollution Load Index (PLI) and Degree of contamination (DC)

The values for Contamination Factor (CF), Pollution Load Index (PLI) and Degree of contamination (DC) of the heavy metals in the Bhindawas wetland sediments for monsoon, post-monsoon and pre-monsoon are shown in Table 4.29. The CF of Cadmium (Cd) varied from 0 to7.50 for monsoon (category: very high) and 3.02 to 5.85 (considerable) for pre-monsoon respectively. Values of CF for chromium (Cr) varied from 0.007 to 0.12 (low CF) in monsoon, 0.17 to 0.28 (Low) in post-monsoon and 0.10 to 0.57 (low CF) in pre-monsoon respectively. Similarly CF for copper (Cu) varied between 0.22 to 0.80 (low CF) for monsoon, 0.19 to 0.24 (low) for post-monsoon and 0.60 to 0.80 (low) for pre-monsoon. Similar observations of CF for Fe, Pb, Ni and Zn are shown in Table 4.29.

The results of PLI for heavy metals in Bhindawas wetland sediments in monsoon, post-monsoon and pre-monsoon is shown in Table 4.29. The PLI varied from 0.94 (unpolluted) to 1.14 (polluted) for monsoon 0.97 (unpolluted) to 1.06 (polluted) for post-monsoon, 1.12 to 1.17 (polluted) for pre-monsoon respectively indicating the overall polluted status of the sediments.

The results for degree of contamination (DC) for heavy metals in Bhindawas wetland sediments in monsoon, post-monsoon and pre-monsoon are shown in Table 4.29. The DC varied from 0.79 to 2.43 (low) for monsoon, 0.82 to 1.50 (low) for post-monsoon, 2.26 to 3.10 (low) for pre-monsoon respectively.

Similarly the values for Contamination Factor (CF), Pollution Load Index (PLI) and Degree of contamination (DC) of the heavy metals in the second year of study in the Bhindawas wetland sediments for monsoon, post-monsoon and pre-monsoon are shown in Table 4.30. The CF of Iron (Fe) varied from 0.05 to 0.21 (low) for monsoon and 0.15 to 0.18 (low) for post-monsoon and 0.07 to 0.14 (low) for pre-monsoon respectively. Values of CF for Nickel (Ni) varied from 0.02 to 0.36 (low) in monsoon, 0.09 to 0.27 (low) in post-monsoon and 0 to 0.09 (low CF) in pre-monsoon respectively. Similarly, CF for Lead (Pb) varied between 0 to 1.06 (low) for monsoon, 0.22 to 0.94 (low) for post-monsoon and 0.06 to 1.02 (low) for pre-monsoon. The values of CF for zinc Varied from 0.18 to 0.67 (low) in monsoon, 0.06 to 0.17 (low) for post- monsoon and 0.45 to 0.85 (low) in pre-monsoon. Similar observations of CF for Cd, Cr and Cu are shown in Table 4.30.

The results of PLI for heavy metals in Bhindawas wetland sediments in monsoon, post-monsoon and pre-monsoon is shown in Table 4.30 for second year. The PLI varied from 0.98 (unpolluted) to 1.13 (polluted) for monsoon, 1.01 to 1.10 (polluted) for post-monsoon, 1.09 to

1.17 (polluted) for pre-monsoon respectively shows high pollution load in sediments.

The results for degree of contamination (DC) for heavy metals in Bhindawas wetland sediments in monsoon, post-monsoon and pre-monsoon are shown in Table 4.26. The DC varied from 0.87 to 2.29 (low) for monsoon, 1.07 to 2.01 (low) for post-monsoon, 1.84 to 2.94 (low) for pre-monsoon respectively.

Table 4.29 The Contamination Factor (CF), Degree of Contamination (DC) and Pollution Load Index (PLI) of heavy metals in the sediment samples of Bhindawas Weland (September, 2015 - May, 2016).

	Monsoon									**Post-monsoon**									**Pre-monsoon**								
Sites	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Fe**	**Ni**	**DC**	**PL1**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Fe**	**Ni**	**DC**	**PL1**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Fe**	**Ni**	**DC**	**PL1**
Inlet	0.65	0.5	0.31	0.01	0.13	0.08	0.21	**1.39**	**1.05**	0.39	0.70	0.51	0.10	0.07	0.14	0.12	**1.33**	**1.04**	1.38	1.53	0.67	0.43	0.64	0.10	0.03	**3.26**	**1.18**
Outlet	1.28	0.3	0.39	0.01	0.28	0.11	0.28	**2.34**	**1.13**	0.28	0.53	0.38	0.10	0.14	0.13	0.19	**1.22**	**1.03**	1.26	1.10	0.60	0.56	0.49	0.03	0.02	**2.95**	**1.17**
S1	0.14		0.26	0.01	0.16	0.07	0.14	**0.79**	**0.97**	0.39	0.00	0.23	0.19	0.16	0.15	0.17	**1.28**	**1.04**	0.74	4.02	0.75	0.16	0.57	0.11	0.00	**2.33**	**1.13**
S2	0.42		0.33	0.01	0.21	0.10	0.19	**1.27**	**1.03**	0.29	0.00	0.22	0.18	0.14	0.12	0.16	**1.11**	**1.02**	0.83	3.02	0.69	0.10	0.55	0.10	0.00	**2.26**	**1.12**
S3	0.51		0.42	0.01	0.32	0.14	0.23	**1.63**	**1.07**	0.31	0.00	0.22	0.19	0.09	0.12	0.14	**1.06**	**1.01**	0.96	3.25	0.78	0.23	0.56	0.09	0.00	**2.62**	**1.15**
S4	0.02		0.44	0.01	0.61	0.16	0.24	**1.48**	**1.06**	0.43	0.00	0.20	0.17	0.07	0.09	0.07	**1.03**	**1.00**	0.72	3.97	0.80	0.28	0.57	0.11	0.00	**2.48**	**1.14**
S5	0.31		0.66	0.01	0.49	0.19	0.32	**1.98**	**1.10**	0.30	0.00	0.19	0.18	0.11	0.06	0.13	**0.98**	**1.00**	0.88	3.65	0.72	0.21	1.16	0.11	0.00	**3.09**	**1.17**
S6	0.35		0.80	0.01	0.71	0.21	0.35	**2.43**	**1.14**	0.38	0.00	0.22	0.20	0.07	0.10	0.10	**1.06**	**1.01**	0.82	3.87	0.68	0.15	0.73	0.05	0.00	**2.44**	**1.14**
S7	0.10		0.58	0.01	0.42	0.07	0.26	**1.44**	**1.05**	0.30	0.00	0.20	0.19	0.17	0.12	0.15	**1.13**	**1.02**	0.91	3.87	0.66	0.28	0.88	0.12	0.00	**2.86**	**1.16**
S8	0.29		0.34	0.01	0.23	0.08	0.20	**1.15**	**1.02**	0.21	0.00	0.24	0.19	0.15	0.12	0.13	**1.05**	**1.01**	0.96	4.10	0.63	0.23	0.78	0.11	0.00	**2.72**	**1.15**
S9	0.40	3.6	0.54	0.01	0.22	0.10	0.22	**1.48**	**1.06**	0.21	0.00	0.20	0.20	0.02	0.06	0.12	**0.82**	**0.97**	0.99	4.25	0.64	0.34	0.71	0.07	0.00	**2.75**	**1.16**
S10	0.61		0.33	0.01	0.23	0.13	0.23	**1.54**	**1.06**	0.34	0.00	0.22	0.21	0.14	0.12	0.11	**1.13**	**1.02**	0.82	4.37	0.64	0.32	0.76	0.10	0.00	**2.65**	**1.15**
S11	0.14		0.22	0.01	0.08	0.04	0.16	**0.65**	**0.94**	0.54	0.00	0.22	0.20	0.15	0.14	0.11	**1.36**	**1.04**	0.91	4.57	0.78	0.29	0.64	0.13	0.00	**2.74**	**1.16**
S12	0.37		0.54	0.01	0.36	0.08	0.27	**1.64**	**1.07**	0.36	0.00	0.20	0.21	0.14	0.13	0.13	**1.17**	**1.02**	0.77	4.45	0.70	0.37	0.59	0.12	0.00	**2.55**	**1.14**
S13	0.63		0.42	0.01	0.28	0.08	0.29	**1.70**	**1.08**	0.35	0.00	0.21	0.21	0.11	0.10	0.12	**1.09**	**1.01**	0.91	4.47	0.71	0.35	0.60	0.10	0.00	**2.67**	**1.15**
S14	0.57		0.40	0.01	0.18	0.12	0.26	**1.54**	**1.06**	0.47	0.00	0.21	0.23	0.19	0.15	0.09	**1.35**	**1.04**	0.93	4.95	0.69	0.29	0.60	0.11	0.00	**2.62**	**1.15**
S15	0.74		0.35	0.01	0.19	0.09	0.24	**1.62**	**1.07**	0.36	0.00	0.20	0.22	0.19	0.18	0.13	**1.28**	**1.04**	0.85	5.08	0.62	0.41	0.57	0.11	0.00	**2.56**	**1.14**
S16	0.81		0.37	0.01	0.26	0.11	0.24	**1.81**	**1.09**	0.31	0.00	0.20	0.21	0.04	0.06	0.17	**1.00**	**1.00**	1.41	5.08	0.65	0.47	0.50	0.04	0.00	**3.08**	**1.17**
S17	0.53		0.35	0.01	0.18	0.10	0.26	**1.43**	**1.05**	0.39	0.00	0.23	0.27	0.16	0.13	0.15	**1.34**	**1.04**	1.40	5.37	0.63	0.49	0.53	0.05	0.00	**3.10**	**1.18**
S18	0.75	7.5	0.52	0.01	0.26	0.11	0.26	**1.91**	**1.10**	0.39	0.00	0.21	0.25	0.10	0.10	0.19	**1.25**	**1.03**	1.34	5.37	0.62	0.57	0.49	0.04	0.00	**3.06**	**1.17**
S19	0.67		0.33	0.01	0.16	0.08	0.24	**1.49**	**1.06**	0.38	0.00	0.19	0.28	0.15	0.13	0.21	**1.34**	**1.04**	1.27	5.55	0.64	0.53	0.53	0.09	0.00	**3.06**	**1.17**
S20	1.05		0.39	0.01	0.16	0.11	0.25	**1.97**	**1.10**	0.56	0.00	0.20	0.26	0.17	0.13	0.17	**1.50**	**1.06**	1.26	5.85	0.60	0.47	0.58	0.08	0.00	**2.99**	**1.17**
Range	0.02-1.05	3.6-7.5	0.22-0.80	0.01-0.01	0.08-0.71	0.04-0.21	0.14-0.35	**0.65-2.43**	**0.94-1.14**	0.21-0.56	-	0.19-0.24	0.17-0.28	0.02-0.19	0.06-0.18	0.07-0.21	**0.82-1.50**	**0.97-1.06**	0.72-1.41	3.02-5.85	0.60-0.80	0.10-0.57	0.49-1.16	0.04-0.13	-	**2.26-3.10**	**1.12-1.18**
Mean ±SD	0.47±0.27	5.57±2.73	0.43 ±0.4	0.01 ±0	0.29 ±0.6	0.11 ±0.4	0.24 ±0.5	**1.55 ±0.0**	**1.06 ±0.4**	0.36 ±0.9	-	0.21 ±0.1	0.21 ±0.3	0.13 ±0.5	0.12 ±0.3	0.14 ±0.4	**1.17 ±0.7**	**1.02 ±0.2**	0.98 ±0.2	4.45 ±0.7	0.68 ±0.6	0.33 ±0.3	0.64 ±0.6	0.09 ±0.3	-	**2.73 ±0.26**	**1.15 ±0.02**

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites).

Table 4.30 The Contamination Factor (CF), Degree of Contamination (DC) and Pollution Load Index (PLI) of heavy metals in the sediment samples of Bhindawas Weland (September, 2016 - May, 2017).

	Monsoon									**Post-monsoon**									**Pre-monsoon**								
Sites	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Fe**	**Ni**	**DC**	**PLI**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Fe**	**Ni**	**DC**	**PLI**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Fe**	**Ni**	**DC**	**PLI**
Inlet	0.73	0.60	0.00	0.00	0.10	0.15	0.26	**1.23**	**1.03**	0.70	0.67	0.11	0.17	0.10	0.16	0.19	**1.42**	**1.05**	0.81	1.70	0.04	0.09	0.63	0.13	0.05	**1.75**	**1.08**
Outlet	1.61	0.33	0.15	0.05	0.19	0.14	0.21	**2.35**	**1.13**	0.95	0.37	0.08	0.14	0.04	0.10	0.59	**1.89**	**1.10**	0.30	0.90	0.00	0.03	0.47	0.10	0.02	**0.92**	**0.99**
S1	0.52	0.07	0.30	0.02	0.24	0.14	0.18	**1.38**	**1.05**	0.45	0.00	0.19	0.19	0.12	0.17	0.10	**1.20**	**1.03**	0.71	3.93	0.50	0.24	0.64	0.13	0.05	**2.27**	**1.12**
S2	0.52	0.00	0.39	0.00	0.28	0.19	0.21	**1.59**	**1.07**	0.37	0.03	0.17	0.21	0.11	0.16	0.13	**1.14**	**1.02**	0.54	1.93	0.71	0.26	0.57	0.13	0.02	**2.23**	**1.12**
S3	0.52	2.50	0.58	0.01	0.45	0.15	0.26	**1.97**	**1.10**	0.45	0.00	0.36	0.22	0.11	0.17	0.12	**1.42**	**1.05**	0.80	2.07	0.79	0.16	0.49	0.13	0.05	**2.42**	**1.13**
S4	0.61	0.00	0.37	0.01	0.67	0.13	0.33	**2.11**	**1.11**	0.39	0.04	0.20	0.20	0.15	0.17	0.09	**1.20**	**1.03**	0.54	2.03	0.55	0.43	0.52	0.13	0.05	**2.22**	**1.12**
S5	1.06	0.00	0.38	0.02	0.53	0.16	0.13	**2.29**	**1.13**	0.34	0.07	0.19	0.23	0.14	0.17	0.09	**1.16**	**1.02**	0.38	3.87	0.64	0.21	0.45	0.13	0.04	**1.84**	**1.09**
S6	0.66	2.03	0.43	0.02	0.47	0.15	0.33	**2.06**	**1.11**	0.70	0.00	0.21	0.17	0.16	0.17	0.10	**1.51**	**1.06**	0.80	3.60	0.67	0.29	0.85	0.14	0.02	**2.78**	**1.16**
S7	0.56	0.00	0.34	0.01	0.58	0.18	0.28	**1.95**	**1.10**	0.59	0.03	0.22	0.21	0.14	0.17	0.18	**1.51**	**1.06**	0.06	4.10	0.59	0.56	0.64	0.13	0.06	**2.04**	**1.11**
S8	0.56	0.07	0.42	0.01	0.24	0.19	0.21	**1.63**	**1.07**	0.94	0.17	0.33	0.19	0.13	0.16	0.26	**2.01**	**1.10**	0.59	2.97	0.83	0.26	0.52	0.13	0.05	**2.37**	**1.13**
S9	0.00	2.60	0.31	0.01	0.30	0.09	0.16	**0.87**	**0.98**	0.41	0.20	0.31	0.21	0.09	0.18	0.12	**1.31**	**1.04**	0.80	3.53	0.79	0.29	0.61	0.11	0.08	**2.67**	**1.15**
S10	0.66	0.03	0.53	0.01	0.20	0.17	0.36	**1.92**	**1.10**	0.22	0.03	0.20	0.22	0.11	0.16	0.16	**1.07**	**1.01**	0.59	3.70	0.73	0.23	0.48	0.12	0.06	**2.20**	**1.12**
S11	0.24	0.00	0.50	0.01	0.18	0.13	0.29	**1.35**	**1.04**	0.69	0.17	0.18	0.18	0.11	0.16	0.17	**1.49**	**1.06**	0.82	4.43	0.57	0.29	0.70	0.11	0.09	**2.58**	**1.15**
S12	0.88	0.00	0.53	0.02	0.40	0.12	0.13	**2.09**	**1.11**	0.44	0.08	0.41	0.15	0.17	0.17	0.18	**1.52**	**1.06**	0.64	3.30	0.81	0.43	0.56	0.14	0.07	**2.65**	**1.15**
S13	0.61	0.03	0.43	0.01	0.32	0.11	0.16	**1.64**	**1.07**	0.69	0.00	0.16	0.21	0.16	0.17	0.27	**1.66**	**1.07**	0.82	3.37	0.74	0.23	0.69	0.09	0.05	**2.61**	**1.15**
S14	0.79	0.00	0.42	0.02	0.21	0.10	0.02	**1.55**	**1.06**	0.44	0.00	0.14	0.24	0.15	0.17	0.25	**1.40**	**1.05**	0.80	4.10	0.69	0.27	0.58	0.09	0.00	**2.43**	**1.14**
S15	0.84	0.00	0.37	0.02	0.18	0.20	0.08	**1.68**	**1.08**	0.30	0.04	0.18	0.21	0.12	0.15	0.24	**1.19**	**1.03**	0.80	4.40	0.77	0.49	0.48	0.10	0.08	**2.73**	**1.15**
S16	0.52	0.00	0.53	0.02	0.37	0.17	0.08	**1.69**	**1.08**	0.39	0.04	0.44	0.22	0.13	0.16	0.20	**1.54**	**1.06**	0.88	2.83	0.88	0.29	0.62	0.11	0.07	**2.85**	**1.16**
S17	0.24	0.00	0.40	0.01	0.27	0.05	0.08	**1.05**	**1.01**	0.49	0.00	0.15	0.20	0.11	0.16	0.14	**1.26**	**1.03**	0.80	2.90	0.81	0.29	0.56	0.07	0.03	**2.56**	**1.14**
S18	0.24	6.40	0.56	0.02	0.27	0.13	0.18	**1.40**	**1.05**	0.30	0.13	0.35	0.16	0.06	0.15	0.13	**1.15**	**1.02**	0.99	3.43	0.82	0.49	0.48	0.11	0.05	**2.94**	**1.17**
S19	0.61	1.70	0.53	0.02	0.24	0.11	0.34	**1.85**	**1.09**	0.69	0.06	0.16	0.22	0.13	0.16	0.20	**1.56**	**1.07**	0.92	2.90	0.63	0.21	0.69	0.09	0.07	**2.60**	**1.15**
S20	0.84	0.00	0.58	0.03	0.20	0.21	0.34	**2.19**	**1.12**	0.45	0.00	0.41	0.23	0.13	0.16	0.12	**1.49**	**1.06**	1.02	3.20	0.65	0.29	0.59	0.09	0.00	**2.64**	**1.15**
Range	0-1.06	0-6.40	0.30-0.58	0-0.03	0.18-0.67	0.05-0.21	0.02-0.36	**0.87-2.29**	**0.98-1.13**	0.22-0.94	0-0.20	0.14-0.44	0.15-0.24	0.06-0.17	0.15-0.18	0.09-0.27	**1.07-2.01**	**1.01-1.10**	0.06-1.02	1.93-4.43	0.50-0.88	0.16-0.56	0.45-0.85	0.07-0.14	0-0.09	**1.84-2.94**	**1.09-1.17**
Mean ±SD	0.57±0.25	0.77±1.61	0.44±0.09	0.01±0.01	0.33±0.14	0.14±0.04	0.21±0.10	**1.71±0.38**	**1.08±0.04**	0.49±0.18	0.05±0.06	0.25±0.10	0.20±0.02	0.13±0.03	0.16±0.01	0.16±0.06	**1.39±0.23**	**1.05±0.02**	0.71±0.22	3.33±0.74	0.71±0.11	0.31±0.11	0.59±0.10	0.11±0.02	0.05±0.03	**2.48±0.28**	**1.14±0.02**

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites).

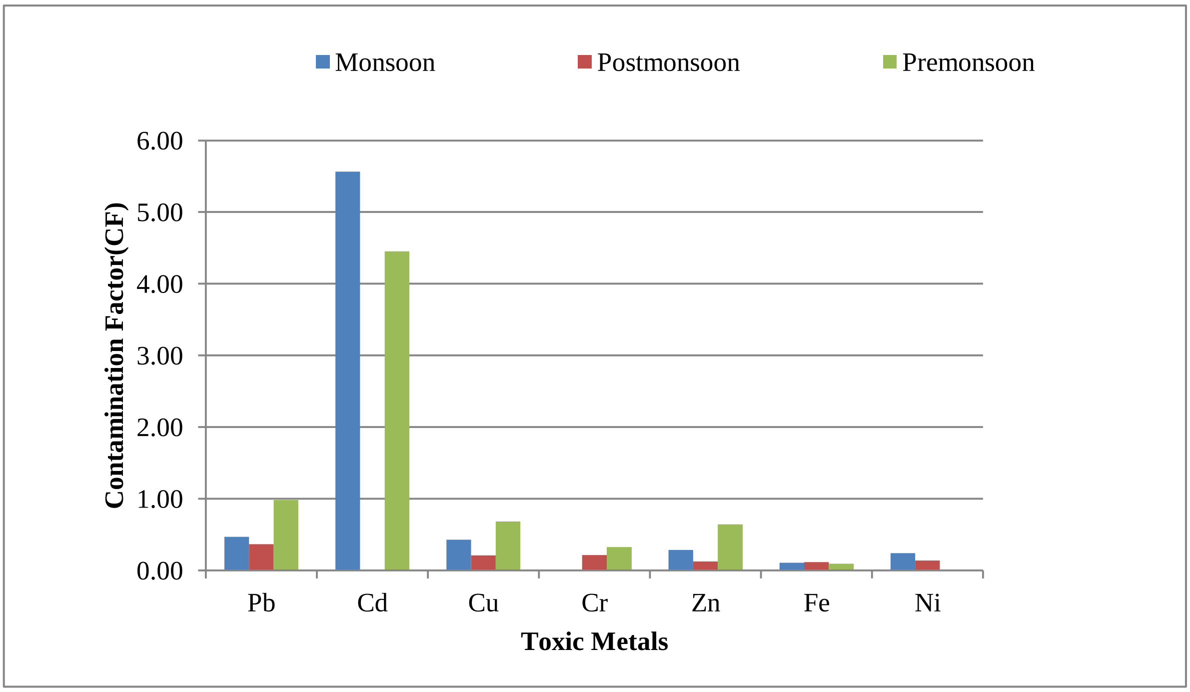

Figure. 4.61 Contamination Factor (CF) of heavy metals in sediment of Bhindawas Wetland during first year (September, 2015 to May, 2016)

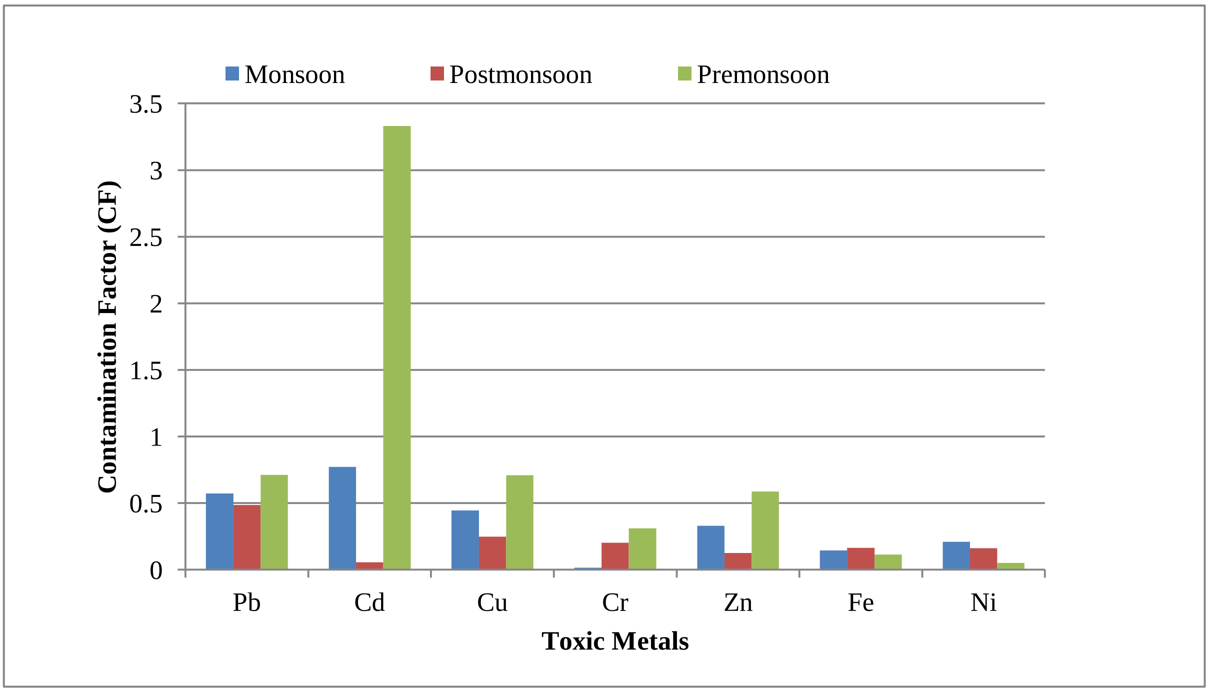

Figure. 4.62 Contamination Factor (CF) of heavy metals in sediment of Bhindawas Wetland during second year (September, 2016 to May, 2017)

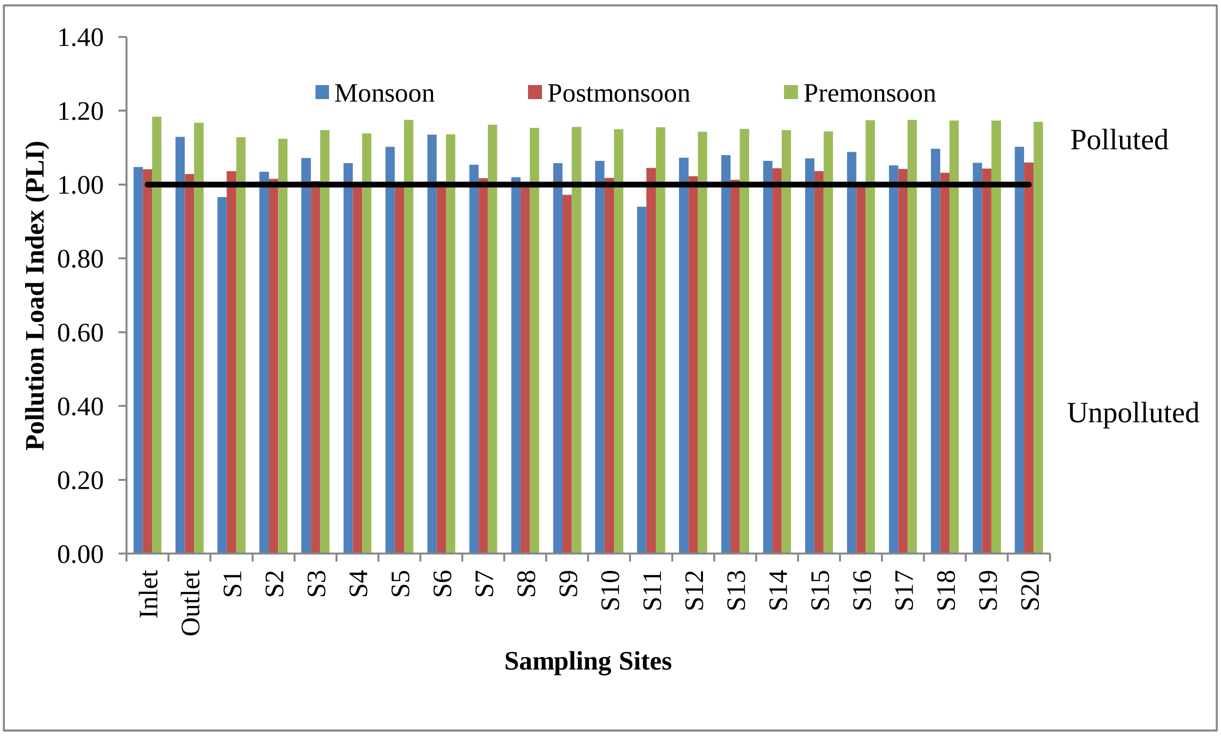

Figure 4.63 Pollution Load Index (PLI) of heavy metals in sediment of Bhindawas Wetland (September, 2015 to May, 2016)

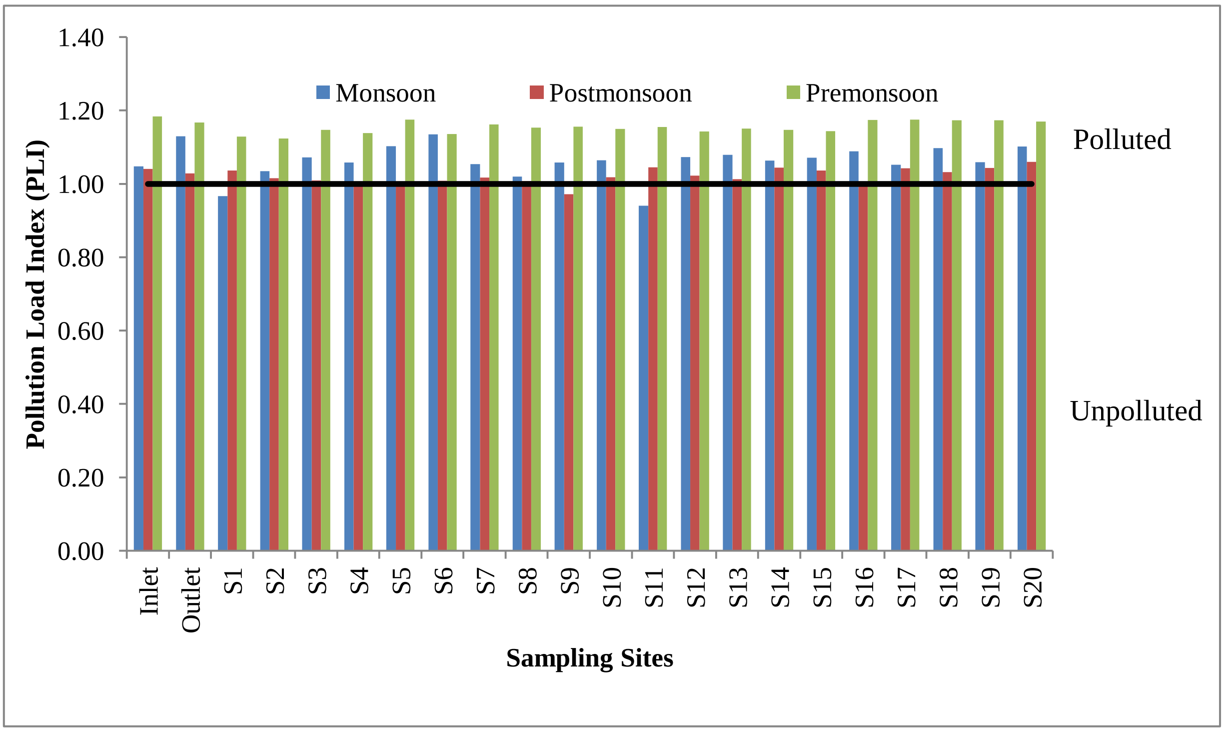

Figure 4.64 Pollution Load Index (PLI) of heavy metals in sediment of Bhindawas Wetland (September, 2016 to May, 2017)

Table 4.31 Description of Pollution Load Index (PLI) of metals along with sampling locations and percentage of samples in Bhindawas wetland during study period (September, 2015 and May, 2017).

Classification		Sept, 2015		Sept, 2016		Jan., 2016		Jan, 2017		May, 2016		May, 2017	
Value	**Inference**	**Sites**	**(%) Sample**	**Sites**	**(%) Sample**	**Sites**	**(%) Sample**	**Sites**	**(%) Sample**	**Sites**	**(%) Sample**	**Sites**	**(%) Sample**
PLI< 1	Baseline Level	S1, S11	10	S9	5	S9	5	NIL	NIL	NIL	NIL	NIL	NIL
PLI = 1	Baseline Level	NIL	NIL	NIL	NIL	S4, S5, S6	15	NIL	NIL	NIL	NIL	NIL	NIL
PLI > 1	Significant Pollution	S2-S10, S12-S20	90	S1-S8, S10-S20	95	S1-S3, S7, S8, S10-S15, S17-S20	80	S1-S20	100	S1-S20	100	S1-S20	100

4.3.3.3 Geo-accumulation Index (I_{geo})

Geo-accumulation (I_{geo}) in all the heavy metals in Bhindawas wetland sediments is shown in Table 4.32 (September, 2015 – May, 2016) and Table 4.33 (September, 2016 – May, 2017). I_{geo} value below 0 determine unpolluted status of sediments. I_{geo} of Cadmium (Cd) varied from 1.28 to 2.32 in monsoon, and 1.01 to 1.96 in pre-monsoon respectively. For Chromium (Cr), I_{geo} varied from -7.76 to -6.97 for monsoon, -3.13 to -2.42 for post-monsoon and -3.94 to -1.40 for pre-monsoon. Similarly for copper it ranged from -2.80 to -0.90 in monsoon,-2.97 to -2.62 in post-monsoon and -1.32 to -0.91 in pre-monsoon respectively. The details of I_{geo} for Ni, Pb and Zn for monsoon, post-monsoon and pre-monsoon are shown in Table 4.32. I_{geo} values of heavy metals in the sediment samples of Bhindawas wetland are shown in Table 4.33 for the second year of study (September, 2016 – May, 2017). Nickel (Ni) varied from -4.16 to -2.06 in monsoon, -4.12 to -2.49 in post-monsoon and -5.95 to 0 in pre-monsoon respectively. I_{geo} for Iron (Fe) varied from-4.99 to -2.84 in monsoon,-3.30 to -3.08 in post-monsoon and -4.48 to -3.40 in pre-monsoon respectively. Similarly Zinc (Zn) ranged from -3.09 to -1.17 in monsoon, -4.63 to -3.17 in post-monsoon and -1.63 to -0.81 in pre-monsoon respectively. The I_{geo} values for Cd, Cr, Cu and Pb for monsoon, post-monsoon and pre-monsoon are shown in Table 4.33.

Table 4.32 The Geoaccumulation Index (I_{geo}) of heavy metals in the sediment samples of Bhindawas Weland (September, 2015 - May, 2016).

	Monsoon							**Postmonsoon**							**Premonsoon**						
Sites	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Fe**	**Ni**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Fe**	**Ni**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Fe**	**Ni**
Inlet	-1.21	-1.68	-2.27	-7.47	-3.53	-4.20	-2.86	-1.94	-1.10	-1.56	-3.92	-4.49	-3.40	-3.69	-0.12	0.03	-1.16	-1.80	-1.22	-3.92	-5.58
Outlet	-0.23	-2.32	-1.96	-7.21	-2.42	-3.79	-2.44	-2.44	-1.49	-1.96	-3.94	-3.42	-3.58	-2.95	-0.25	-0.45	-1.33	-1.42	-1.63	-5.89	-6.63
S1	-3.44		-2.51	-7.74	-3.23	-4.33	-3.39	-1.94	0.00	-2.71	-3.00	-3.25	-3.33	-3.15	-1.03	1.42	-1.00	-3.21	-1.38	-3.80	0.00
S2	-1.84		-2.17	-7.52	-2.85	-3.85	-2.95	-2.36	0.00	-2.77	-3.04	-3.43	-3.61	-3.26	-0.86	1.01	-1.12	-3.94	-1.45	-3.97	0.00
S3	-1.56		-1.82	-7.23	-2.23	-3.47	-2.73	-2.29	0.00	-2.78	-3.00	-4.00	-3.65	-3.44	-0.65	1.12	-0.94	-2.71	-1.43	-4.03	0.00
S4	-6.42		-1.78	-7.27	-1.29	-3.23	-2.62	-1.79	0.00	-2.91	-3.13	-4.48	-4.10	-4.45	-1.06	1.40	-0.91	-2.40	-1.40	-3.79	0.00
S5	-2.27		-1.19	-7.18	-1.62	-2.95	-2.25	-2.32	0.00	-2.97	-3.03	-3.73	-4.62	-3.50	-0.76	1.28	-1.07	-2.81	-0.37	-3.73	0.00
S6	-2.10		-0.90	-6.97	-1.08	-2.85	-2.10	-2.00	0.00	-2.78	-2.94	-4.39	-3.88	-3.95	-0.88	1.37	-1.13	-3.28	-1.04	-4.78	0.00
S7	-3.95		-1.38	-7.08	-1.84	-4.39	-2.51	-2.32	0.00	-2.91	-2.96	-3.18	-3.70	-3.28	-0.72	1.37	-1.18	-2.44	-0.76	-3.59	0.00
S8	-2.39		-2.13	-7.48	-2.68	-4.25	-2.92	-2.80	0.00	-2.62	-2.99	-3.29	-3.63	-3.54	-0.64	1.45	-1.24	-2.70	-0.95	-3.76	0.00
S9	-1.93	1.28	-1.48	-7.46	-2.76	-3.92	-2.77	-2.81	0.00	-2.90	-2.91	-5.95	-4.71	-3.60	-0.60	1.50	-1.22	-2.13	-1.08	-4.35	0.00
S10	-1.29		-2.19	-7.23	-2.69	-3.54	-2.69	-2.16	0.00	-2.78	-2.82	-3.45	-3.69	-3.72	-0.87	1.54	-1.22	-2.23	-0.98	-3.89	0.00
S11	-3.38		-2.80	-7.76	-4.32	-5.15	-3.20	-1.48	0.00	-2.75	-2.89	-3.33	-3.40	-3.81	-0.72	1.61	-0.94	-2.39	-1.24	-3.50	0.00
S12	-2.01		-1.47	-7.02	-2.07	-4.25	-2.45	-2.05	0.00	-2.92	-2.83	-3.38	-3.56	-3.57	-0.96	1.57	-1.10	-2.01	-1.36	-3.65	0.00
S13	-1.26		-1.83	-7.12	-2.43	-4.21	-2.39	-2.12	0.00	-2.86	-2.81	-3.82	-3.86	-3.69	-0.72	1.57	-1.07	-2.09	-1.33	-3.91	0.00
S14	-1.39		-1.89	-7.05	-3.05	-3.70	-2.55	-1.69	0.00	-2.81	-2.70	-2.95	-3.28	-4.05	-0.69	1.72	-1.12	-2.37	-1.31	-3.81	0.00
S15	-1.03		-2.10	-7.25	-2.95	-4.07	-2.67	-2.05	0.00	-2.92	-2.74	-2.96	-3.10	-3.51	-0.83	1.76	-1.27	-1.87	-1.39	-3.81	0.00
S16	-0.88		-2.01	-7.00	-2.54	-3.77	-2.64	-2.27	0.00	-2.90	-2.81	-5.25	-4.57	-3.14	-0.08	1.76	-1.22	-1.67	-1.58	-5.18	0.00
S17	-1.50		-2.08	-7.17	-3.06	-3.98	-2.55	-1.93	0.00	-2.73	-2.45	-3.21	-3.53	-3.29	-0.10	1.84	-1.24	-1.63	-1.51	-4.79	0.00
S18	-1.00	2.32	-1.52	-7.08	-2.53	-3.80	-2.53	-1.95	0.00	-2.81	-2.59	-3.90	-3.88	-2.95	-0.17	1.84	-1.27	-1.40	-1.60	-5.19	0.00
S19	-1.15		-2.21	-7.12	-3.25	-4.16	-2.63	-1.99	0.00	-2.96	-2.42	-3.30	-3.56	-2.81	-0.24	1.89	-1.22	-1.49	-1.51	-4.11	0.00
S20	-0.52		-1.93	-7.03	-3.22	-3.76	-2.61	-1.41	0.00	-2.89	-2.51	-3.13	-3.49	-3.16	-0.26	1.96	-1.32	-1.67	-1.38	-4.14	0.00
Mean	-2.06	1.80	-1.87	-7.24	-2.58	-3.88	-2.66	-2.09	0.00	-2.83	-2.83	-3.72	-3.76	-3.49	-0.64	1.55	-1.14	-2.32	-1.25	-4.09	0.00
SD	1.37	0.74	0.45	0.24	0.75	0.53	0.30	0.36	0.00	0.09	0.20	0.78	0.44	0.39	0.31	0.26	0.12	0.66	0.31	0.51	0.00
Min	-6.42	1.28	-2.80	-7.76	-4.32	-5.15	-3.39	-2.81	0.00	-2.97	-3.13	-5.95	-4.71	-4.45	-1.06	1.01	-1.32	-3.94	-1.60	-5.19	0.00
Max	-0.52	2.32	-0.90	-6.97	-1.08	-2.85	-2.10	-1.41	0.00	-2.62	-2.42	-2.95	-3.10	-2.81	-0.08	1.96	-0.91	-1.40	-0.37	-3.50	0.00

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites).

Table 4.33 The Geoaccumulation Index (Igeo) of heavy metals in the sediment samples of Bhindawas Weland (Sept, 2016 - May, 2017).

	Monsoon							Post-monsoon							Pre-monsoon						
Sites	Pb	Cd	Cu	Cr	Zn	Fe	Ni	Pb	Cd	Cu	Cr	Zn	Fe	Ni	Pb	Cd	Cu	Cr	Zn	Fe	Ni
Inlet	-1.04	-1.32	0.00	0.00	-3.95	-3.33	-2.53	-1.10	-1.17	-3.78	-3.11	-3.95	-3.24	-3.01	-0.89	0.18	-5.11	-3.99	-1.26	-3.53	-4.93
Outlet	0.10	-2.17	-3.35	-4.91	-2.95	-3.39	-2.81	-0.66	-2.03	-4.31	-3.42	-5.33	-3.86	-1.35	-2.35	-0.74	0.00	-5.49	-1.68	-3.91	-6.02
S1	-1.54	-4.49	-2.34	-6.49	-2.67	-3.43	-3.05	-1.75	0.00	-3.02	-3.02	-3.69	-3.13	-3.94	-1.08	1.39	-1.57	-2.65	-1.23	-3.56	-4.95
S2	-1.54	0.00	-1.93	-10.40	-2.42	-2.99	-2.81	-2.02	0.00	-3.15	-2.85	-3.81	-3.24	-3.52	-1.48	0.37	-1.08	-2.53	-1.40	-3.56	-5.95
S3	-1.54	0.74	-1.37	-7.26	-1.74	-3.28	-2.52	-1.75	0.00	-2.06	-2.78	-3.75	-3.13	-3.70	-0.92	0.46	-0.92	-3.22	-1.61	-3.53	-4.85
S4	-1.30	0.00	-2.02	-7.15	-1.17	-3.50	-2.20	-1.95	0.00	-2.89	-2.94	-3.29	-3.18	-3.99	-1.48	0.44	-1.44	-1.81	-1.52	-3.53	-4.99
S5	-0.50	0.00	-1.96	-6.02	-1.51	-3.26	-3.50	-2.13	0.00	-2.96	-2.72	-3.38	-3.16	-4.12	-1.99	1.37	-1.23	-2.87	-1.73	-3.53	-5.27
S6	-1.20	0.44	-1.80	-6.49	-1.66	-3.29	-2.20	-1.10	0.00	-2.81	-3.11	-3.25	-3.13	-3.92	-0.92	1.26	-1.17	-2.35	-0.81	-3.40	-5.95
S7	-1.42	0.00	-2.15	-7.20	-1.37	-3.03	-2.43	-1.34	0.00	-2.75	-2.85	-3.38	-3.18	-3.07	-4.59	1.45	-1.35	-1.43	-1.22	-3.50	-4.67
S8	-1.42	-4.49	-1.85	-7.53	-2.62	-3.02	-2.81	-0.68	0.00	-2.18	-2.96	-3.58	-3.21	-2.52	-1.35	0.98	-0.86	-2.55	-1.52	-3.50	-5.03
S9	0.00	0.79	-2.29	-7.72	-2.32	-3.99	-3.19	-1.89	0.00	-2.29	-2.86	-4.01	-3.08	-3.68	-0.92	1.24	-0.92	-2.35	-1.31	-3.78	-4.27
S10	-1.20	-5.49	-1.50	-7.35	-2.93	-3.12	-2.06	-2.76	0.00	-2.89	-2.77	-3.81	-3.24	-3.27	-1.35	1.30	-1.05	-2.72	-1.63	-3.71	-4.71
S11	-2.63	0.00	-1.59	-7.70	-3.09	-3.51	-2.35	-1.12	0.00	-3.05	-3.09	-3.75	-3.27	-3.11	-0.87	1.56	-1.40	-2.35	-1.10	-3.82	-4.03
S12	-0.77	0.00	-1.50	-6.20	-1.90	-3.62	-3.50	-1.79	0.00	-1.86	-3.30	-3.17	-3.11	-3.03	-1.23	1.14	-0.89	-1.81	-1.42	-3.43	-4.35
S13	-1.30	-5.49	-1.79	-7.35	-2.25	-3.79	-3.19	-1.12	0.00	-3.21	-2.85	-3.25	-3.13	-2.49	-0.88	1.17	-1.02	-2.72	-1.13	-4.04	-4.93
S14	-0.93	0.00	-1.85	-6.13	-2.87	-3.85	-6.35	-1.76	0.00	-3.41	-2.64	-3.29	-3.18	-2.57	-0.92	1.45	-1.11	-2.46	-1.36	-4.09	0.00
S15	-0.85	0.00	-2.02	-6.07	-3.09	-2.93	-4.16	-2.35	0.00	-3.05	-2.86	-3.69	-3.30	-2.66	-0.90	1.55	-0.96	-1.62	-1.63	-3.86	-4.27
S16	-1.54	0.00	-1.50	-6.29	-2.03	-3.13	-4.16	-1.96	0.00	-1.76	-2.78	-3.48	-3.27	-2.89	-0.77	0.92	-0.77	-2.35	-1.28	-3.78	-4.35
S17	-2.63	0.00	-1.90	-7.51	-2.47	-4.99	-4.16	-1.61	0.00	-3.29	-2.92	-3.75	-3.27	-3.37	-0.92	0.95	-0.89	-2.35	-1.41	-4.48	-5.59
S18	-2.63	2.09	-1.42	-6.36	-2.49	-3.48	-3.05	-2.31	0.00	-2.11	-3.19	-4.63	-3.30	-3.59	-0.60	1.19	-0.87	-1.62	-1.63	-3.78	-4.88
S19	-1.30	0.18	-1.50	-6.45	-2.62	-3.79	-2.13	-1.12	0.00	-3.19	-2.77	-3.53	-3.27	-2.89	-0.70	0.95	-1.26	-2.87	-1.12	-4.14	-4.35
S20	-0.85	0.00	-1.38	-5.85	-2.93	-2.84	-2.13	-1.75	0.00	-1.88	-2.71	-3.58	-3.21	-3.68	-0.56	1.09	-1.21	-2.35	-1.35	-4.09	0.00
AVG	-1.35	-0.79	-1.78	-6.98	-2.31	-3.44	-3.10	-1.71	0.00	-2.69	-2.90	-3.60	-3.20	-3.30	-1.22	1.11	-1.10	-2.35	-1.37	-3.76	-4.37
SD	0.68	2.23	0.30	1.02	0.59	0.49	1.04	0.51	0.00	0.54	0.17	0.34	0.07	0.53	0.86	0.35	0.22	0.47	0.23	0.29	1.59
Min	-2.63	-5.49	-2.34	-10.40	-3.09	-4.99	-6.35	-2.76	0.00	-3.41	-3.30	-4.63	-3.30	-4.12	-4.59	0.37	-1.57	-3.22	-1.73	-4.48	-5.95
Max	0.00	2.09	-1.37	-5.85	-1.17	-2.84	-2.06	-0.68	0.00	-1.76	-2.64	-3.17	-3.08	-2.49	-0.56	1.56	-0.77	-1.43	-0.81	-3.40	0.00

Note: The mean (± SD) & Range were carried out for S1 to S20 (20 sites).

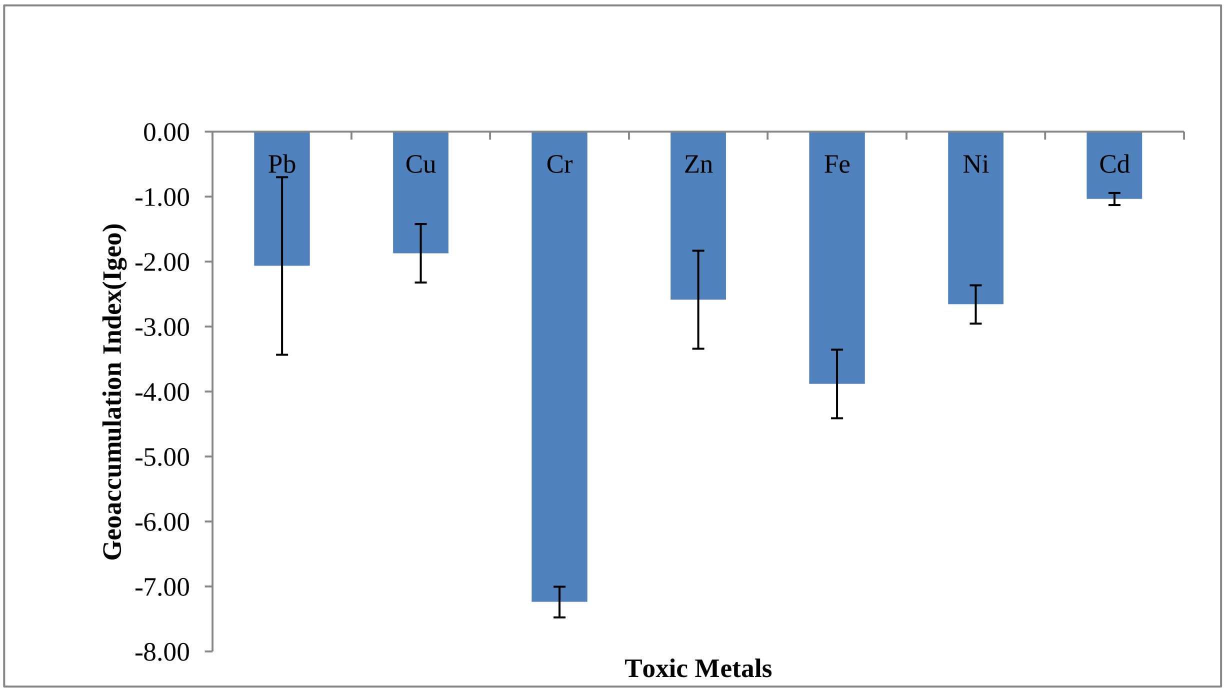

Figure.4.65 Geoaccumulation Index (I_{geo}) of heavy metals in sediment of Bhindawas Wetland during monsoon (September, 2015)

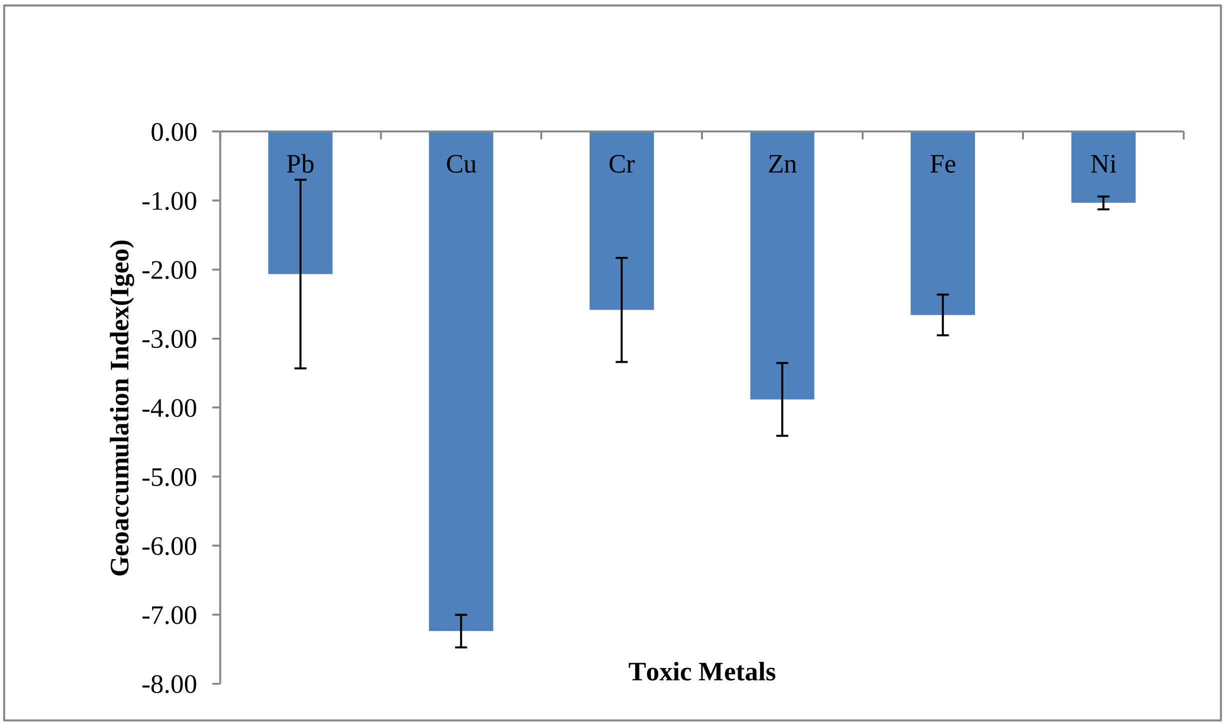

Figure.4.66. Geoaccumulation Index (I_{geo}) of heavy metals in sediment of Bhindawas Wetland during post-monsoon (January, 2016)

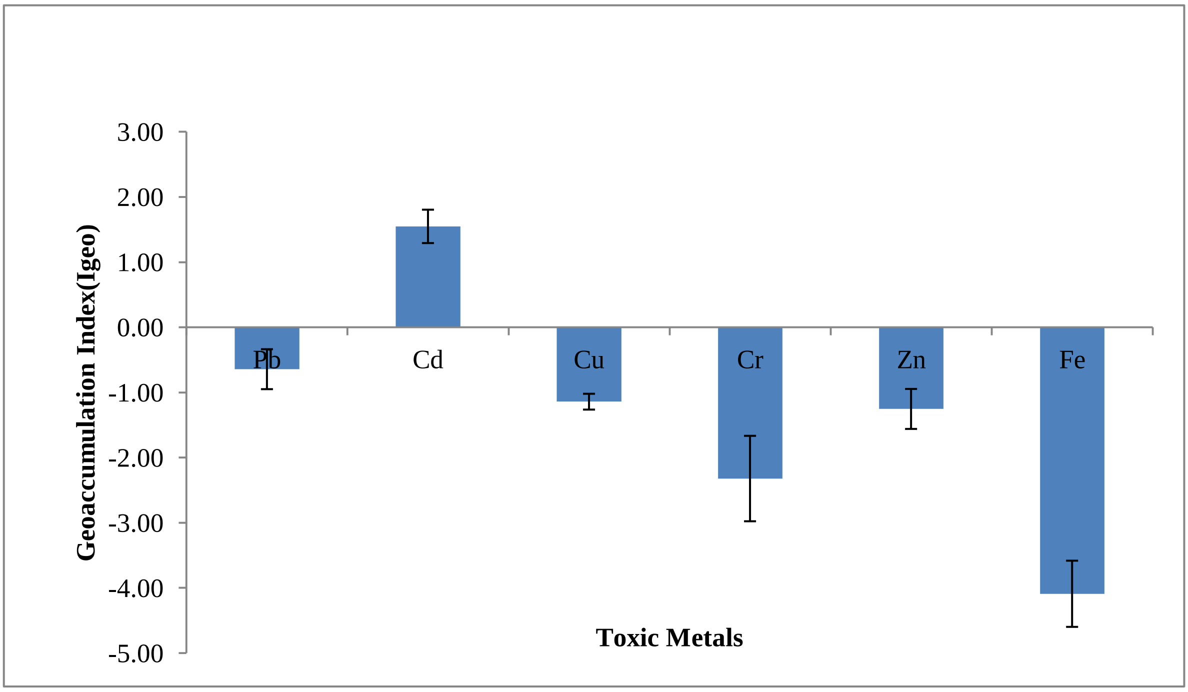

Figure.4.67 Geoaccumulation Index (I_{geo}) of heavy metals in sediment of Bhindawas Wetland during pre-monsoon (May, 2016)

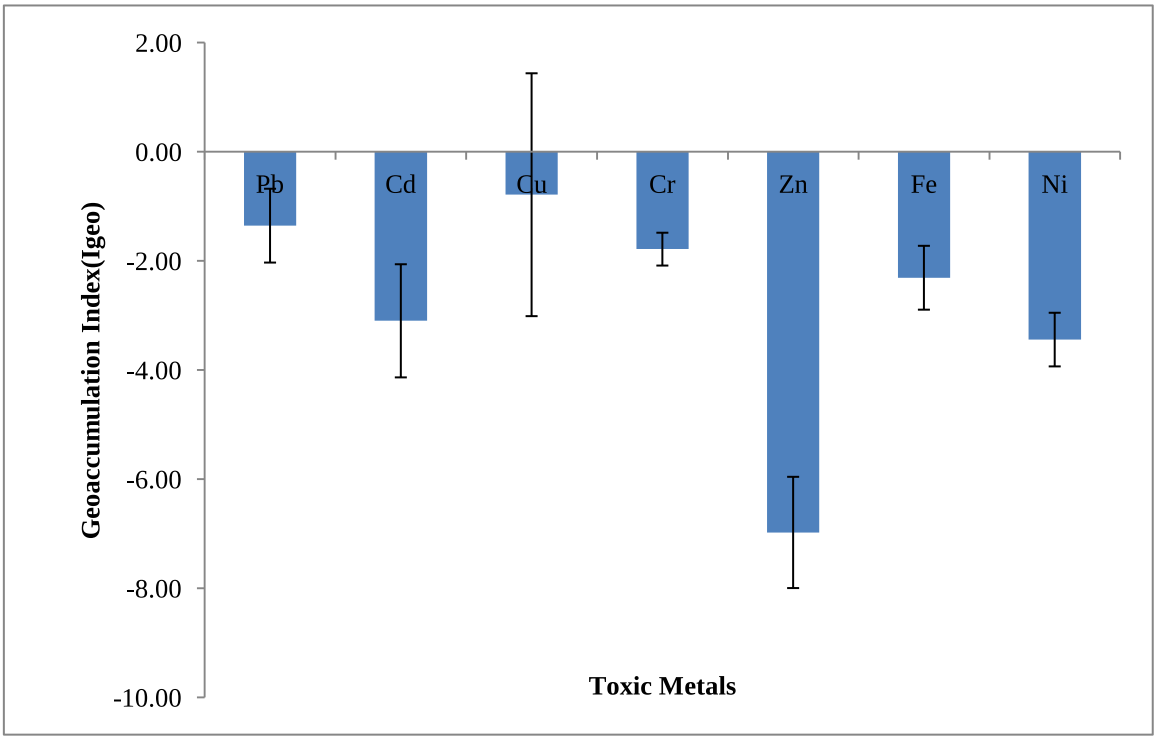

Figure.4.68 Geoaccumulation Index (I_{geo}) of heavy metals in sediment of Bhindawas Wetland during monsoon (September, 2016)

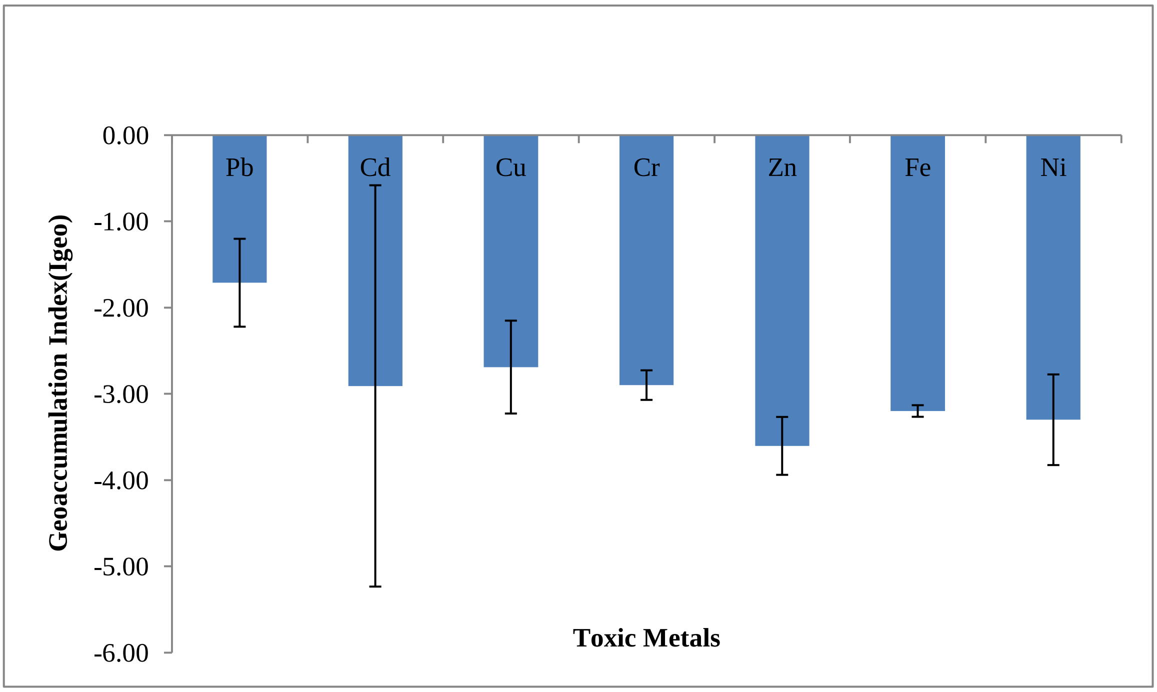

Figure.4.69 Geoaccumulation Index (I_{geo}) of heavy metals in sediment of Bhindawas Wetland during post-monsoon (January, 2017)

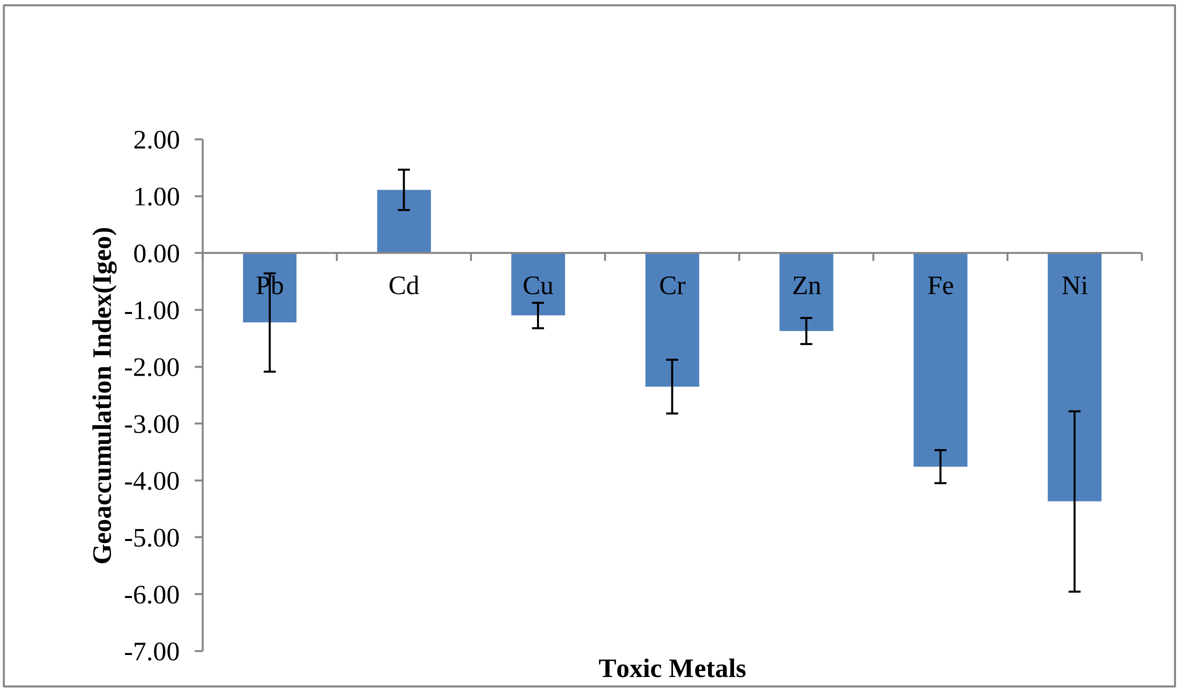

Figure.4.70 Geoaccumulation Index (I_{geo}) of heavy metals in sediment of Bhindawas Wetland during pre-monsoon (May, 2017)

Table 4.34 Description of Geoaccumulation Index ($_{Igeo}$) of heavy metals along with sampling locations and percentage of samples in Bhindawas wetland in monsoon (September, 2015 and September, 2016)

Classification		September, 2015		September, 2016	
Value	Inference	Sampling Location	(%) Samples	Sampling Location	(%) Samples
Igeo < 0	Uncontaminated	Pb (S1-S20)	100	Pb (S1-S20)	100
		Cu (S1-S20)	100	Cu (S1-S20)	100
		Cr (S1-S20)	100	Cr (S1-S20)	100
		Zn (S1-S20)	100	Zn (S1-S20)	100
		Fe (S1-S20)	100	Fe (S1-S20)	100
		Ni(S1-S20)	100	Ni (S1-S20)	100
0 < Igeo < 1	Uncontaminated to moderately contaminated	NIL	NIL	Cd (S3, S6, S9, S19)	20
1 < Igeo < 2	Moderately contaminated	Cd (S9)	50	NIL	NIL
2 < Igeo < 3	Moderately to Strongly contaminated	Cd (S18)	50	Cd (S18)	5
3 < Igeo < 4	Strongly contaminated	NIL	NIL	NIL	NIL
4 < Igeo < 5	Strongly to extremely contaminated	NIL	NIL	NIL	NIL
Igeo > 5	Extremely contaminated	NIL	NIL	NIL	NIL

Table 4.35 Description of Geoaccumulation Index (I_{geo}) of heavy metals along with sampling locations and percentage of samples in Bhindawas wetland in post-monsoon (January, 2016 and January, 2017)

Classification		Jan., 2016		Jan., 2017	
Value	Inference	Sampling Location	(%) Samples	Sampling Location	(%) Samples
Igeo < 0	Uncontaminated	Pb(S1-S20)	100	Pb(S1-S20)	100
		Cu(S1-S20)	100	Cu(S1-S20)	100
		Cr(S1-S20)	100	Cr(S1-S20)	100
		Zn(S1-S20)	100	Zn(S1-S20)	100
		Fe(S1-S20)	100	Fe(S1-S20)	100
		Ni(S1-S20)	100	Ni(S1-S20)	100
0 < Igeo < 1	Uncontaminated to moderately contaminated	NIL	NIL	NIL	NIL
1 < Igeo < 2	Moderately contaminated	NIL	NIL	NIL	NIL
2 < Igeo < 3	Moderately to Strongly contaminated	NIL	NIL	NIL	NIL
3 < Igeo < 4	Strongly contaminated	NIL	NIL	NIL	NIL
4 < Igeo < 5	Strongly to extremely contaminated	NIL	NIL	NIL	NIL
Igeo > 5	Extremely contaminated	NIL	NIL	NIL	NIL

Table 4.36 Description of Geoaccumulation Index (I_{geo}) of heavy metals alongwith sampling locations and percentage of samples in Bhindawas wetland in pre-monsoon (May, 2016 and May, 2017)

Classification		May, 2016		May, 2017	
Value	**Inference**	**Sampling Location**	**(%) Samples**	**Sampling Location**	**(%) Samples**
Igeo < 0	Uncontaminated	Pb (S1-S20)	100	Pb (S1-S20)	100
		Cu (S1-S20)	100	Cu (S1-S20)	100
		Cr (S1-S20)	100	Cr (S1-S20)	100
		Zn (S1-S20)	100	Zn (S1-S20)	100
		Fe (S1-S20)	100	Fe (S1-S20)	100
		Ni (S1-S20)	100	Ni (S1-S20)	100
0 < Igeo < 1	Uncontaminated to moderately contaminated	NIL	NIL	Cd (S2-S4, S8, S16, S17, S19)	35
1 < Igeo < 2	Moderately contaminated	Cd (S1-S20)	100	Cd (S1, S5-S7, S9-S15, S18, S20)	65
2 < Igeo < 3	Moderately to Strongly contaminated	NIL	NIL	NIL	NIL
3 < Igeo < 4	Strongly contaminated	NIL	NIL	NIL	NIL
4 < Igeo < 5	Strongly to extremely contaminated	NIL	NIL	NIL	NIL
Igeo > 5	Extremely contaminated	NIL	NIL	NIL	NIL

4.3.3.4. Sediment Pollution Index (SPI)

Sediment Pollution Index (SPI) is an efficient method in overall assessment of sediment quality with respect to number of selected heavy metals. Being a multi metal assessment method, it determines relative metal toxicity. It is defined as sum of the metal enrichment factors by sum of metal toxicity weights. Metal toxicity weight depends on relative metal toxicity of studied heavy metals and inversely related to lithogenic limits of their average crust values. Different metals were assigned with different numbers like weight 1 to Cr and Zn which are less toxic,2 for Ni and Cd, and 5 for Pb.

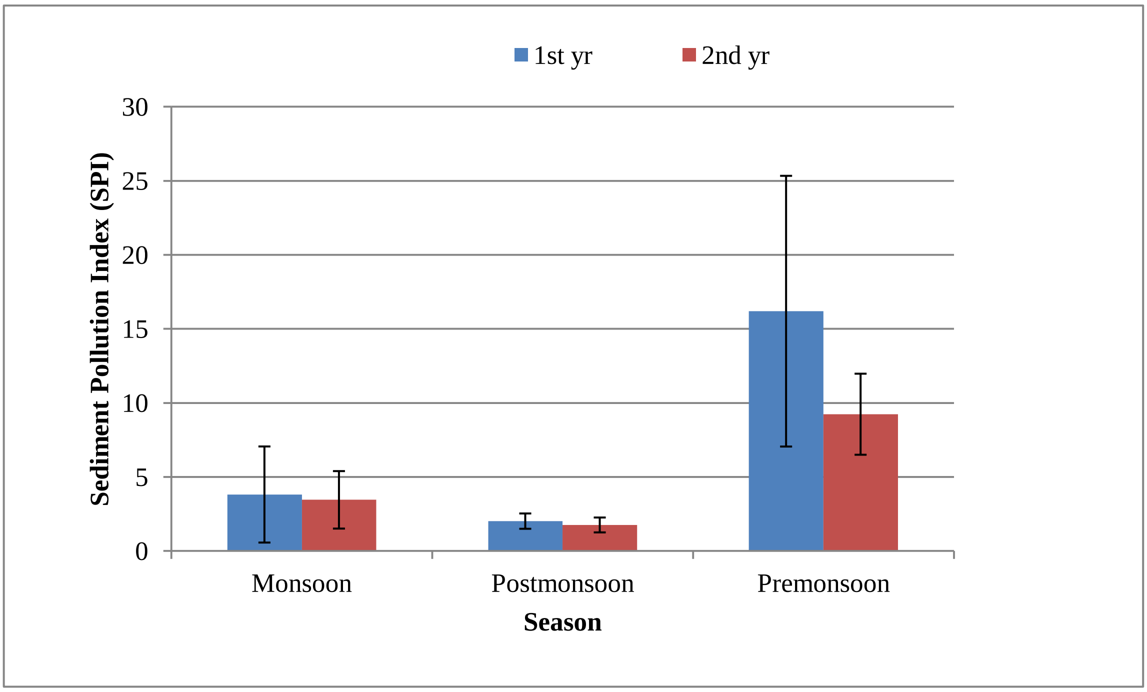

Figure.4.71 Sediment Pollution Index (SPI) of heavy metals in sediment of Bhindawas Wetland (September, 2015 - May, 2016)

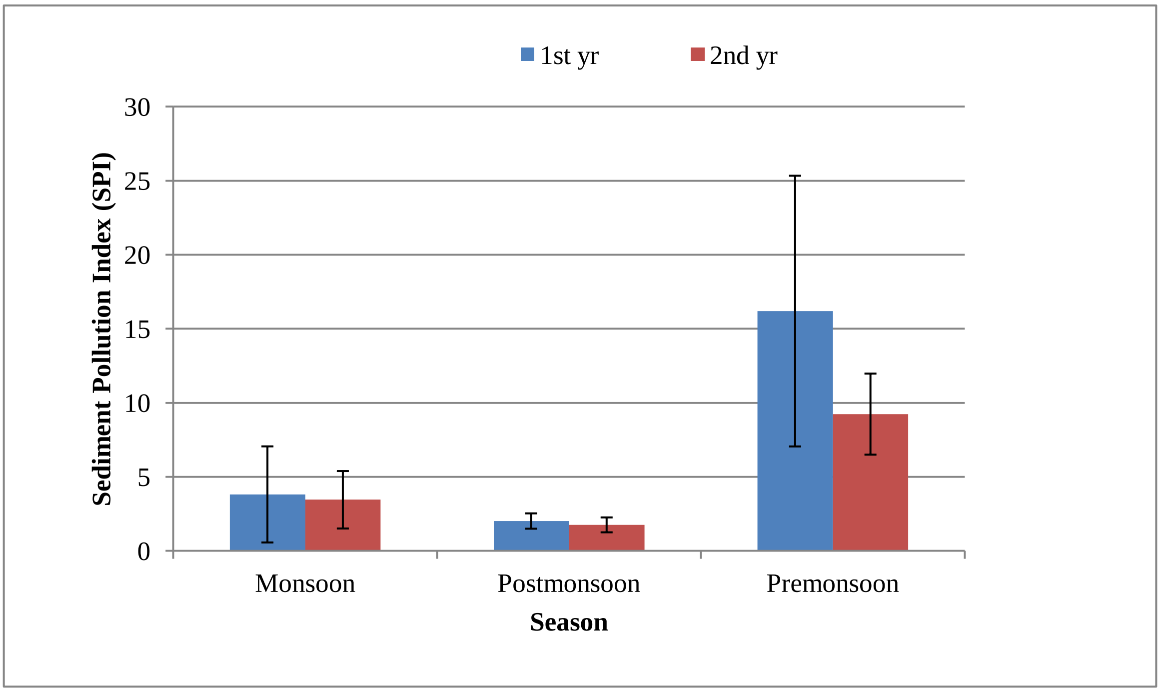

Figure.4.72 Sediment Pollution Index (SPI) of heavy metals in sediment of Bhindawas Wetland (September, 2016 - May, 2017)

Table 4.37. Description of Sediment Pollution Index (SPI) of heavy metals alongwith sampling locations and percentage of samples in Bhindawas wetland in during study period (September, 2015 and May, 2017)

Classification		**Sept., 2015**		**Sept., 2016**		**Jan. 2016**		**Jan, 2017**		**May,2016**		**May, 2017**	
Value	**Inference**	**Sampling Location**	**(%) Samples**	**Sampling Location**	**(%) Samples**	**Sampling Location**	**(%) Samples**	**Sampling Location**	**(%) Samples**	**Sampling Location**	**(%) Samples**	**Sampling Location**	**(%) Samples**
0 < SPI < 2	Natural Sediments	S1, S4, S5, S6	20	S2, S7, S8, S11, S16	25	S1-S3, S7, S8, S10, S12, S14, S15 , S17, S19	55	S1-S5, S9, S10, S12, S14-S18, S20	70	NIL	NIL	NIL	NIL
2 < SPI < 5	Low Polluted	S2, S3, S7, S8, S0-S17, S19, S20	70	S1, S3-S6, S10, S12-S15, S17, S20	60	S4-S6, S9, S11, S13, S16, S20	40	S6-S8, S11, S13, S19	30	NIL	NIL	NIL	
5 < SPI< 10	Moderately Polluted	S9	5	S9, S18, S19	15	NIL	NIL	NIL	NIL	S2, S7, S11	15	S1-S10, S12, S16	60
10 < SPI < 20	Highly Polluted	S18	5	NIL	NIL	NIL	NIL	NIL	NIL	S1-S5, S8-S10, S12-S15, S19, S20	65	S11, S13-S15, S17-S20	40
SPI >20	Critically Polluted	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	S6, S16-S18	20	NIL	NIL

Table 4.38 Sediment Pollution Index (SPI) of heavy metals in the sediment samples of Bhindawas Weland (September, 2015 - May, 2016).

	Monsoon							Post-monsoon							Pre-monsoon						
Sites	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**	**SPI**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**	**SPI**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**	**SPI**
Inlet	39.82	11.44	3.81	0.10	1.60	5.08	5.15	13.79	9.85	3.58	0.70	0.47	1.63	2.50	69.47	0.10	6.76	4.34	6.49	0.63	7.31
Outlet	59.00	5.51	3.54	0.09	2.58	5.07	6.32	11.02	8.52	3.07	0.78	1.12	3.10	2.30	248.78	0.38	23.60	22.12	19.18	1.19	26.27
S1	9.27	0.00	3.53	0.09	2.13	3.83	1.57	13.15	0.00	1.54	1.26	1.06	2.28	1.61	34.05	74.39	6.94	1.50	5.32	0.00	10.18
S2	20.07	0.00	3.20	0.08	1.99	3.72	2.42	11.86	0.00	1.79	1.49	1.13	2.54	1.57	43.11	62.86	7.18	1.02	5.73	0.00	9.99
S3	18.87	0.00	3.14	0.07	2.37	3.35	2.32	12.79	0.00	1.82	1.56	0.78	2.31	1.61	51.94	70.70	8.53	2.50	6.04	0.00	11.64
S4	0.55	0.00	2.74	0.06	3.83	3.05	0.85	24.74	0.00	2.28	1.96	0.77	1.57	2.61	33.11	73.07	7.36	2.62	5.25	0.00	10.12
S5	7.98	0.00	3.39	0.05	2.52	3.25	1.43	24.59	0.00	3.13	3.01	1.85	4.33	3.08	38.97	64.38	6.31	1.89	10.24	0.00	10.15
S6	8.43	0.00	3.86	0.06	3.41	3.37	1.59	18.50	0.00	2.15	1.92	0.71	1.90	2.10	74.65	141.35	12.50	2.82	13.30	0.00	20.38
S7	6.79	0.00	8.04	0.15	5.87	7.35	2.35	13.01	0.00	1.73	1.67	1.43	2.67	1.71	36.63	62.26	5.34	2.22	7.12	0.00	9.46
S8	18.23	0.00	4.35	0.11	2.98	5.04	2.56	8.83	0.00	2.01	1.56	1.26	2.12	1.32	43.45	74.11	5.74	2.09	7.04	0.00	11.04
S9	19.89	73.12	5.40	0.09	2.23	4.44	8.76	18.74	0.00	3.51	3.48	0.42	4.32	2.54	67.38	115.87	8.75	4.67	9.64	0.00	17.19
S10	23.66	0.00	2.53	0.08	1.80	3.58	2.64	14.45	0.00	1.88	1.83	1.18	1.96	1.78	40.73	86.57	6.39	3.18	7.56	0.00	12.04
S11	17.12	0.00	5.13	0.16	1.79	7.76	2.66	18.91	0.00	1.57	1.43	1.05	1.50	2.04	34.37	69.04	5.90	2.16	4.81	0.00	9.69
S12	23.58	0.00	6.87	0.15	4.51	6.92	3.50	14.30	0.00	1.57	1.66	1.13	1.99	1.72	32.33	74.61	5.85	3.12	4.91	0.00	10.07
S13	38.72	0.00	5.22	0.13	3.43	7.06	4.55	16.78	0.00	2.01	2.08	1.03	2.25	2.01	45.38	89.21	7.12	3.52	5.95	0.00	12.60
S14	24.76	0.00	3.51	0.10	1.57	4.44	2.86	15.06	0.00	1.39	1.49	1.25	1.17	1.70	43.30	92.35	6.43	2.72	5.62	0.00	12.53
S15	41.08	0.00	3.92	0.11	2.17	5.28	4.38	10.37	0.00	1.13	1.28	1.10	1.50	1.28	39.66	95.29	5.83	3.84	5.35	0.00	12.50
S16	36.96	0.00	3.38	0.11	2.35	4.37	3.93	24.57	0.00	3.19	3.37	0.62	5.36	3.09	171.45	246.44	15.65	11.46	12.19	0.00	38.10
S17	27.89	0.00	3.73	0.11	1.89	5.38	3.25	15.13	0.00	1.75	2.11	1.25	2.36	1.88	129.10	198.58	11.75	8.98	9.72	0.00	29.84
S18	34.91	139.30	4.87	0.10	2.41	4.83	15.53	19.03	0.00	2.09	2.43	0.99	3.80	2.36	163.02	261.68	15.15	13.90	12.06	0.00	38.82
S19	40.23	0.00	3.88	0.13	1.88	5.79	4.33	14.82	0.00	1.51	2.19	1.20	3.34	1.92	72.67	127.31	7.36	6.12	6.03	0.00	18.29
S20	47.35	0.00	3.55	0.10	1.45	4.44	4.74	21.09	0.00	1.51	1.96	1.28	2.51	2.36	73.86	137.70	7.06	5.55	6.80	0.00	19.25
Range	0.55-47.35	0-139.30	2.53-8.04	0.05-0.16	1.45-5.87	3.05-7.76	0.85-15.53	8.83-24.74	-	1.13-3.51	1.26-3.48	0.42-1.85	1.17-5.36	1.28-3.09	32.33-171.45	62.26-261.68	5.34-15.65	1.02-13.90	4.81-13.90	-	9.46-38.82
Mean	23.32	10.62	4.21	0.10	2.63	4.86	3.81	16.54		1.98	1.99	1.07	2.59	2.01	63.46	110.89	8.16	4.29	7.54		16.19
±SD	±13.20	±34.41	±1.38	±0.03	±1.10	±1.45	±3.25	±4.65	-	±0.63	±0.64	±0.31	±1.10	±0.52	±42.24	±59.83	±3.10	±3.42	±2.67	-	±9.14

Note: The mean and (±SD) was carried out from sampling sites (S1-S20).

Table 4.39 Sediment Pollution Index (SPI) of heavy metals in the sediment samples of Bhindawas Weland (September, 2016 - May, 2017).

	Monsoon							**Post-monsoon**							**Pre-monsoon**						
Sites	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**	**SPI**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**	**SPI**	**Pb**	**Cd**	**Cu**	**Cr**	**Zn**	**Ni**	**SPI**
Inlet	24.43	8.05	0.00	0.00	0.65	3.48	3.05	22.01	8.41	0.69	1.09	0.61	2.36	2.93	31.14	26.13	0.33	0.73	4.82	0.76	5.33
Outlet	56.00	4.64	1.02	0.35	1.35	2.97	5.53	46.01	7.12	0.73	1.36	0.36	11.42	5.58	14.74	17.98	0.00	0.33	4.68	0.46	3.18
S1	18.53	0.96	2.13	0.12	1.70	2.60	2.17	12.99	0.00	1.08	1.08	0.68	1.14	1.41	27.94	61.88	3.97	1.88	5.02	0.76	8.46
S2	13.67	0.00	2.09	0.01	1.49	2.26	1.63	11.65	0.42	1.06	1.31	0.67	1.65	1.40	21.15	30.42	5.59	2.04	4.49	0.38	5.34
S3	16.72	32.44	3.78	0.06	2.92	3.40	4.94	13.06	0.00	2.10	1.27	0.65	1.35	1.54	30.57	31.76	6.09	1.24	3.78	0.80	6.19
S4	22.98	0.00	2.79	0.08	5.03	4.95	2.99	11.74	0.48	1.23	1.18	0.93	1.14	1.39	20.67	31.25	4.26	3.29	4.01	0.72	5.35
S5	33.81	0.00	2.45	0.15	3.35	1.68	3.45	10.18	0.79	1.14	1.35	0.85	1.02	1.28	14.48	59.43	4.92	1.58	3.49	0.60	7.04
S6	21.33	26.47	2.80	0.11	3.09	4.26	4.84	20.36	0.00	1.25	1.01	0.92	1.16	2.06	27.98	50.66	4.71	2.07	6.01	0.34	7.65
S7	15.33	0.00	1.84	0.06	3.16	3.04	1.95	17.95	0.40	1.35	1.26	0.87	2.16	2.00	2.35	61.59	4.44	4.18	4.84	0.89	6.52
S8	15.18	0.72	2.24	0.04	1.32	2.30	1.82	28.94	2.06	2.05	1.19	0.77	3.22	3.19	22.08	44.57	6.24	1.92	3.92	0.69	6.62
S9	0.00	54.88	3.25	0.08	3.17	3.48	5.40	11.41	2.25	1.73	1.16	0.52	1.32	1.53	36.45	64.76	7.27	2.70	5.55	1.43	9.85
S10	19.01	0.39	3.08	0.05	1.14	4.17	2.32	6.97	0.42	1.27	1.39	0.67	1.96	1.06	25.53	64.28	6.32	1.98	4.21	0.99	8.61
S11	9.24	0.00	3.80	0.06	1.34	4.49	1.58	22.23	2.14	1.16	1.13	0.72	2.23	2.47	38.73	83.56	5.38	2.78	6.60	1.73	11.56
S12	36.08	0.00	4.34	0.17	3.28	2.16	3.84	12.47	0.96	2.36	0.87	0.96	2.10	1.64	22.92	47.44	5.82	3.08	4.02	1.06	7.03
S13	27.99	0.61	4.01	0.08	2.91	3.04	3.22	20.14	0.00	0.95	1.21	0.92	3.12	2.20	44.79	73.91	8.11	2.50	7.55	1.08	11.50
S14	37.84	0.00	3.99	0.21	1.97	0.35	3.70	13.40	0.00	0.86	1.46	0.93	3.06	1.64	45.15	93.08	7.88	3.09	6.64	0.00	12.99
S15	21.17	0.00	1.87	0.11	0.89	0.85	2.07	9.66	0.52	1.19	1.35	0.76	3.11	1.38	38.92	85.35	7.49	4.74	4.70	1.51	11.89
S16	15.04	0.00	3.10	0.11	2.14	0.98	1.78	12.36	0.51	2.85	1.40	0.86	2.61	1.72	40.46	51.93	8.04	2.70	5.65	1.35	9.18
S17	25.60	0.00	8.47	0.17	5.72	3.54	3.63	15.81	0.00	0.98	1.28	0.72	1.86	1.72	59.29	86.45	12.12	4.39	8.39	0.93	14.30
S18	8.99	94.90	4.16	0.14	1.98	2.68	9.40	9.91	1.75	2.28	1.07	0.40	1.64	1.42	45.28	62.93	7.53	4.48	4.44	0.93	10.47
S19	27.92	31.24	4.87	0.16	2.24	6.31	6.06	22.15	0.79	1.06	1.41	0.83	2.61	2.40	54.24	68.16	7.36	2.42	8.12	1.73	11.84
S20	19.86	0.00	2.74	0.12	0.94	3.27	2.24	13.82	0.00	2.52	1.42	0.77	1.44	1.66	57.70	72.65	7.37	3.34	6.70	0.00	12.31
Range	0-37.84	0-94.90	1.84-8.47	0.01-0.21	0.89-5.72	0.35-6.31	1.58-9.40	6.97-28.94	0-2.25	0.86-2.85	0.87-1.46	0.40-0.96	1.02-3.22	1.06-3.19	2.35-59.29	30.42-93.08	3.97-12.12	1.24-4.74	3.49-8.39	0-1.73	5.34-14.30
Mean ±SD	20.31 ±9.45	12.13 ±24.93	3.39 ±1.49	0.10 ±0.05	2.49 ±1.29	2.99 ±1.45	3.45 ±1.94	14.86 ±5.45	0.67 ±0.77	1.52 ±0.61	1.24 ±0.15	0.77 ±0.15	1.99 ±0.75	1.76 ±0.50	33.83 ±14.90	61.30 ±18.47	6.54 ±1.87	2.82 ±1.01	5.41 ±1.50	0.90 ±0.50	9.23 ±2.74

Note: The mean and (±SD) was carried out from sampling sites (S1-S20).

4.4 Nutrient Loading

The advantage of determining nutrient loading is that it can be integrated over the appropriate time scale for characterizing wetland nutrient condition. In some cases, historical loading patterns can be reconstructed. Nutrient Loading in wetland calculated as-

Total Nitrogen = Nitrate –Nitrogen (NO_3 –N) + Total Kjeldahl Nitrogen (TKN) (4.1)

$$TN_{avg} = \sum TN_{S1} - TN_{S20} / 20 \quad (4.2)$$

$$TP_{avg} = \sum TP_{S1} - TP_{S20} / 20 \quad (4.3)$$

$$TN_L = TN_{avg} \times \text{Depth(m)} \times \text{Surface Area } (m^2) \quad (4.4)$$

$$TN_P = TP_{avg} \times \text{Depth (m)} \times \text{Surface Area } (m^2) \quad (4.5)$$

Table 4.40 Seasonal nutrient loading of Total Nitrogen (tonnes) in Bhindawas wetland.

Sites	Monsoon (Sept., 2015)	Post-monsoon (Jan., 2016)	Pre-monsoon (May, 2016)	Monsoon (Sept., 2016)	Post-monsoon (Jan., 2017)	Pre-monsoon (May, 2017)
Inlet	1.4	1.8	1.0	2.5	2.9	1.4
outlet	0.8	0.4	0.2	0.6	0.8	0.4
S1	4.1	4.4	3.1	5.0	4.5	1.4
S2	2.6	4.2	1.7	4.1	2.7	1.6
S3	1.9	1.6	1.3	8.9	6.4	2.2
S4	1.2	2.3	1.5	2.8	4.1	1.0
S5	3.5	4.9	2.9	2.9	3.0	2.1
S6	0.8	5.1	1.4	2.9	5.4	1.6
S7	0.6	1.3	0.8	1.5	2.6	1.0
S8	4.7	3.1	1.5	3.1	2.3	2.0
S9	4.6	2.3	1.3	3.7	3.2	2.3
S10	6.9	3.0	1.4	3.4	6.5	0.8
S11	3.3	2.6	2.4	2.7	1.8	2.2
S12	3.5	5.5	1.4	4.7	7.1	2.2
S13	3.3	4.8	1.5	3.6	1.7	2.1
S14	1.7	3.5	1.3	4.0	5.8	0.7
S15	1.1	2.1	1.9	3.3	2.5	0.8
S16	1.8	3.1	1.7	2.6	2.8	1.1
S17	1.7	1.4	1.7	3.2	4.7	1.4
S18	1.9	1.5	0.9	2.4	2.9	0.8
S19	2.6	1.5	0.9	3.3	3.4	0.5
S20	3.1	1.7	2.1	6.6	5.2	1.0
Mean	2.74	3.00	1.62	3.73	3.93	1.44
SD	1.55	1.39	0.60	1.62	1.66	0.61

Where, NO_3-N, TKN, TN_{avg} and TP_{avg} represents nitrate nitrogen, total kjeldhal nitrogen, average concentration of total nitrogen (mg/l) and average concentration of total phosphorous (mg/l) respectively, samples, n = Number of samples, TKN = Total Kjeldhal Nitrogen. TN_L and TP_L is loading due to total nitrogen and total phosphorous respectively.

Spatial variation (September, 2015 to May, 2017)

Table 4.41 Seasonal nutrient loading of Total Phosphorous (tonnes) in Bhindawas wetland.

Sites	Monsoon (Sept., 2015)	Post-monsoon (Jan., 2016)	Pre-monsoon (May, 2016)	Monsoon (Sept., 2016)	Post-monsoon (Jan., 2017)	Pre-monsoon (May, 2017)
Inlet	0.10	0.21	0.04	0.40	0.05	0.09
outlet	0.19	0.04	0.02	0.21	0.01	0.02
S1	1.35	0.35	0.06	0.27	0.08	0.11
S2	0.77	1.83	0.22	1.77	0.04	0.04
S3	1.12	0.32	0.06	0.38	0.27	0.05
S4	0.79	0.22	0.13	0.29	0.41	0.06
S5	1.46	0.34	0.43	0.50	0.08	0.16
S6	0.27	0.54	0.45	0.10	0.08	0.09
S7	0.14	0.12	0.04	0.07	0.02	0.17
S8	0.96	0.24	0.49	0.34	0.15	0.09
S9	0.44	0.24	0.10	0.76	0.09	0.30
S10	1.63	0.16	0.06	0.73	0.12	0.18
S11	0.08	0.45	0.04	0.55	0.14	0.04
S12	1.30	0.11	0.11	0.17	0.15	0.13
S13	0.28	0.37	0.19	0.61	0.21	0.23
S14	0.25	0.32	0.04	0.47	0.22	0.03
S15	0.97	0.28	0.08	0.21	0.05	0.19
S16	0.24	0.60	0.22	0.07	0.07	0.09
S17	1.01	0.29	0.09	0.38	0.19	0.23
S18	1.17	0.07	0.28	0.11	0.16	0.31
S19	0.86	0.04	0.27	0.39	0.12	0.08
S20	0.65	0.11	0.32	1.28	0.05	0.06
Mean	0.79	0.35	0.18	0.47	0.13	0.13
SD	0.48	0.38	0.15	0.42	0.09	0.09

Seasonal variation (September, 2015 to May, 2017)

In the present study nutrient loading of water sample was studied for three different seasons i.e. monsoon, post-monsoon and pre-monsoon for two consecutive years (September, 2015 to May, 2017). Nnutrient loading has been evaluated with respect to total nitrogen and total phsphorous concentration. The error bar graph has been shown for TN (Fig. 4.73) and TP

(Fig. 4.74) respectively. The higher mean value for TN has been observed in post-monsoon 3.00 tonnes (2015-16); 3.93 tonnes (2016-17) followed by monsoon 2.74 tonnes (2015-16) 3.73 tonnes(2016-17) and pre-monsoon 1.62 tonnes (2015-16); 1.44 tonnes (2016-17) for two consecutive years. The higher values of TN were observed in post-monsoon indicates higher nutrient loading in Bhindawas wetland, which may be due to leaching and surface runoff of nitro-phosphate fertilizers from agricultural land nearby wetland as well as domestic sewage from villages. Similarly the higher mean value for TP has been observed in monsoon 0.79 tonnes (2015-16); 0.47 tonnes (2016-17) followed by post-monsoon 3.50 tonnes (2015-16); 1.35 tonnes (2016-17) and pre-monsoon 1.84 tonnes (2015-16); 1.31 tonnes (2016-17) respectively for two consecutive years. The higher value of TP was observed in monsoon indicates higher nutrient loading in Bhindawas wetland, which may be due to washing out of chemical fertilizers by agricultural fields. The higher values of TP was observed in monsoon indicates higher nutrient loading in Bhindawas wetland, which may be due to washing out of chemical fertilizers by agricultural fields.

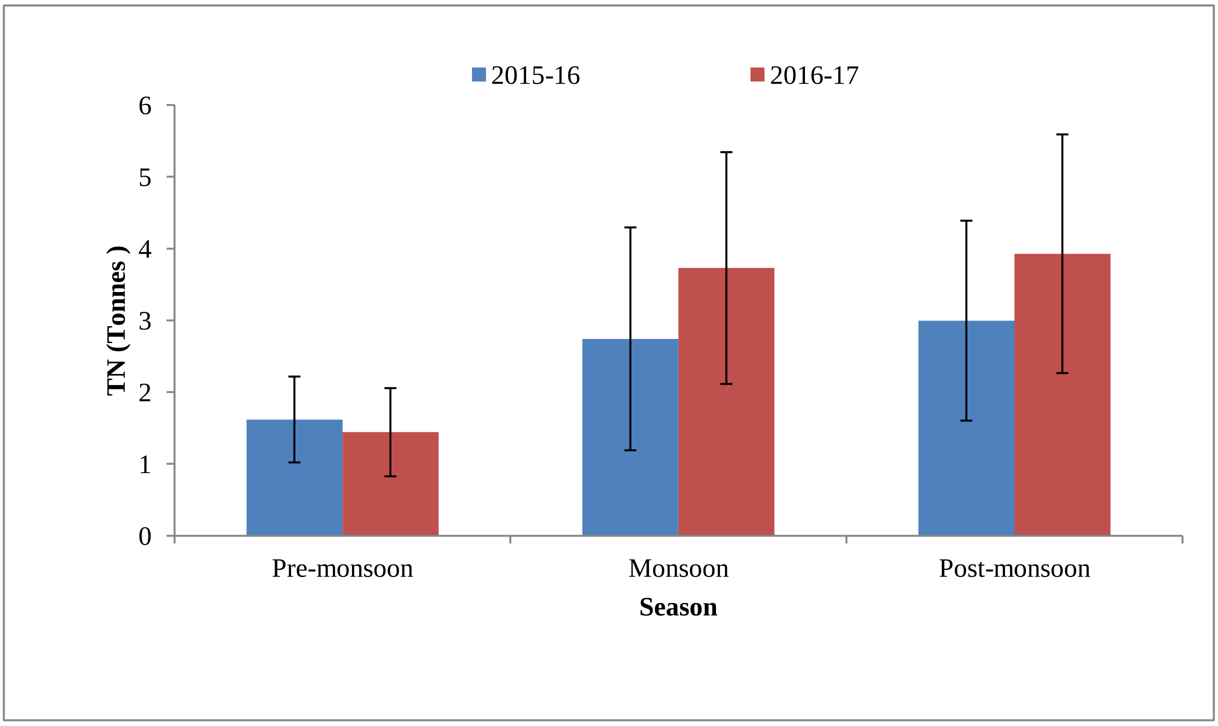

Figure 4.73 Seasonal variations in nutrient loading of Total Nitrogen (tonnes) in Bhindawas wetland during study period (September, 2015 to May, 2017)

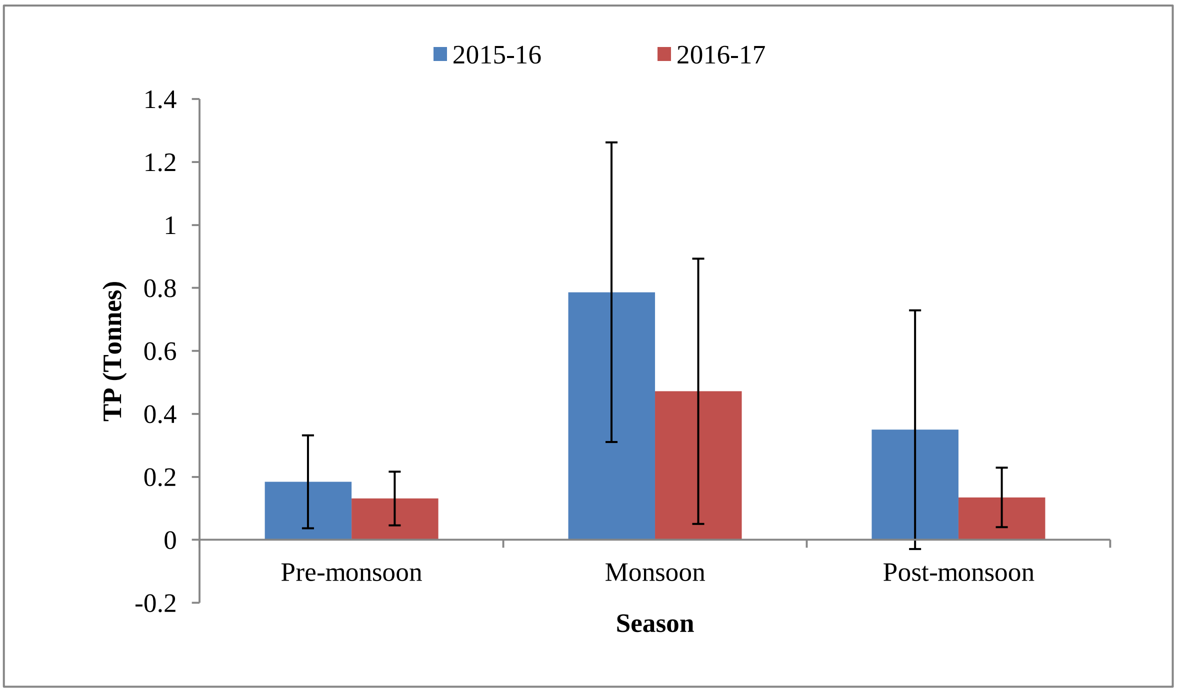

Figure 4.74 Seasonal variations in nutrient loading of Total Phosphorous (tonnes) in Bhindawas wetland during study period (September, 2015 to May, 2017)

The highest nutrient load due to TN and TP is mainly during post-monsoon; monsoon and monsoon season respectively. TN and TP contribute yearly load of 7.36 tonnes and 9.10 tonnes and 1.32 tonnes and 0.74 tonnes for TN

4.5 Trophic Status Index (TSI) of Bhindawas wetland

A widely used method to determine the trophic status of a lake is productivity whereas frequently used mehod is biomass based Carlson trophic status index (CTSI) (Ramesh and Krishnaiah, 2014).

Table 4.42 Classification criteria of water body based on Trophic status index **(Chapra, 1997)**

TSI	Chl -a (µg/l)	TP (µg/l)	SD (m)	Trophic Status
< 30-40	0 - 2.6	0 -12	> 8- 4	Oligotrophic
40 - 50	2.6 - 7.3	12 -24	4- 2	Mesotrophic
50 - 70	7.3 - 56	24 - 96	2 - 0.5	Eutrophic
70 - 100+	56 - 155+	96 - 384+	0.5 - < 0.25	Hypereutrophic

Enrichment of nutrients corresponds to increased productivity and decreased clarity. Carlson derived TSI based on the belief that the main reason for eutrophication of lake is mainly increased nutrient concentrations (P primarily). The range of the index is from approximately zero to 100, although theoretically, index doesn't represent any upper and lower limit. Most of the world's lakes generally have TSI range between 0 to 100 where 10 unit increase (10, 20, 30, etc.), represents a halving of the Secchi depth, a doubling of the TP, and about a 2.8 fold increase in Chl-a. Therefore, a TSI value close to zero indicates an ultra-oligotrophic status of water body, whereas a TSI with value approaching towards 100 represents a hypereutrophic status. Chapra (1997) classified water bodies based based on their trophic state. They are oligotrophic (poorly nourished), mesotrophic (moderately nourished), eutrophic (well nourished) and hypereutrophic (over nourished; Table 4.42).

Table 4.43 Carlson's trophic state index values and classification of lakes .

TSI value	Trophic Status	Attributes
< 30	Oligotrophic	Clear water, oxygen throughout the year in the hypolimnion
30 - 40	Oligotrophic	A lake will still exhibit oligotrophy, but some shallower lakes will become anoxic during the summer
40 - 50	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
50 - 60	Eutrophic	Lower boundary of classical eutrophy: Decreased transparency, warm-water fisheries only
60 - 70	Eutrophic	Dominance of blue-green algae, algal scum probable, extensive macrophyte problems
70 - 80	Eutrophic	Heavy algal blooms possible throughout the summer, often hypereutrophic
> 80	Eutrophic	Algal scum, summer fish kills, few macrophytes

The individual TSI values with respect to Chl-a, and TP represents the hypereutrophic status of wetland in all the three seasons except secchi disc depth, which determine eutrophic (monsoon) to hypereutrophic status (post-monsoon and pre-monsoon) in wetland. The variation in the TSI-Chl a (Table. 4.45) indicates the spatial and temporal variations with highest average values during pre-monsoon (79 and 80) followed by monsoon (72 and 73) and minimum value (59 and 61) was observed during post-monsoon during two successive years of study from September, 2015 to May, 2017. Maximum value during pre-monsoon may be due to increased temperature and excessive plant growth. During monsoon season wetland get excessive nutrients from agricultural runoff and untreated sewage waste from villages surrounding wetland system.

TSI-SD (Table 4.44) shows a slight difference in the average values during all the seasons during the study period. However, the highest mean value was observed during the post-monsoon (76 and 77) and least was observed during monsoon (68 and 69). The high value during post-monsoon may be due to settling of inorganic suspended materials and stabilisation of organic materials by various physicochemical processes and least value may be due to mixing of sediments decreasing clarity. Based on the TSI- SD value in monsoon, Bhindawas wetland falls under eutrophic class and in post-monsoon and pre-monsoon it represents hypereutrophic status.

TSI-TP (Table 4.46) showed seasonal as well spatial variations in average TSI-TP values. Seasonal average TSI-TP value was observed in order of monsoon > pre-monsoon > post-monsoon. Average TSI-TP value during both year of study represented hyper-eutrophic status in all three seasons with average values 123, 105 and 114 respectively as compared to second year of study with average TSI-TP values, 114, 97 and 113 in monsoon, post-monsoon and pre-monsoon respectively.

Table 4.44 Trophic Status Index based on Secchi disk depth (TSI(SD)) during September 2015 to May, 2017.

		2015-16			**2016-17**	
	Monsoon	**Postmonsoon**	**Premonsoon**	**Monsoon**	**Postmonsoon**	**Premonsoon**
Sites	**TSI-SD**	**TSI-SD**	**TSI-SD**	**TSI SD**	**TSI-SD**	**TSI-SD**
Si	55	85	78	52	50	65
So	56	75	71	58	55	76
S1	71	72	72	70	81	71
S2	71	73	76	74	82	74
S3	68	71	76	71	79	73
S4	73	69	78	77	81	71
S5	69	65	81	72	76	67
S6	70	65	74	73	78	71
S7	68	72	76	70	76	69
S8	67	75	73	70	82	71
S9	65	74	74	68	78	68
S10	70	78	76	70	79	70
S11	69	81	76	69	82	69
S12	68	83	78	68	80	70
S13	69	78	76	69	82	72
S14	63	81	75	63	71	74
S15	66	78	74	66	75	70
S16	70	82	69	70	70	73
S17	65	83	69	65	77	69
S18	68	84	69	68	70	74
S19	66	83	75	66	73	72
S20	65	79	74	65	71	78
Mean	68	76	74	69	77	71
SD	2.41	5.98	2.98	3.31	4.32	2.50

The values of the CTSI (Table 4.47) show significant variation during the period of study with a minimum 80.10 and 78.56 recorded in Jan, 2016 and Jan, 2017 respectively and to the mid of the year, the CTSI values increase reaching a maximum of 89.09 and 88.02 respectively in May, 2016 and May, 2017. Increased TSI values in summer may be due to increased temperature influencing the higher photosynthetic activity in phytoplanktonic biomass. The CTSI maximum value was recorded during pre-monsoon (May, 2016 and May, 2017), and if taking into account this value and the trophic state classification established by Carlson **(Carlson, 1977),** the waters of the Bhindawas wetland should be considered as a hypereutrophic water category characterized by very high productivity.

Table 4.45 Trophic Status Index based on Chlorophyll a (TSI(Chl a)) during September, 2015 to May, 2017.

	2015-16			2016-17		
	Monsoon	Postmonsoon	Premonsoon	Monsoon	Postmonsoon	Premonsoon
Sites	**TSI -TChl**	**TSI -TChl**	**TSI -TChl**	**TSI -TChl**	**TSI -TChl**	**TSI –TChl**
Si	81	76	89	84	77	90
So	86	73	83	89	78	81
S1	69	65	75	68	64	82
S2	77	61	84	77	57	86
S3	61	63	86	82	62	86
S4	66	55	84	60	67	85
S5	67	58	88	72	52	91
S6	77	55	94	70	68	89
S7	66	62	84	79	46	85
S8	75	58	51	70	52	74
S9	77	54	77	60	62	77
S10	78	55	72	71	75	62
S11	70	60	80	72	52	82
S12	79	67	80	68	42	80
S13	71	66	73	66	64	70
S14	69	52	83	68	71	84
S15	65	65	87	79	58	88
S16	77	48	88	78	70	75
S17	73	60	82	82	66	81
S18	66	58	77	88	70	82
S19	78	69	69	78	67	72
S20	78	44	58	74	61	70
Mean	72	59	79	73	61	80
SD	5.68	6.41	10.30	7.30	8.87	7.47

According to Carlson (1977), if the value of TSI (Chl- a) is equal to or greater than TSI (SD) it indicates that the growth of phytoplankton dominates the light attenuation in the water body. Whereas if value of TSI (Chl- a) is lower than TSI (SD), it represents that the suspended particles (none algal) are responsible for the light attenuation. When TSI (Chl a) is equal to or greater than TSI (TP) or TSI (TN) that means that the phosphorus or nitrogen is limiting the algal growth . The values of the TSI (Chl- a) (Fig. 4.75) were largely higher than those of the TSI (SD) in monsoon and pre-monsoon, while during the post-monsoon, the values of the TSI (Chl- a) (Fig.4.75) was observed significantly lower than those of the TSI (SD).This suggests that the light attenuation and overall water turbidity of the Bhindawas wetland are mainly due to large biomass of phytoplankton suspended in the waters and independent on inorganic and organic impurities. Indeed, the value of TSI (TP) is significantly higher if compared to those recorded for the TSI (Chl a) and TSI (SD). This indicates that both Phosphorus is in excess in the wetland water and do not constitute a limiting factor for the growth of phytoplankton. Based on these observations, the amount of phytoplankton biomass may be greater than studied and there may be other factor like higher zooplankton grazing that limit the algal growth in wate

Table 4.46 Trophic Status Index based on Total Phosphorous (TSI (TP)) during September, 2015 to May, 2017.

		2015-16			2016-17	
	Monsoon	Postmonsoon	Premonsoon	Monsoon	Postmonsoon	Premonsoon
Sites	**TSI-TP**	**TSI-TP**	**TSI-TP**	**TSI-TP**	**TSI-TP**	**TSI-TP**
Si	105	115	105	125	96	116
So	133	111	111	137	91	114
S1	130	102	110	106	86	111
S2	126	130	97	137	81	96
S3	126	105	102	110	108	101
S4	126	101	104	111	114	102
S5	133	106	115	118	91	112
S6	109	115	109	94	91	108
S7	112	104	126	102	81	124
S8	128	105	111	115	99	109
S9	126	102	125	128	94	124
S10	138	101	121	127	96	120
S11	91	111	96	120	99	94
S12	134	91	115	104	101	113
S13	112	109	123	123	105	120
S14	111	115	96	121	109	96
S15	132	108	123	109	86	121
S16	115	119	116	96	94	114
S17	132	109	125	118	109	123
S18	137	94	140	102	111	137
S19	128	91	119	117	106	116
S20	119	94	112	129	86	111
Mean	123	105	114	114	97	113
SD	11.70	9.69	11.57	11.60	10.26	11.17

Table 4.47 Seasonal variations in Carlson Trophic Status Index (TSI) of Bhindawas Wetland (September, 2015 to May, 2017)

	2015-16			2016-17		
Sites	**Monsoon**	**Postmonsoon**	**Premonsoon**	**Monsoon**	**Postmonsoon**	**Premonsoon**
Si	80	92	91	87	75	90
So	92	86	88	95	75	90
S1	90	80	86	82	77	88
S2	91	88	86	96	73	85
S3	85	80	88	88	83	87
S4	88	75	89	83	87	86
S5	90	77	95	87	73	90
S6	85	78	92	79	79	89
S7	82	79	95	84	68	93
S8	90	79	78	85	78	85
S9	89	77	92	85	78	90
S10	95	78	90	89	84	84
S11	77	84	84	87	78	82
S12	93	80	91	80	74	88
S13	84	84	91	86	84	88
S14	81	83	84	84	84	85
S15	87	84	95	85	73	93
S16	87	83	91	81	78	87
S17	90	84	92	88	84	91
S18	90	78	95	86	84	98
S19	91	81	88	87	82	87
S20	87	72	81	89	73	86
Mean	87.74	80.10	89.09	85.57	78.56	88.02
SD	4.34	3.68	4.71	3.88	5.20	3.64

Table 4.48 Mean values of Total Chl a, Secchi disk depth and Total Phosphorous in Bhindawas Wetland.

Season	**Total Chl a (mg/l)**		**Secchi Disk Depth (m)**		**Total Phosphorous (mg/l)**	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
September	72±5.68	73±7.30	68±2.41	69±3.31	123±11.90	114±11.60
January	59±6.41	61±8.87	76±5.98	77±4.32	105±9.70	97±10.26
May	79±10.3	80±7.47	74±2.98	71±2.50	114±11.57	113±11.17

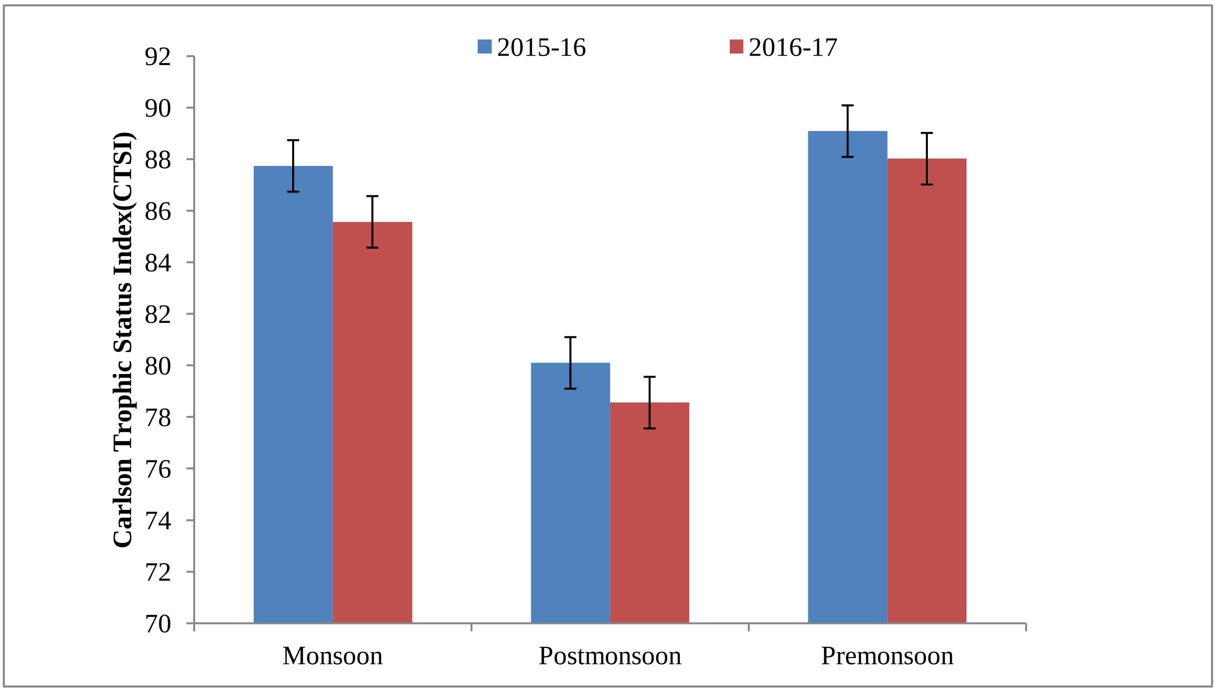

Figure 4.75 Seasonal variations in Carlson Trophic Status Index of Bhindawas Wetland during September, 2015 to May, 2017

4.6 Productivity in Wetland

Productivity is defined as the rate of production of organic food by producers, per unit time. Gross primary productivity and net primary productivity are two major types of productivity which play major role during photosynthetic process (Oglesby, 1977). In an aquatic ecosystem, the main source of energy input is primary productivity (Sharma and Giri, 2018). A large number of meteorological factors like light intensity, photoperiod, rainfall, wind velocity, etc., and water level, water transparency, water temperature, nutrient concentration (inflow and outflow) have great impact on the rate of primary productivity in lacustrine and flowing waters (Jhingran and Pathak, 1988). Primary productivity of Bhindawas wetland was studied during the study period from September, 2015 to May, 2017. The study was carried out by light and dark bottle method (Gaarder and Gran, 1927). The seasonal variation of gross primary productivity, net primary productivity and community respiration of Bhindawas wetland is given in Table 4.49.

Seasonally, the minimum GPP was recorded in monsoon i.e. 0.111 mgC $m^{-3}h^{-1}$ and maximum value, 0.164 mgC $m^{-3}h^{-1}$ was recorded during pre- monsoon. An intermediate value, 0.141 mgC $m^{-3}h^{-1}$ of GPP was observed during post-monsoon. Similar trend in NPP values was observed in study during first year (September, 2015 to May, 2016) with values 0.090 mgC $m^{-3}h^{-1}$; 0.124mgC $m^{-3}h^{-1}$; 0.132 mgC $m^{-3}h^{-1}$ in monsoon, post-monsoon and pre-monsoon respectively. Whereas, the trend for CR values was observed to be pre-monsoon (0.031 mgC $m^{-3}h^{-1}$) > monsoon (0.021 mgC $m^{-3}h^{-1}$) > post -monsoon (0.017 mgC $m^{-3}h^{-1}$).

Similarly, for the second year, the maximum values of GPP and NPP (0.154 mgC $m^{-3}h^{-1}$ and 0.124 mgC $m^{-3}h^{-1}$) was recorded during pre-monsoon followed by post- monsoon (0.134 mgC $m^{-3}h^{-1}$ and 0.117 mgC $m^{-3}h^{-1}$) and monsoon (0.099 mgC $m^{-3}h^{-1}$ and 0.079 mgC $m^{-3}h^{-1}$). Also similar trend in CR values was found with sequence pre-monsoon > monsoon > post-monsoon with values 0.030 mgC $m^{-3}h^{-1}$, 0.020 mgC $m^{-3}h^{-1}$and 0.016 mgC $m^{-3}h^{-1}$ respectively.

A well defined seasonal variation was observed during the research study.On comparision of seasonal variations, an increasing trend in primary productivity was observed from monsoon to post-monsoon and then pre-monsoon. The minimum value of NPP was observed during monsoon and maximum value was recorded during post-monsoon (Prasad et al., 1963; Nasar et al., 1975; Kaul, 1977 and Shukla and Pawar, 2000) during each year.

The higher values of GPP and NPP during pre-monsoon may be due to penetration of maximum sunlight into water body upto euphotic zone which speed up higher photosynthetic rate and productivity. Whereas in monsoon, decreased concentration of GPP and NPP might be due to higher amount of suspended particles and dissolved solids which make water turbid and restricts the light penetration into water and thereby affect the photosynthetic activity (Ahmad and Singh, 1987). Also cloudy weather, low transparency and higher water current caused low productivity. An intermediate values for GPP and NPP during post monsoon is due to limited sunlight and low water temperature.

Table. 4.49 Primary productivity (mgC $m^{-3}h^{-1}$) values of Bhindawas wetland.

		(2015-16)			**(2016-17)**	
Parameter	**Monsoon**	**Post-monsoon**	**Pre-monsoon**	**Monsoon**	**Post-monsoon**	**Pre-monsoon**
GPP	0.111	0.141	0.164	0.099	0.134	0.154
NPP	0.090	0.124	0.132	0.079	0.117	0.124
CR	0.021	0.017	0.031	0.020	0.016	0.030
% R	18.855	12.234	18.993	20.152	12.079	19.512
NPP/GPP	0.808	0.878	0.808	0.798	0.879	0.805
NPP/CR	4.286	7.174	4.253	3.962	7.279	4.125

Where, GPP- Gross primary productivity, NPP - Net primary productivity, CR- Community respiration in mgC $m^{-3}h^{-1}$

The higher community respiration (CR) value in pre-monsoon may be due to increased microbial growth due to higher temperature which utilize more and more oxygen for various metabolic activities. Whereas, least value during winter determines less microbial activity with low water temperature and reduced sunlight which lesser photosynthetic rate (Datta et al, 1984). Ahmed (1990) and Sharma (1993) stated that NPP/CR value > 1, water is polluted. In case of Bhindawas wetland, NPP to CR ratio exceeds more than 1, which determines that wetland has been highly polluted. According to Ketcham et al. (1958) in healthy water body, ratio of NPP to GPP should approach to unity, when community respiration (CR) falls between 5 to 10 %. In present study NPP/GPP values are < 1, indicating that Bhindawas wetland is tending toward unhealthy status and need to be preserved.

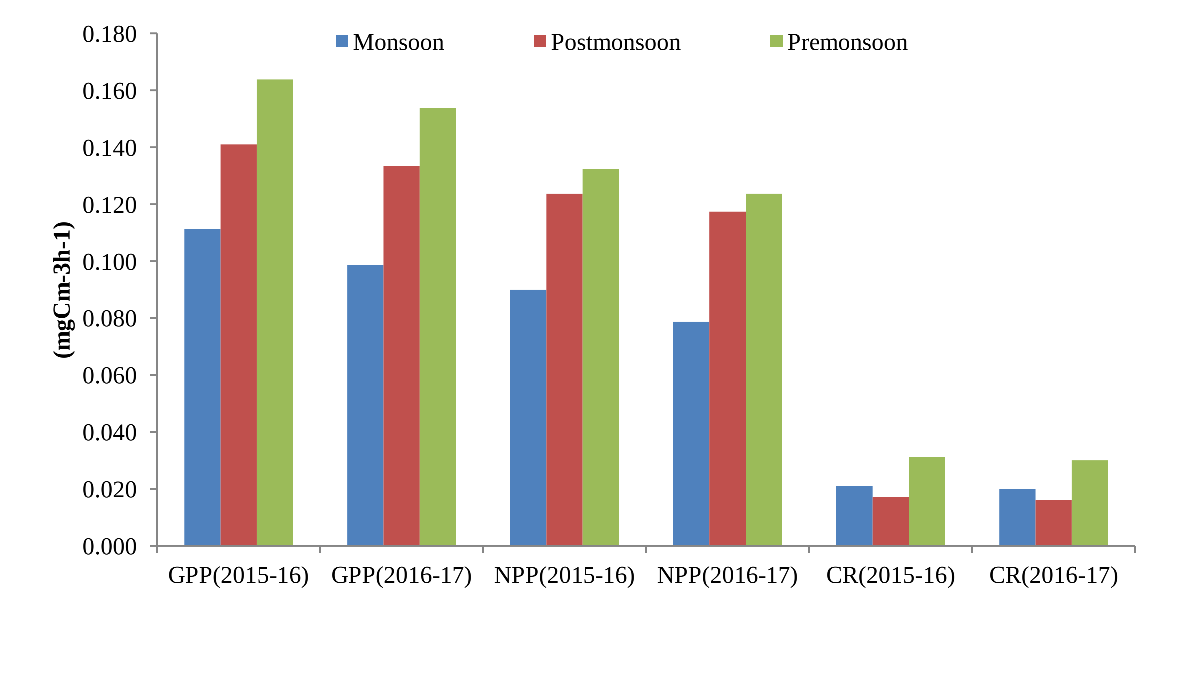

Figure 4.76 Seasonal variations in Primary Productivity (GPP, NPP & CR) (mgc m^{-3} h^{-1}) of Bhindawas wetland during September, 2015-May, 2017

The average GPP of Bhindawas wetland was observed to be 0.139 mg Cm3/h and 0.131 mgC m3/h during first and second year of study. Also wetland was observed with increased nutrients content and with low transparency. The low value of primary productivity can also indicated dominating role of the macrophytes and their associated ephiphytes uptake and accumulate nutrients in their tissue which further make unavailable them for the phytoplankton growth and reduced their biomass (Kaul and Trishal, 1991).

4.7 Nutrient Cycling in Wetland

Continuous exchange of major nutrients in wetland takes place between various compartments of water, soil and vegetation. Also importance of storage compartment to water quality depends on both rate of entrance and duration of retention of nutrients in that compartment. Due to shallow depth, wetlands differ from other water ecosystems, which help rooted vegetation to become established as compared to deep aquatic ecosystems. Vegetation compartment is complex structure of emergent and submerged plants in water, So most emergent plants (macrophytes) possess complex root system along with high root-shoot ratio .Maximum transfer of nutrients take place by emergent plants as compared to submerged plants. During spring and summer, wetland plants uptake inorganic nitrogen and phosphorus in the forms of nitrate, ammonia, and phosphate through their roots and/or foliage and convert them into organic compounds for their growth. However, this process helps in

Table . 4.50 Average values of nutrient concentration in various compartments viz. water, sediment and vegetation in Bhindawas Wetland during September, 2015 – May, 2017)

			Water			
Parameter	**Monsoon**	**Postmonsoon**	**Premonsoon**	**Monsoon**	**Postmonsoon**	**Premonsoon**
	(Sept, 2015)	**(Jan, 2016)**	**(May, 2016)**	**(Sept., 2016)**	**(Jan, 2017)**	**(May, 2017)**
TP(mg/l)	5	1.4	3.4	2.8	0.79	2.5
TN(mg/l)	18.4	13.18	28.3	22.21	19.1	28.5
NH_3(mg/l)	0.5	0.41	0.7	0.52	0.25	0.96
TKN(mg/l)	3.4	5.18	12.7	5.7	6.9	11.7
TOC(mg/l)	17	25	43	28.6	37.4	61.7
			Sediment			
Parameter	**Monsoon**	**Postmonsoon**	**Premonsoon**	**Monsoon**	**Postmonsoon**	**Premonsoon**
	(Sept, 2015)	**(Jan, 2016)**	**(May, 2016)**	**(Sept., 2016)**	**(Jan, 2017)**	**(May, 2017)**
AP (mg/kg)	0.06	0.07	0.03	0.09	0.1	0.05
TP (mg/kg)	0.16	0.3	0.15	0.39	0.41	0.32
TKN(mg/kg)	0.03	0.07	0.02	0.06	0.08	0.04
TOC(%)	9.67	8.31	7.05	10.9	8.98	5.69
OM(%)	16.48	14.32	12.15	18.79	15.48	9.82
			Vegetation			
Parameter	**Monsoon**	**Postmonsoon**	**Premonsoon**	**Monsoon**	**Postmonsoon**	**Premonsoon**
	(Sept, 2015)	**(Jan, 2016)**	**(May, 2016)**	**(Sept, 2016)**	**(Jan, 2017)**	**(May, 2017)**
Salvinia						
TP(mg/kg)	6.65	10.64	5.94	6.86	10.92	6.52
TN(mg/kg)	26.85	27.92	26.25	27.62	27.95	26.18
Eicchornia						
TP(mg/kg)	7.15	11.44	6.63	7.64	11.82	7.03
TN(mg/kg)	42.54	43.63	42.32	43.12	43.64	42.12
Vallisineria						
TP(mg/kg)	3.12	6.24	2.49	3.53	6.61	3.02
TN(mg/kg)	17.40	18.32	17.08	17.93	18.07	17.16

temporary storage of the nutrients. With passage of time plants grow old and their fallen leaves decompose and released assimilated nutrients back into wetland system during winter.

Dissolved inorganic form of N and P are assimilated by vegetation and microorganisms and transformed into organic compounds. Two floating (*Eicchornia* and *Salvinia*) and one submerged (*Vallisineria*) macrophyte were analysed to determine seasonal variations in nutrient and heavy metal concentration in present study area.

Seasonal change in wetland functions was observed in Bhindawas wetland. During the growing season, in the summer and early fall, emergent and submerged aquatic plants alongwith some algae uptake large concentrations of nutrients from water and sediment and retaining them as plant material (Pinay et al., 1993; Rotkin-Ellman and M. et al., 2004; Silvan et al., 2004; Hefting, et al., 2005) doing so they convert the wetland into a "nutrient sink,". By holding nutrients in plant tissue, during the summer, wetlands reduce the contamination of downstream. In most cases nutrients are recycled within the wetland. Emergent and submerged plants act "nutrients pumps" as they transport nutrients from the sediment to the water column whereas algae and floating plants uptake nutrients from the water and returned them back again in the bottom sediment after they died and serve as "nutrient dumps". The release of nitrogen gas to the atmosphere by denitrification, ammonia volatilization or possibly nitrification of ammonia also causes nutrients to be lost bh various biochemical processes.

The representative macrophytes in three different seasons show similar trends in removing phosphate and nitrate from water and sediments. Seasonal analysis revealed that higher NO_3-N and PO_4-P concentrations removal was observed in pre-monsoon whereas N and P higher content in plant tissues were noted in post-monsoon followed by monsoon and pre-monsoon. Occurence of nutrients in macrophytes of Bhindawas wetland was in order of *Eichhornia crassipes* > *Salvinia molesta* > *Vallisneria spiralis.* Also the rate of accumulation of nutrients showed similar trends among all macrophytes in different seasons in decreasing order of post-monsoon > monsoon > pre-monsoon. The present study revealed that the aquatic macrophytes act as a nutrient sink in aquatic ecosystem and help in reducing excess nutrients in wetland.

4.8 Statistical Analysis

4.8.1 Statistical Interpretation for Water

4.8.1.1 Principal Component Analysis

Principal component analysis was performed to determine major factors and various water quality parameters that have significant influence on water quality of wetland. Any factor with an Eigen value greater than 1 is considered significant. The factor loadings are classified as "strong", "moderate" and "weak" corresponding to the absolute loading values of >0.75, 0.75-0.5 and 0.50-0.30, respectively. Principal component analysis was applied on the available data for monsoon, post-monsoon and pre-monsoon for two consecutive years after removing all the outliers.

Monsoon (September, 2015)

The result for monsoon first year is shown in Table 4.51, explaining 7 components. The extracted 7 components make interpretation easier and fundamental significance of extracted components to the water quality status of the wetland. The result of component matrix

Table 4.51 Principal component analysis (Monsoon, September, 2015)

Parameters	Component						
	1	2	3	4	5	6	7
pH	-0.72	-0.59	-0.08	-0.18	0.13	0.01	0.10
TSS	0.69	-0.56	-0.04	0.01	-0.13	-0.17	-0.15
DO	-0.69	-0.37	0.02	0.05	0.31	0.36	0.18
ORP	-0.39	0.48	0.03	0.49	0.22	-0.37	0.14
COD	0.69	0.32	-0.13	-0.15	0.05	-0.15	0.24
Na^+	0.31	-0.56	0.48	-0.01	0.31	-0.19	0.19
K^+	0.65	0.21	0.56	0.14	-0.07	0.13	0.09
Ca^{2+}	0.55	0.06	0.43	0.53	0.08	0.08	0.10
Mg^{2+}	0.53	-0.12	-0.20	0.67	0.17	-0.15	-0.11
Cl^-	-0.02	-0.50	0.12	-0.30	-0.13	-0.18	0.25
SO_4^{2-}	-0.01	-0.06	0.07	0.32	0.39	0.76	0.21
TP	0.03	0.70	0.28	0.02	-0.33	0.21	-0.11
TN	-0.30	0.73	-0.07	-0.32	0.04	0.00	0.39
NH_3	0.58	0.01	0.24	-0.47	-0.26	0.40	-0.10
Cr	-0.65	-0.02	0.62	0.14	-0.18	-0.20	0.15
Cu	0.36	0.12	-0.82	0.04	0.20	0.13	-0.08
Fe	-0.18	0.57	0.14	-0.31	0.60	-0.19	-0.11
Ni	-0.67	0.03	-0.18	0.35	-0.28	0.04	-0.28
Pb	-0.58	0.03	0.29	0.14	-0.17	0.11	-0.41
Zn	0.10	0.01	0.39	-0.30	0.58	-0.04	-0.57
Eigenvalues	5.01	3.13	2.31	1.91	1.54	1.33	1.10
CV%	25.07	40.70	52.24	61.78	69.49	76.13	81.65

revealed further, the percentages of the total variances of the 7 extracted components when added account for 81.65% as cumulative variance. The calculated loadings and eigenvalues are shown in Table 4.51. The first component has the highest eigenvector sum (5.01) and represents the most important source of variation in the data. The last factor is the least important process contributing to the data variation. The Component-1 explains the existence of positive correlation between TSS, COD, potassium, calcium, magnesium, and NH_3 and characterized by high loading of minerals.Major source for these ions are mainly natural origin with weathering of soil, dissolved salts from inlet. Component-2 shows the existence of positive correlation between Fe, TP and TN and is associated with high nutrient loading alongwith iron which influences water quality in wetland from non point sources e.g., agricultural run off from fields. Component-3 shows the existence of positive correlation between K and Cr respectively. Component-4 highlights positive correlation between calcium and magnesium which depicts the hydrogeochemistry of wetland water with ionic salts.And component 5,6 and 7 have moderate loading with Fe, SO_4^{2-} and zinc respectively. Fertilizer pollution from agricultural fields are mainly responsible for increased risk of eutrophication from anthropogenic source.

Monsoon (September, 2016)

The result for monsoon second year is shown in Table 4.52, explaining 9 components. The extracted 9 components make interpretation easier and fundamental significance of extracted components to the water quality status of the lake. The result of component matrix revealed further, the percentages of the total variances of the 9 extracted components when added account for 85.10% as cumulative variance.

The calculated loadings and eigenvalues are shown in Table 4.52. Component - 1 has the highest eigenvector sum of 3.41, and represents maximum variation in the data. The nine different components explain the existence of positive correlation between various parameters. Component - 1 has moderate loading of heavy metals,Cr, Pb, Ni alongwith COD and ORP. Component - 2 is mainly associated with a number of variable species viz. heavy metals, Zn, Cu; pH, TP, NH_3 and ORP. The major source of heavy metal pollution may be the run off from fields where a variety of pesticides are used for crop productin. Component - 3 is majorly influenced by pH and DO. In component - 4, total phosphorous, minerals (Na^+, K^+, Cl^-), suspended solids, heavy metal (Cd) represents weak loading whereas Pb and TP are

Table 4.52 Principal component analysis (Monsoon, September, 2016)

Parameters	Component								
	1	2	3	4	5	6	7	8	9
pH	0.35	0.50	0.69	0.00	0.06	0.11	-0.08	0.19	0.06
TSS	-0.26	-0.08	-0.47	0.45	-0.13	0.03	0.27	-0.21	-0.09
DO	-0.46	-0.22	0.55	0.24	0.10	-0.32	0.20	0.17	0.32
ORP	0.58	0.58	-0.02	-0.09	-0.05	-0.33	0.14	-0.04	0.09
COD	0.56	-0.23	-0.02	0.26	-0.19	0.49	0-.06	0.05	-0.29
Na^+	0.22	-0.15	-0.39	0.35	-0.42	0.18	0.23	0.52	0.23
K^+	-0.02	-0.36	0.15	0.47	0.25	0.48	0.21	-0.38	0.16
Ca_{2+}	0.13	0.01	0.05	0.49	0.61	0.07	-0.20	-0.05	-0.01
Mg^{2+}	0.03	-0.11	0.27	0.07	-0.51	0.32	-0.48	-0.01	0.47
Cl^-	-0.46	0.10	0.30	0.39	-0.04	0-.05	-0.41	0.13	-0.52
SO_4^{2-}	-0.22	-0.34	0.11	-0.23	0.60	0.22	-0.17	0.46	0.08
TP	-0.48	0.54	-0.03	0.09	-0.04	0.17	0.49	0.27	0.10
TN	-0.18	0.22	0.19	0.64	-0.27	-0.27	-0.11	0.41	-0.15
NH_3	-.022	0.69	0.13	0.17	-0.06	0.06	-0.24	-0.41	0.22
Cd	0.37	-0.25	0.07	0.46	0.16	-0.62	0.11	-0.17	0.14
Cr	0.70	0.42	0.08	0.02	0.10	0.06	-0.17	0.09	0.12
Cu	-0.51	0.50	0.31	0.20	0.09	0.33	0.33	-0.13	0-.03
Fe	0.03	0.32	-0.62	0.15	0.49	0.06	-0.12	0.29	0.22
Ni	0.61	0.20	0.40	-0.21	0.09	0.16	0.47	0.09	-0.24
Pb	0.68	-0.19	0.07	0.53	0.06	0.03	0.05	-0.02	-0.01
Zn	0.00	0.65	-0.58	0.15	0.08	0.05	-0.20	-0.05	-0.09
Eigenvalues	3.41	2.89	2.39	2.21	1.68	1.53	1.44	1.31	1.02
CV%	16.23	29.99	41.36	51.88	59.89	67.15	74.02	80.25	85.10

associated with moderate loading and in component - 5, Ca^{2+}, sulphate, Fe predominates indicating moderate loading causing pollution due to point as well as nonpoint sources. Components 6, 7, 8 and 9, showed least variation among its data set.

Post-monsoon (January, 2016)

The result for post-monsoon first year is shown in Table 4.53, explaining 8 components. The extracted 8 components make interpretation easier and fundamental significance of extracted components to the water quality status of the lake. The result of component matrix revealed further, the percentages of the total variances of the 8 extracted components when added account for 86.33% as cumulative variance. The calculated loadings and eigenvalues are shown in Table 4.53. The component- 1 has the highest eigenvector sum of 5.21, and represents maximum variation in the data. The eight different components explain the existence of positive correlation between various parameters. Component- 1 represents strong relationship among ORP, Na^+ and Ca^{2+} and Mg^{2+}, SO_4^{2-} and Cr indicating hydrogeochemistry of wetland water with moderate loading of cations and anion. pH, Cl^-, TN are major contributing factor in component - 2, with moderate loading. Component - 3 determines the influence of pH, DO, K^+ and Zn; and component - 4 indicates moderate loading due to TP and TN. Component – 5 and 6 represents mineral loading (K^+, Mg^{2+}); nutrient and chemical loading (TP, Fe and Zn) whereas components – 7 and 8, are influenced by physical (TSS) and chemical variables (COD, TN).

Table 4.53 Principal component analysis (Post-monsoon, Jan., 2016)

Parameters	Component							
	1	2	3	4	5	6	7	8
pH	0.16	0.58	0.46	0.32	-0.11	-0.24	-0.01	-0.26
TSS	-0.19	-0.10	-0.44	0.25	0.01	-0.15	0.67	-0.35
DO	-0.64	0.00	0.42	0.36	0.02	-0.35	0.24	0.04
ORP	0.71	0.24	0.04	-0.04	0.02	-0.15	0.23	0.20
COD	-0.40	0.38	0-.26	-0.24	-0.42	-0.06	-0.04	0.49
Na^+	0.84	-0.19	0.25	0.12	-0.23	0.08	0.01	0.07
K^+	-0.12	-0.30	0.49	-0.20	0.60	0.20	0.01	0.06
Ca_{2+}	0.77	0.11	-0.19	0.37	-0.12	0.19	-0.23	-0.06
Mg^{2+}	0.51	0.18	0.30	-0.42	0.46	-0.12	-0.04	-0.32
Cl^-	0.16	0.61	-0.26	0.04	0.38	-0.47	-0.18	0.24
SO_4^{2-}	0.51	0.28	0.00	-0.35	0.26	0.37	0.21	0.32
TP	0.01	-0.27	-0.24	0.68	0.17	0.42	-0.18	0.17
TN	-0.28	0.53	0.18	0.46	0.23	0.15	0.37	0.40
NH_3	0.23	-0.76	0.27	-0.13	0.09	0.04	0.31	0.25
Cd	-0.80	0.17	0.20	0.05	0.27	-0.10	-0.29	0.02
Cr	0.70	0.46	-0.10	-0.33	-0.22	0.02	0.20	-0.07
Cu	0.31	-0.18	-0.75	0.21	0.38	-0.02	-0.06	-0.07
Fe	-0.54	0.26	0.10	-0.52	-0.15	0.41	-0.02	-0.12
Ni	-0.72	0.02	-0.36	-0.24	-0.14	0.26	0.13	-0.08
Pb	0.20	-0.61	0.26	-0.03	-0.36	-0.41	-0.11	0.23
Zn	0.11	0.31	0.53	0.45	-0.23	0.47	0.00	-0.15
Eigenvalues	5.21	2.93	2.41	2.21	1.62	1.53	1.11	1.10
CV%	24.81	38.75	50.24	60.79	68.50	75.78	81.09	86.33

Post-monsoon (January, 2017)

The result for post-monsoon second year is shown in Table 4.54, explaining 8 components. The extracted 8 components make interpretation easier and fundamental significance of extracted components to the water quality status of the lake. The result of component matrix revealed further, the percentages of the total variances of the 8 extracted components when added account for 83% as cumulative variance. The calculated loadings and eigenvalues are shown in Table 4.54. The first component has the highest eigenvector sum of 4.32, and represents maximum variation in the data. The eight different components explain the existence of positive correlation between various parameters. First five components represents major information. Component – 1 represents positive correlation between DO, Na^+, Cl^-, Cd, Fe and Ni and component – 2 determine significant interaction among pH, TSS, ORP and Cu. Component -3 determines the positive correlation between Na^+, Ca^{2+}, TP and TN.

Table 4.54 Principal component analysis (Post-monsoon, Jan., 2017)

Parameters	Component							
	1	2	3	4	5	6	7	8
pH	-0.40	0.69	-0.22	-0.01	0.27	-0.16	0.02	0.28
TSS	0.02	0.57	0.06	-0.54	-0.04	-0.15	0.10	0.04
DO	0.75	0.23	-0.07	0.42	0.05	-0.21	0.20	-0.21
ORP	-0.17	0.77	0.20	0.18	0.27	-0.03	0.11	0.33
COD	-0.19	-0.41	-0.37	0.03	0.31	0.28	0.52	0-.29
Na^+	0.58	0.15	0.66	-0.18	-0.06	0.18	0.15	-0.25
K^+	-0.67	-0.43	-0.45	-0.08	0.08	0.18	-0.18	-0.07
Ca_{2+}	-0.33	0.18	0.51	-0.08	0.13	-0.06	0.52	-0.02
Mg^{2+}	0.25	0.22	-0.30	0.78	0.17	0.17	-0.03	-0.09
Cl^-	0.48	-0.62	0.07	0.07	0.45	-0.21	0.13	-0.04
SO_4^{2-}	-0.41	-0.19	0.11	0.43	-0.08	-0.52	0.26	0.19
TP	0.03	-0.09	0.52	0.39	-0.24	-0.15	-0.49	-0.08
TN	0.12	-0.03	0.49	0.19	0.33	0.55	-0.28	0.16
NH_3	-0.63	0.03	0.24	-0.33	0.39	0.02	-0.21	-0.38
Cd	0.47	0.33	-0.51	-0.21	-0.06	0.13	-0.25	0.21
Cr	-0.35	-0.52	0.21	0.02	0.45	-0.09	-0.27	0.26
Cu	-0.44	0.52	-0.05	0.23	0.42	-0.13	-0.16	-0.25
Fe	0.68	-0.05	0.01	-0.14	0.44	0.30	0.16	0.36
Ni	0.81	-0.05	-0.13	-0.19	0.23	-0.26	-0.23	-0.13
Pb	-0.30	0.37	0.02	0.24	-0.27	0.64	0.11	-0.09
Zn	-0.15	-0.63	0.13	0.06	-0.22	0.12	0.18	0.39
Eigenvalues	4.32	3.54	2.15	1.85	1.57	1.53	1.38	1.10
CV%	20.58	37.42	47.64	56.44	63.93	71.19	77.76	83.00

Pre-monsoon (May, 2016)

The result for pre-monsoon first year is shown in Table 4.55, explaining 8 components. The extracted 8 components make interpretation easier and fundamental significance of extracted components to the water quality status of the lake. The result of component matrix revealed further, the percentages of the total variances of the 8 extracted components when added account for 83.48% as cumulative variance. The calculated loadings and eigenvalues are shown in Table 4.55. The first component has the highest eigenvector sum of 4.21, and represents maximum variation in the data. The eight different components explain the existence of positive correlation between various parameters. First three components represents maximum information with respect to different parameters, component – 1 with positive correlation between ORP, pH and DO; component – 2 represents metal influence due to Ni and Pb. Component -3 indicates significant correlation betweeen TSS, magnesium and Cr. Component -4 represented Na^+ ions loading

Table 4.55 Principal component analysis (Pre-monsoon, May, 2016)

Parameters	Component							
	1	2	3	4	5	6	7	8
pH	0.77	0.33	0.20	-0.04	0.21	0.04	0.08	0.17
TSS	0.14	-0.01	0.60	-0.10	0.02	0.55	0.36	-0.18
DO	0.75	0.26	0.16	0.03	-0.12	0.24	-0.28	-0.26
ORP	0.80	0.26	0.17	-0.19	0.19	-0.22	-0.17	0.01
COD	0.19	-0.60	-0.37	0.11	-0.36	-0.01	0.20	0.33
Na^+	-0.08	0.20	0.13	0.74	0.31	0.18	-0.27	0.19
K^+	0.43	-0.20	0.41	0.03	-0.33	-0.08	0.30	-0.09
Ca_{2+}	-0.02	0.38	-0.55	0.21	-0.24	0.28	0.24	0.41
Mg^{2+}	-0.10	-0.46	0.52	-0.44	0.28	-0.15	0.09	0.19
Cl^-	-0.70	0.24	-0.08	-0.01	-0.30	0.34	-0.25	-0.16
SO_4^{2-}	0.27	-0.62	-0.10	-0.04	0.25	-0.27	-0.26	0.24
TP	-0.71	-0.02	0.48	0.13	0.04	0.09	0.05	0.36
TN	0.08	0.09	0.34	-0.54	-0.66	0.05	-0.01	0.21
NH_3	0.07	-0.59	0.12	0.16	0.39	0.47	0.11	0.18
Cd	-0.12	0.01	-0.05	0.43	0.04	-0.48	0.58	-0.29
Cr	-0.12	0.15	0.73	0.50	0.00	-0.03	0.11	0.02
Cu	-0.41	-0.16	0.39	0.38	-0.32	-0.24	-0.40	-0.07
Fe	-0.81	0.03	0.13	-0.33	0.14	-0.23	-0.11	-0.06
Ni	0.20	0.76	0.12	0.32	-0.04	-0.30	0.11	0.31
Pb	-0.27	0.62	0.18	-0.55	0.16	-0.11	0.10	0.29
Zn	-0.34	0.37	-0.29	-0.24	0.50	0.14	0.18	-0.17
Eigenvalues	4.21	2.99	2.56	2.32	1.71	1.43	1.23	1.08
CV%	20.05	34.30	46.47	57.51	65.67	72.47	78.34	83.48

Pre-monsoon (May, 2017)

The result for pre-monsoon second year is shown in Table 4.56, explaining 8 components. The extracted 8 components make interpretation easier and fundamental significance of extracted components to the water quality status of the lake. The result of component matrix revealed further, the percentages of the total variances of the 8 extracted components when added account for 80.95% as cumulative variance. The calculated loadings and eigenvalues are shown in Table 4.56. The first component has the highest eigenvector sum of 3.75, and represents maximum variation in the data. The eight different components explain the existence of positive correlation between various parameters . Component -1 is characterized by significant loading of SO_4^{2-} and $NH_{3.}$ Component -2 is influenced by heavy metal loading and component -3 determines high magnesium ions concentration.

Table 4.56 Principal component analysis (Pre-monsoon, May, 2017)

Parameters	Component							
	1	2	3	4	5	6	7	8
pH	-0.45	-0.13	-0.49	0.33	0.25	0.35	0.21	0.27
TSS	0.44	-0.39	0.37	0.55	0.01	-0.12	-0.18	0.33
DO	0.61	0.31	0.27	-0.17	-0.09	-0.31	0.33	0.14
ORP	0.07	-0.80	-0.01	0.16	0.20	-0.10	0.38	0.02
COD	-0.17	0.38	0.16	0.43	0.54	-0.17	0.22	-0.02
Na^+	0.32	-0.07	-0.35	0.14	0.66	-0.12	0.28	0.26
K^+	0.52	0.60	0.25	0.03	-0.09	0.36	-0.04	0.08
Ca_{2+}	0.43	-0.61	0.28	0.14	0.33	0.01	-0.32	-0.01
Mg^{2+}	-0.58	-0.14	0.60	0.16	-0.21	-0.12	0.20	0.12
Cl^-	-0.56	-0.45	0.06	0.10	0.19	0.32	-0.10	-0.30
SO_4^{2-}	0.60	-0.16	0.44	0.45	0.00	-0.04	-0.04	-0.29
TP	-0.37	0.14	0.14	0.44	-0.21	0.12	-0.41	0.53
TN	0.18	0.21	0.03	0.45	-0.21	0.43	0.44	-0.08
NH_3	0.83	0.26	-0.02	-0.10	-0.02	0.28	0.03	0.08
Cd	-0.14	0.10	0.40	-0.26	0.33	0.67	0.02	0.03
Cr	0.02	0.51	-0.52	0.32	0.20	-0.22	-0.41	-0.12
Cu	-0.10	-0.12	-0.19	0.21	-0.56	-0.10	0.32	-0.07
Fe	-0.01	0.13	-0.29	0.65	-0.44	0.09	0.00	-0.11
Ni	-0.61	0.21	0.59	0.00	0.07	-0.19	0.04	-0.06
Pb	-0.36	0.70	0.16	-0.05	0.18	-0.16	0.15	0.22
Zn	-0.08	0.49	0.17	0.42	0.32	-0.05	-0.02	-0.43
Eigenvalues	3.75	3.24	2.26	2.13	1.91	1.40	1.26	1.03
CV%	17.87	33.29	44.07	54.22	63.33	70.02	76.04	80.95

4.8.1.2 Cluster analysis

Monsoon (September, 2015)

A hierarchical cluster analysis using Centroid Linkage was performed to highlight the spatial inter-relationships and similarities as per the hydrochemistry of the selected parameters (pH, TSS, DO, ORP, COD, Na, K, Ca, Mg, Cl, SO4, TP, TN, NH_3, Cd, Cr, Cu, Fe, Ni, Pb and Zn) between the sampling locations considered in the lake study based on the acquired data for Monsoon first year as shown in Figure 4.77. Three clusters were formed containing different sites showing their pollution potential on water quality. All the sites were present in the cluster 2 except S1 (cluster 1) and S10 (cluster 3). Cluster two contains the sites that are located in open wetland water whereas Cluster 1 includes sites that are closer to the wetland boundary. Cluster 3 corresponds to the mid point of the wetland. JLN Canal is the major feeder canal of Bhindawas wetland which may bring excessive amount of organic, inorganic and dissolved minerals runoff from agricultural fields in catchment area. Also backflow of water in wetland from Drain no.8 leads to excessive nutrient load in water. Different type of water quality depending upon source of pollution and their proximity to wetland water occurs in wetland based on cluster Analysis.

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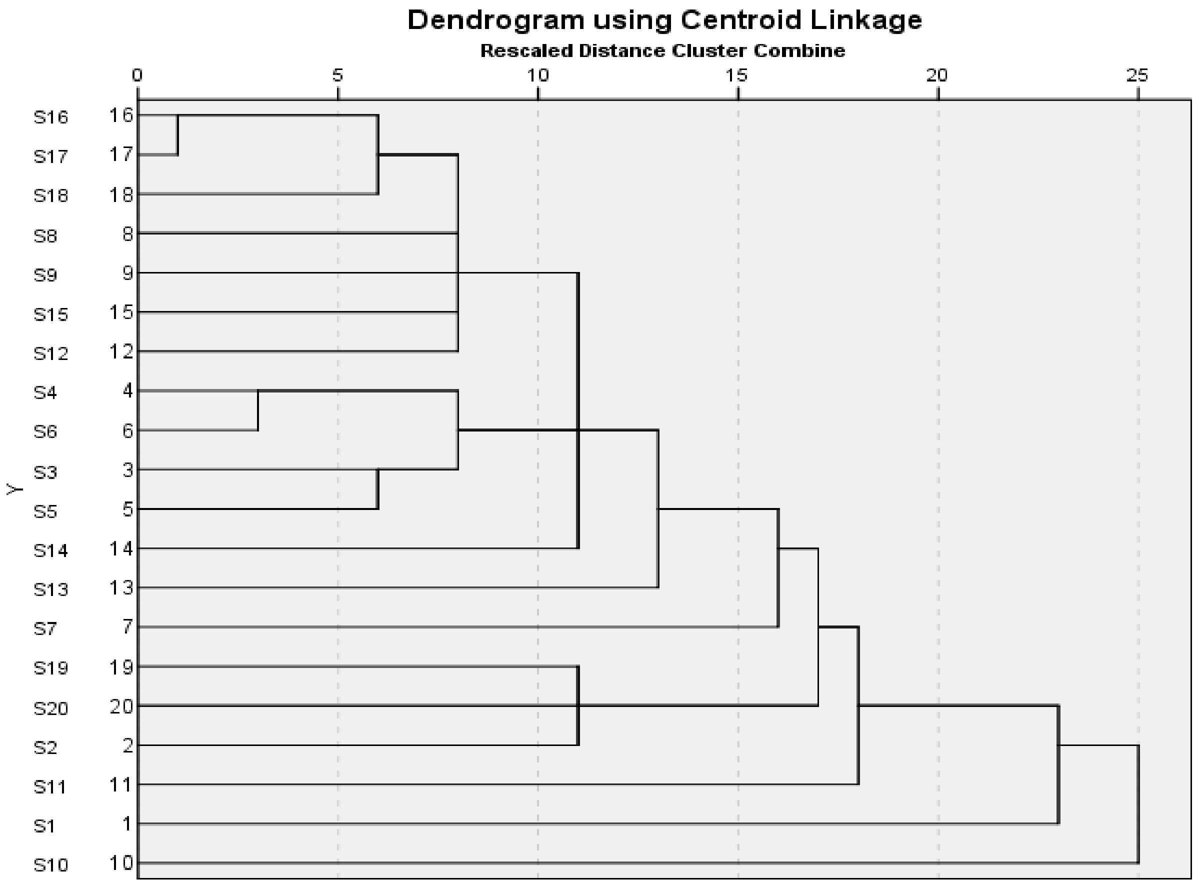

Fig 4.77 Hierarchical cluster analysis during monsoon first year (September, 2015)

Monsoon (September, 2016)

Similarly the hierarchical cluster analysis was performed for monsoon second year to highlight the spatial inter-relationships and similarities as per the hydrochemistry of the selected parameters between the sampling locations of the lake (Figure 4.78). Three clusters were formed showing different sites along with their pollution potential on water quality. All the sites were present in the cluster 1 except S12 (cluster 3) and S10 (cluster 2). Cluster one contains the sites that are located in open wetland water whereas Cluster 2 includes site located in off shore side of wetland with high floating vegetation. Anthropogenic sources like agricultural run off are major factor for affecting various variable with varying degree of pollution. The collection of these sites into different clusters may be due to the varying environmental conditions they are exposed to.

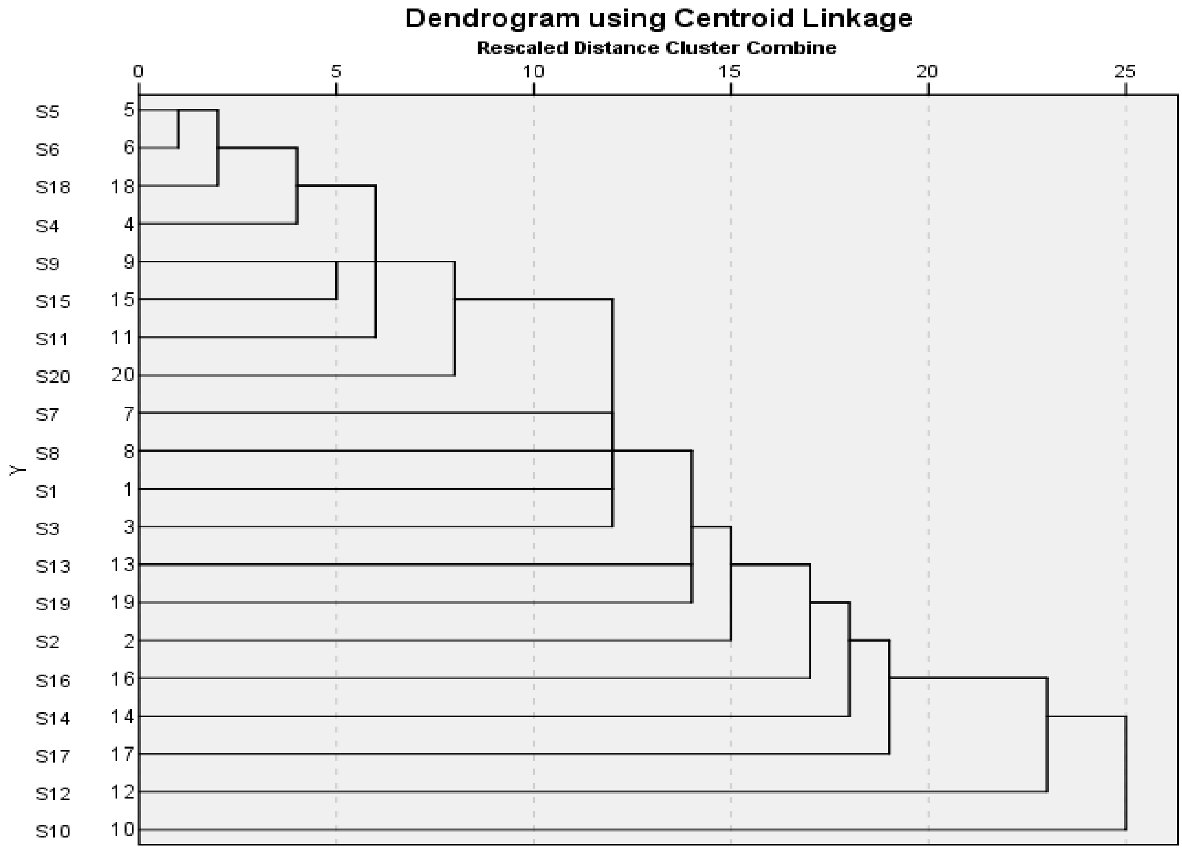

Fig 4.78 Hierarchical cluster analysis during monsoon second year (September, 2016)

Post-monsoon (January, 2016)

Similarly the hierarchical cluster analysis was performed for post-monsoon first year to highlight the spatial inter-relationships and similarities as per the hydrochemistry of the selected parameters between the sampling locations of the lake (Figure 4.79). Three clusters were formed showing different sites along with their pollution potential on water quality. All the sites were present in the cluster 2 except S1 (cluster 1) and S5 (cluster 3). Site 1 is located near the wetland boundary, site 5 is located to near islands located in between wetland area.

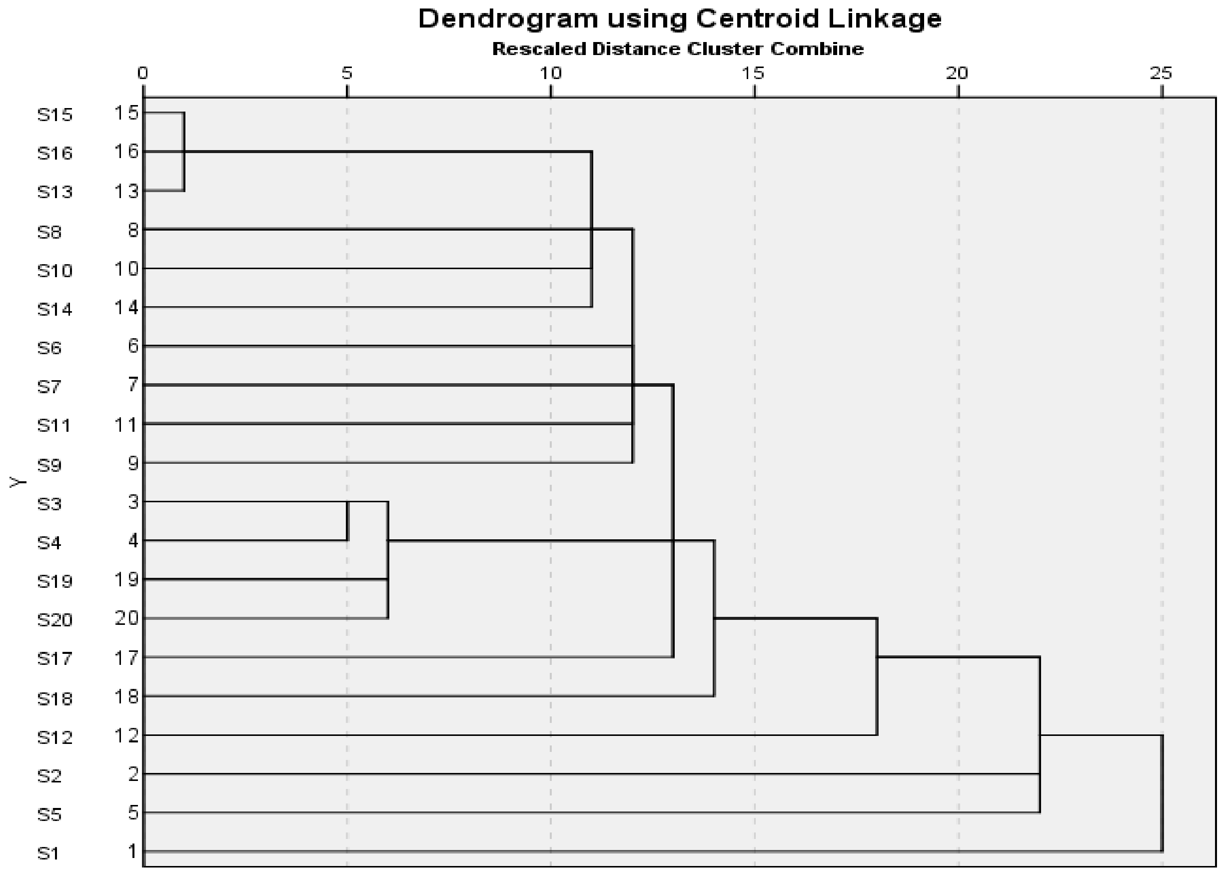

Fig 4.79 Hierarchical cluster analysis during post-monsoon first year (January, 2016)

Post-monsoon(January, 2017)

Similarly the hierarchical cluster analysis was performed for post-monsoon second year to highlight the spatial inter-relationships and similarities as per the hydrochemistry of the selected parameters between the sampling locations of the lake (Figure 4.80). Three clusters were formed showing different sites along with their pollution potential on water quality. All the sites were present in the cluster 2 except S1 (cluster 1) and S12 (cluster 3). All the sites present in cluster two are present in open wetland water and site 1 is near wetland shore and site 12 is present near green belt in north –west direction representing the different sources of pollution. Major sources includes agricultural runoff, sewage waste and dead organic matter near green belt zone.

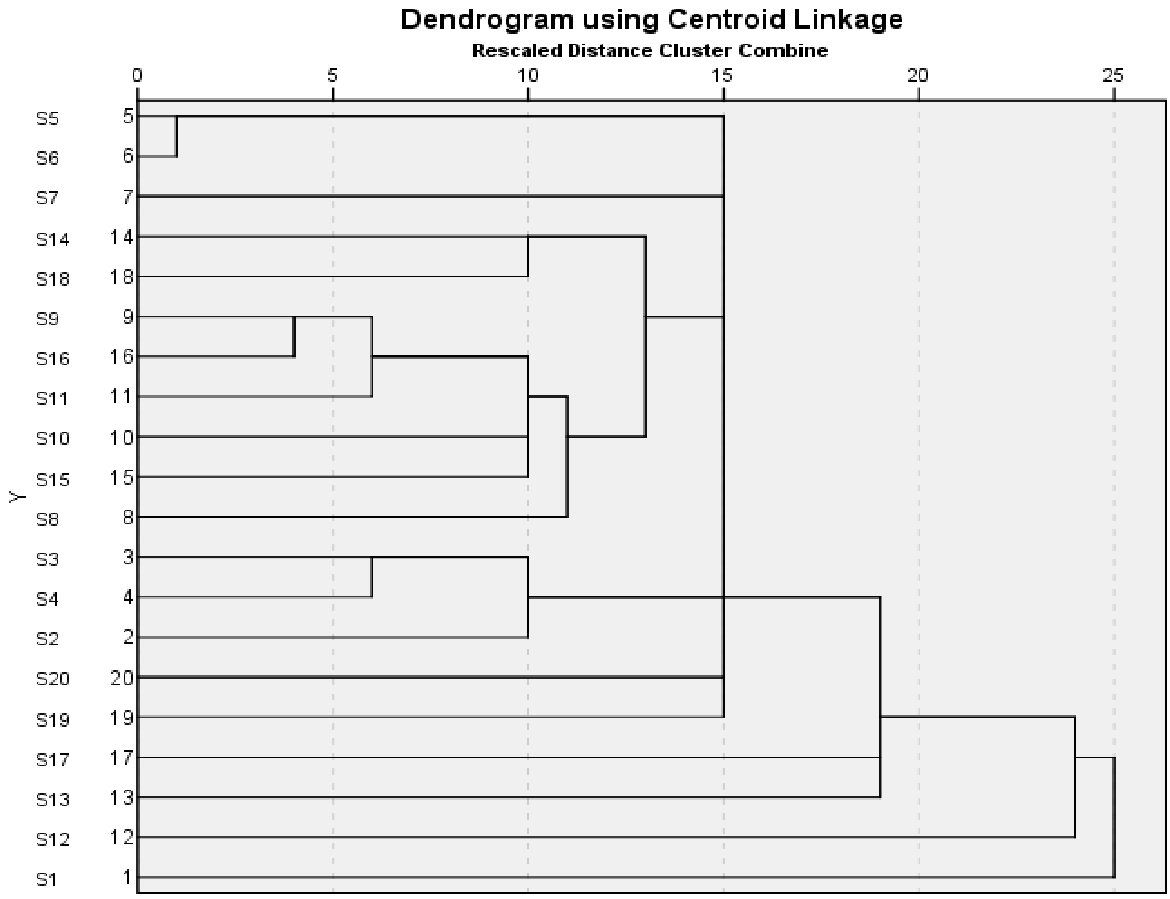

Fig 4.80 Hierarchical cluster analysis during post-monsoon second year (January, 2017)

Pre-monsoon (May, 2016)

Similarly the hierarchical cluster analysis was performed for pre-monsoon first year to highlight the spatial inter-relationships and similarities as per the hydrochemistry of the selected parameters between the sampling locations of the lake (Figure 4.81). Three clusters were formed showing different sites along with their pollution potential on water quality. All the sites were present in the cluster 1 except S5 (cluster 2) and S8 (cluster 3). Site S5 is located near island with some land vegetation. Whereas site 8 is located in North west direction near inlet. So wastes discharge in canal alongwith dissolved impurities vary the water quality of wetland alongwith environmental conditions.

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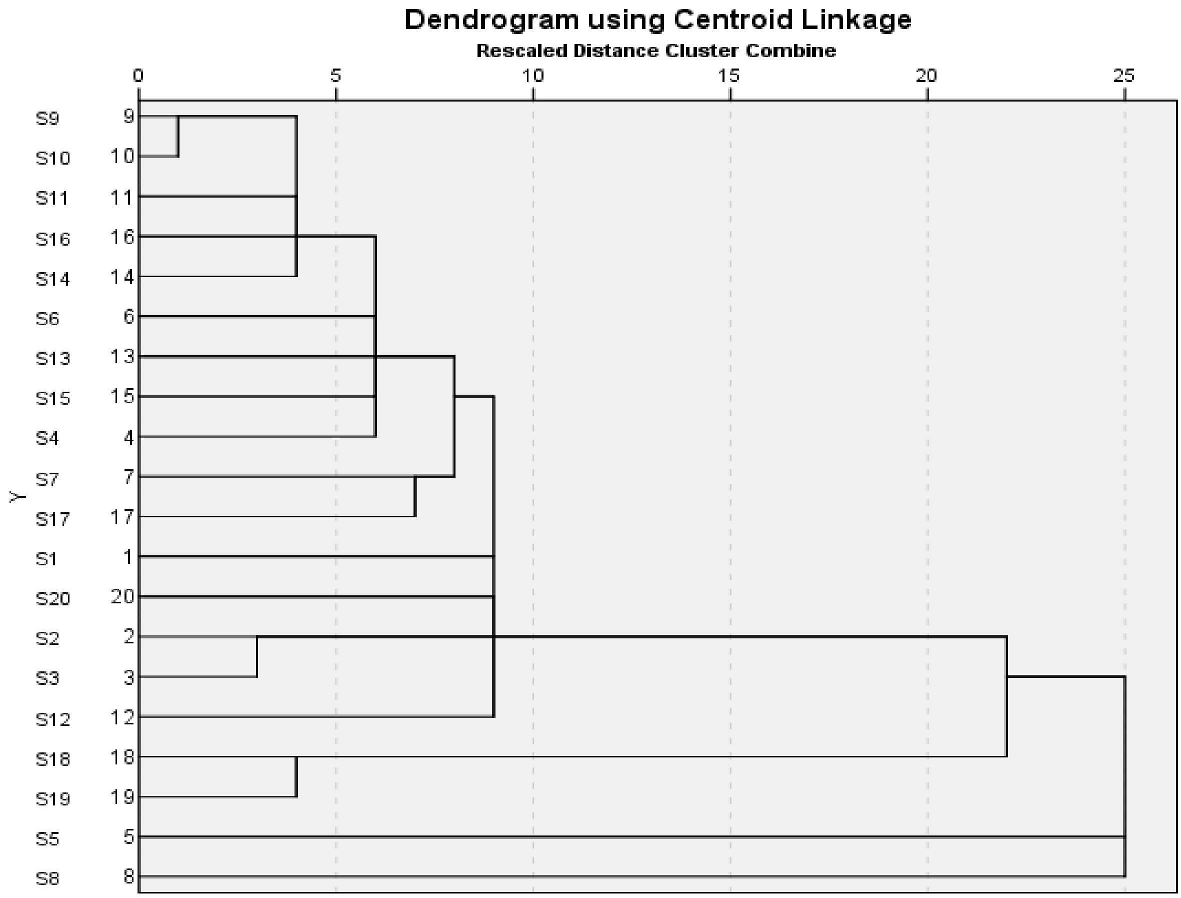

Fig 4.81. Hierarchical cluster analysis during pre-monsoon first year (May, 2016)

Pre-monsoon (May, 2017)

Similarly the hierarchical cluster analysis was performed for pre-monsoon second year to highlight the spatial inter-relationships and similarities as per the hydrochemistry of the selected parameters between the sampling locations of the lake (Figure 4.82). Three clusters were formed showing different sites along with their pollution potential on water quality. All the sites were present in the cluster 2 except S1 (cluster 1) and S10 (cluster 3). Site 10 is located in between wetland area and site I is near wetland shore. Also water near shore have different water quality as compared to wetland open area as there is continuous interaction of soil of land surface and wetland water.

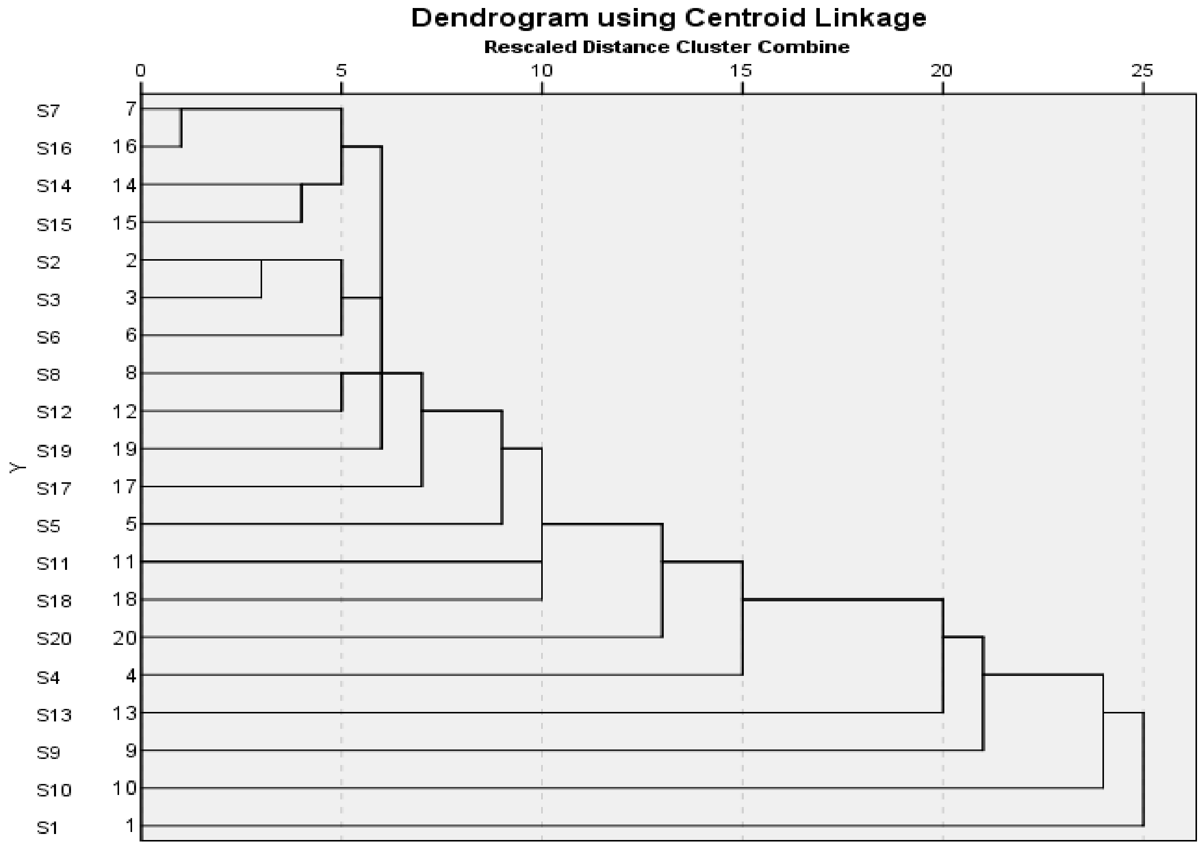

Fig 4.82. Hierarchical cluster analysis during pre-monsoon second year (May, 2017)

4.8.2 Statistical Interpretation for Sediments

4.8.2.1 Principal Component Analysis

Monsoon (September, 2015)

Principal component analysis was applied on the available data (sediment parameters) for monsoon, post-monsoon and pre-monsoon for two consecutive years after removing all the outliers. The result for monsoon first year is shown in Table 4.57, explaining 6 components. The extracted 6 components make interpretation easier and fundamental significance of extracted components to the sediment quality status of the lake. The result of component matrix revealed further, the percentages of the total variances of the 6 extracted components when added account for 84.05% as cumulative variance. The calculated loadings and eigenvalues are shown in Table 4.57. The first component has the highest eigenvector sum and represents the most important source of variation in the data. The last factor is the least important process contributing to the data variation. The Component-1 explains the existence of positive correlation between Na^+, K^+, Cr, Cu, Fe, Ni, Zn and pH. Component-2 shows the existence of positive correlation between Na^+, K^+, TOC and OM. Component-3 shows the existence of positive correlation between OM and Cd respectively. Component-4 contains only AP. Similarly correlations between different parameters were obtained for other two components..

Table 4.57 Principal component analysis (Monsoon, September, 2015)

Parameters	Component					
	1	2	3	4	5	6
Moisture	-0.28	-0.35	-0.22	-0.23	0.65	-0.29
EC	0.10	0.38	-0.05	-0.42	-0.10	0.76
Na^+	0.56	0.69	-0.09	-0.02	-0.23	-0.30
K^+	0.50	0.58	-0.23	-0.26	-0.11	-0.01
Ca^{2+}	-0.48	-0.38	-0.14	0.40	-0.30	0.29
TP	-0.49	0.29	-0.64	-0.23	0.12	0.06
AP	0.13	-0.15	-0.42	0.63	0.41	0.30
TKN	0.40	-0.28	-0.13	-0.19	-0.63	-0.10
TOC	-0.43	0.65	0.49	0.29	0.02	0.11
OM	-0.42	0.63	0.52	0.28	0.06	0.08
Cd	-0.05	-0.11	0.54	-0.53	0.40	0.16
Cr	0.61	-0.58	0.19	-0.05	-0.03	0.17
Cu	0.90	0.06	0.14	-0.15	0.20	0.08
Fe	0.79	0.04	0.30	0.40	0.04	-0.10
Ni	0.83	-0.27	0.18	0.03	0.13	0.13
Pb	-0.10	-0.85	0.34	-0.03	-0.20	0.02
Zn	0.89	0.26	0.00	0.12	0.18	-0.09
pH	0.72	-0.01	-0.41	0.17	0.08	0.21
Eigenvalues	5.50	3.43	2.00	1.62	1.48	1.10
CV%	30.57	49.63	60.75	69.73	77.95	84.05

Monsoon (September, 2016)

The result for monsoon second year is shown in Table 4.58, explaining 6 components. The extracted 6 components make interpretation easier and fundamental significance of extracted components to the sediment quality status of the lake. The result of component matrix revealed further, the percentages of the total variances of the 6 extracted components when added account for 85.27% as cumulative variance. The calculated loadings and eigenvalues are shown in Table 4.58. The six different components explain the existence of positive correlation between various parameters. Component -1 represents mineral and organic loading, component -2 indicates high TKN content whereas component 3 determines high mineral content in sediments indicating high conductivity.

Table 4.58 Principal component analysis (Monsoon, September, 2016)

Parameters	Component					
	1	2	3	4	5	6
Moisture	0.56	0.55	0.22	-0.17	-0.36	0.19
pH	0.22	-0.10	0.70	0.41	0.18	0.34
EC	0.22	0.65	0.52	0.06	-0.34	-0.24
Na^+	0.87	-0.13	-0.22	-0.16	0.05	0.28
K^+	0.81	-0.39	0.16	0.24	-0.05	0.08
Ca^{2+}	0.94	-0.22	-0.03	-0.02	-0.01	0.19
TP	0.46	-0.23	-0.34	0.30	-0.02	-0.36
AP	-0.64	0.36	0.06	-0.04	-0.10	0.51
TKN	-0.24	0.68	-0.41	0.27	0.20	-0.01
TOC	0.76	0.38	-0.02	-0.42	-0.01	-0.20
OM	0.76	0.31	-0.06	-0.46	-0.03	-0.19
Cd	-0.30	0.15	0.75	-0.07	-0.04	-0.03
Cr	0.09	0.71	-0.20	0.55	-0.06	0.09
Cu	-0.12	0.63	0.30	-0.08	0.54	-0.26
Fe	0.78	0.27	0.04	-0.08	0.29	0.36
Ni	0.31	-0.25	0.45	0.09	0.68	-0.16
Pb	0.54	0.33	-0.38	0.57	0.12	-0.02
Zn	0.38	-0.20	0.42	0.46	-0.44	-0.26
Eigenvalues	5.76	3.03	2.39	1.70	1.37	1.10
CV%	32.02	48.87	62.13	71.55	79.17	85.27

Post-monsoon (January, 2016)

The result for post-monsoon first year is shown in Table 4.59, explaining 7 components. The extracted 7 components make interpretation easier and fundamental significance of extracted components to the sediment quality status of the lake. The result of component matrix revealed further, the percentages of the total variances of the 7 extracted components when added account for 81.23% as cumulative variance. The calculated loadings and eigenvalues are shown in Table 4.59. The seven different components explain the existence of positive correlation between various parameters. Component 1 represents high heavy metal loading whereas component 2 represents high organic and nutrient loading.

Table 4.59 Principal component analysis (Post-monsoon, January, 2016)

Parameters	Component						
	1	2	3	4	5	6	7
pH	-0.25	-0.15	0.04	0.69	0.15	0.29	-0.22
EC	-0.11	-0.10	-0.50	0.54	-0.21	-0.12	-0.30
Na^+	0.02	0.06	-0.66	0.05	-0.39	0.34	0.37
K^+	0.38	0.20	-0.16	0.41	-0.48	-0.43	0.14
Ca^{2+}	-0.19	-0.46	0.09	0.40	0.35	0.09	0.47
TP	0.15	0.52	0.14	0.28	0.37	0.26	-0.37
AP	0.19	0.44	0.16	-0.25	0.43	0.03	0.43
TKN	0.39	-0.09	0.56	0.37	-0.38	0.08	0.09
TOC	-0.29	0.71	0.43	0.10	-0.27	0.04	0.17
OM	-0.32	0.70	0.48	0.11	-0.27	0.03	0.10
Cr	0.77	-0.29	0.46	0.02	-0.02	0-.04	0-.15
Cu	0.10	0.62	-0.23	-0.05	0.25	-0.55	-0.24
Fe	0.77	0.35	-0.37	0.07	0.05	-0.02	0.07
Ni	0.34	-0.35	0.47	0.37	0.19	-0.41	0.14
Pb	0.60	0.23	0.12	-0.02	-0.05	0.57	-0.18
Zn	0.74	0.19	-0.38	0.23	0.25	0.10	0.23
Moisture	-0.51	0.36	-0.12	0.55	0.30	-0.01	0.14
Eigenvalues	3.12	2.68	2.29	1.91	1.44	1.29	1.09
CV%	18.36	34.14	47.60	58.82	67.26	74.84	81.23

Post-monsoon (January, 2017)

The result for post-monsoon second year is shown in Table 4.60, explaining 7 components. The extracted 7 components make interpretation easier and fundamental significance of extracted components to the sediment quality status of the lake. The result of component matrix revealed further, the percentages of the total variances of the 7 extracted components when added account for 86.10% as cumulative variance. The calculated loadings and eigenvalues are shown in Table 4.60. The seven different components explain the existence of positive correlation between various parameters. Comonent 1 containing high correlation among cations representing high mineral content whereas component 2 determines high conductivity Component 3 determines high organic loading.

Table 4.60 Principal component analysis (Post-monsoon, January, 2017)

Parameters	Component						
	1	2	3	4	5	6	7
Moisture	0.13	0.68	0.15	-0.17	-0.01	0.30	0.50
pH	0.30	-0.62	-0.15	-0.01	-0.32	0.52	-0.11
EC	0.19	0.55	-0.13	0.01	-0.40	-0.52	-0.08
Na^+	0.69	0.31	0.32	-0.21	-0.10	0.24	-0.10

K^+	0.97	0.11	0.04	0.05	0.05	0.05	-0.05
Ca^{2+}	0.89	0.04	0.25	-0.09	0.16	0.00	0.18
TP	-0.44	0.43	-0.30	0.37	0.18	0.48	-0.02
AP	-0.64	0.43	0.28	-0.36	0.14	0.20	0.11
TKN	-0.07	-0.33	0.58	-0.05	0.51	0.04	-0.36
TOC	-0.20	-0.21	0.80	0.25	-0.32	-0.05	0.27
OM	-0.20	-0.23	0.83	0.24	-0.28	0.03	0.26
Cd	-0.09	-0.52	-0.48	-0.35	-0.08	-0.18	0.50
Cr	-0.28	0.70	0.00	0.36	0.29	-0.04	0.06
Cu	0.08	-0.31	0.19	-0.54	0.67	-0.14	0.15
Fe	0.73	0.30	-0.06	-0.35	0.08	0.00	0.18
Ni	0.05	-0.15	-0.09	0.69	0.36	-0.25	0.32
Pb	0.35	-0.35	-0.35	0.42	0.17	0.26	0.30
Zn	0.71	0.02	0.18	0.46	0.18	-0.11	-0.14
Eigenvalues	4.29	2.91	2.49	2.00	1.52	1.17	1.12
CV%	23.84	40.02	53.85	64.95	73.38	79.89	86.10

Pre-monsoon (May, 2016)

The result for pre-monsoon first year is shown in Table 4.61, explaining 5 components. The extracted 5 components make interpretation easier and fundamental significance of extracted

Table 4.61 Principal component analysis (Pre-monsoon, May, 2016)

Parameters	Component				
	1	2	3	4	5
pH	-0.40	-0.45	0.50	-0.12	-0.001
Moisture	0.76	-0.12	0.25	0.22	-0.23
EC	0.40	0.50	-0.48	-0.24	-0.01
Na^+	0.42	0.56	0.40	-0.002	0.24
K^+	0.73	-0.02	0.15	0.60	0.12
Ca^{2+}	0.68	-0.07	0.06	0.56	0.11
TP	0.27	0.21	-0.48	-0.22	0.38
AP	-0.52	0.26	-0.44	0.22	-0.40
TKN	0.07	0.53	0.63	-0.14	-0.06
TOC	0.03	-0.94	-0.03	-0.09	-0.01
OM	0.03	-0.93	-0.06	-0.08	-0.003
Cd	-0.79	0.12	-0.10	0.51	-0.06
Cr	-0.80	0.21	0.06	0.45	0.07
Cu	0.65	0.26	0.09	-0.30	-0.48
Fe	0.76	-0.11	-0.30	0.39	-0.21
Pb	-0.87	0.17	0.05	0.09	0.23
Zn	0.53	-0.07	-0.13	-0.02	0.57
Eigenvalues	5.71	3.12	1.69	1.63	1.10
CV%	33.58	51.91	61.88	71.48	77.95

components to the sediment quality status of the lake. The result of component matrix revealed further, the percentages of the total variances of the 5 extracted components when added account for 77.95% as cumulative variance. The calculated loadings and eigenvalues are shown in Table 4.61. The five different components explain the existence of positive correlation between various parameters. Component 1 determines high correlation among moisture content, K+ and heavy metals indicating high metal pollution and mineral content and component 2 contains moderate loading of cations with electrical conductivity.

Pre-monsoon (May, 2017)

The result for pre-monsoon second year is shown in Table 4.62, explaining 6 components. The extracted 6 components make interpretation easier and fundamental significance of extracted components to the sediment quality status of the lake. The result of component

Table 4.62. Principal component analysis (Pre-monsoon, May, 2017)

Parameters	Component					
	1	2	3	4	5	6
Moisture	0.91	-0.29	-0.05	0.00	0.03	0.00
pH	-0.62	-0.10	-0.06	0.45	0.41	0.28
EC	0.86	-0.36	0.00	0.06	0.20	0.05
Na^{+}	-0.06	-0.50	0.43	-0.01	0.37	0.40
K^{+}	0.88	-0.24	-0.23	0.08	0.18	-0.08
Ca^{2+}	0.85	-0.27	-0.05	0.06	-0.07	0.04
TP	0.02	0.12	0.71	0.00	-0.23	0.33
AP	-0.48	-0.42	-0.24	0.46	0.19	0.29
TKN	0.00	-0.23	0.36	0.61	-0.29	-0.17
TOC	0.56	0.57	-0.12	0.47	-0.10	0.10
OM	0.55	0.60	-0.09	0.44	-0.11	0.19
Cd	-0.12	0.69	-0.15	0.01	0.06	0.24
Cr	-0.16	0.57	0.28	-0.15	0.49	0.07
Cu	-0.56	-0.29	0.20	0.22	0.15	-0.34
Fe	0.69	0.09	0.36	0.18	0.26	-0.26
Ni	-0.18	0.32	0.06	0.19	0.48	-0.56
Pb	-0.60	-0.14	-0.54	0.24	-0.33	-0.13
Zn	0.20	-0.02	-0.80	-0.11	0.32	0.13
Eigenvalues	5.55	2.55	2.18	1.42	1.36	1.11
CV%	30.83	45.00	57.13	65.01	72.59	78.75

matrix revealed further, the percentages of the total variances of the 6 extracted components when added account for 78.75% as cumulative variance. The calculated loadings and eigenvalues are shown in Table 4.62. The six different components explain the existence of positive correlation between various parameters. Component 1 is characterized by high organic loading and strong mineral influence. Component 2 determine high organic content.

4.8.2.2 Cluster Analysis

Monsoon (September, 2015)

A hierarchical cluster analysis using Centroid Linkage was performed to highlight the spatial inter-relationships and similarities as per the sediments chemistry of the selected parameters (Moisture, pH, EC, Na^+, K^+, Ca^{2+}, TP, AP, TKN, TOC, OM, Cd, Cr, Cu, Fe, Ni, Pb and Zn) between the sampling locations considered in the lake study based on the acquired data for Monsoon first year as shown in Figure 4.83.

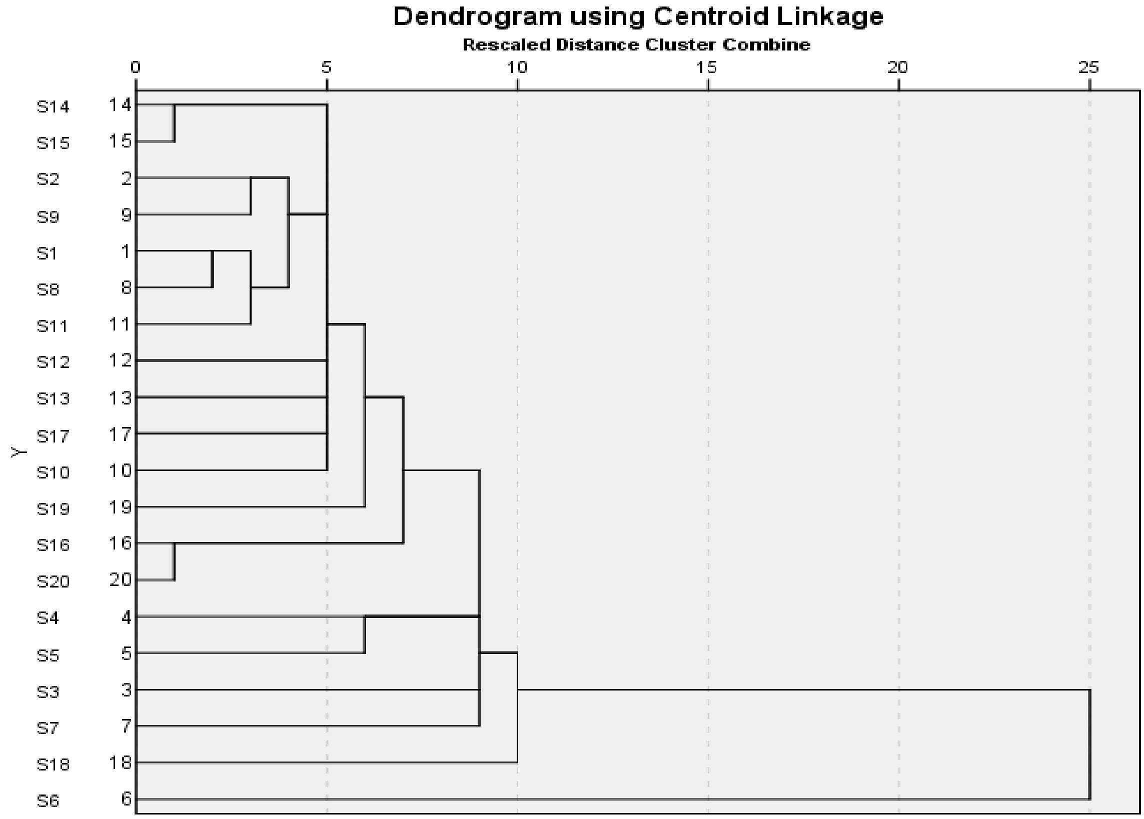

Fig 4.83. Hierarchical cluster analysis during monsoon first year (September, 2015)

Three clusters were formed containing different sites showing their pollution potential on sediment quality. All the sites were present in the cluster 1 except S6 (cluster 2) and S18 (cluster 3). Sampling sites S6 and S18 are located near island and green belt respectively and rest of all sites of cluster 1 are located in open area.

Monsoon (September, 2016)

Similarly the hierarchical cluster analysis was performed for monsoon second year to highlight the spatial inter-relationships and similarities as per the sediment chemistry of the selected parameters between the sampling locations of the lake (Figure 4.84). Three clusters were formed showing different sites along with their pollution potential on sediment quality. All the sites were present in the cluster 1 except S16 (cluster 2) and S18 (cluster 3). Sampling sites S16 and S18 are located near inlet and green belt respectively and rest of all sites of cluster 1 are located in open area depending upon the proximity to source sediment possess varying physic-chemical characteristics.

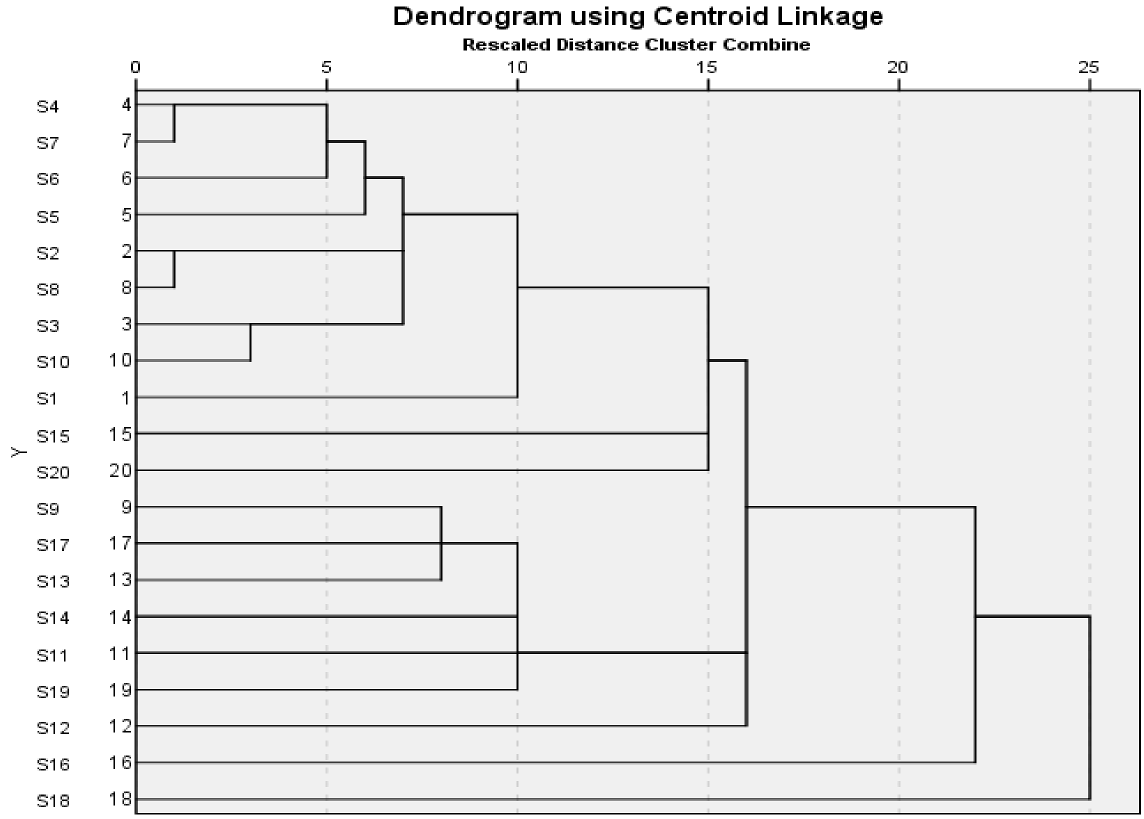

Fig 4.84. Hierarchical cluster analysis during monsoon second year (September, 2016)

Post-monsoon (January, 2016)

Similarly the hierarchical cluster analysis was performed for post-monsoon first year to highlight the spatial inter-relationships and similarities as per the sediment chemistry of the selected parameters between the sampling locations of the lake (Figure 4.85). Three clusters were formed showing different sites along with their pollution potential on sediment quality. All the sites were present in the cluster 1 except S9 (cluster 2) and S19 (cluster 3). Both the Sites S9 are located nearby but away from the wetland shore and S19 is located near island and green belt area having distinct sediment quality from cluster 1 sites having similar source of pollution.

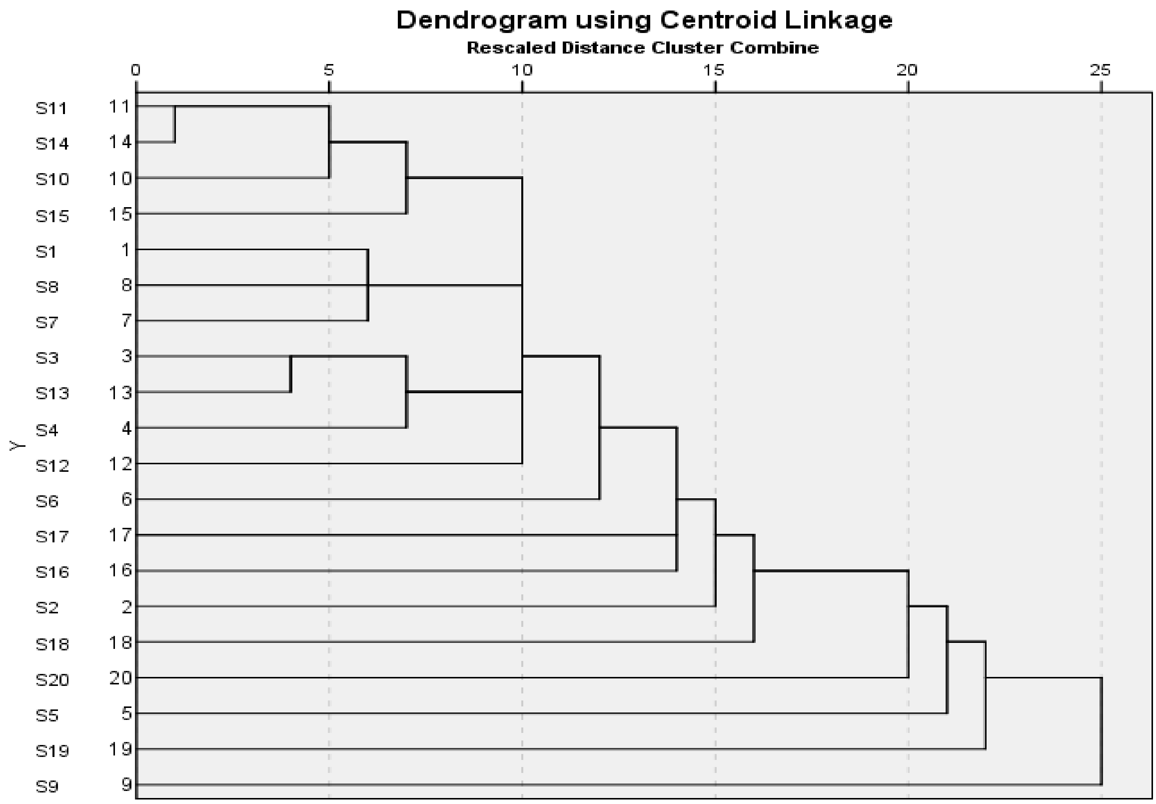

Fig 4.85. Hierarchical cluster analysis during post-monsoon first year (January, 2016)

Post-monsoon (January, 2017)

Similarly the hierarchical cluster analysis was performed for post-monsoon second year to highlight the spatial inter-relationships and similarities as per the sediment chemistry of the selected parameters between the sampling locations of the lake (Figure 4.86). Three clusters were formed showing different sites along with their pollution potential on sediment quality. All the sites were present in the cluster 1 except S12 (cluster 2) and S13 (cluster 3).Sites S12 and S13 possess different sources of pollution as compared to other sites as S12 is located in north west direction near village Chadwana and S13 located near inlet .

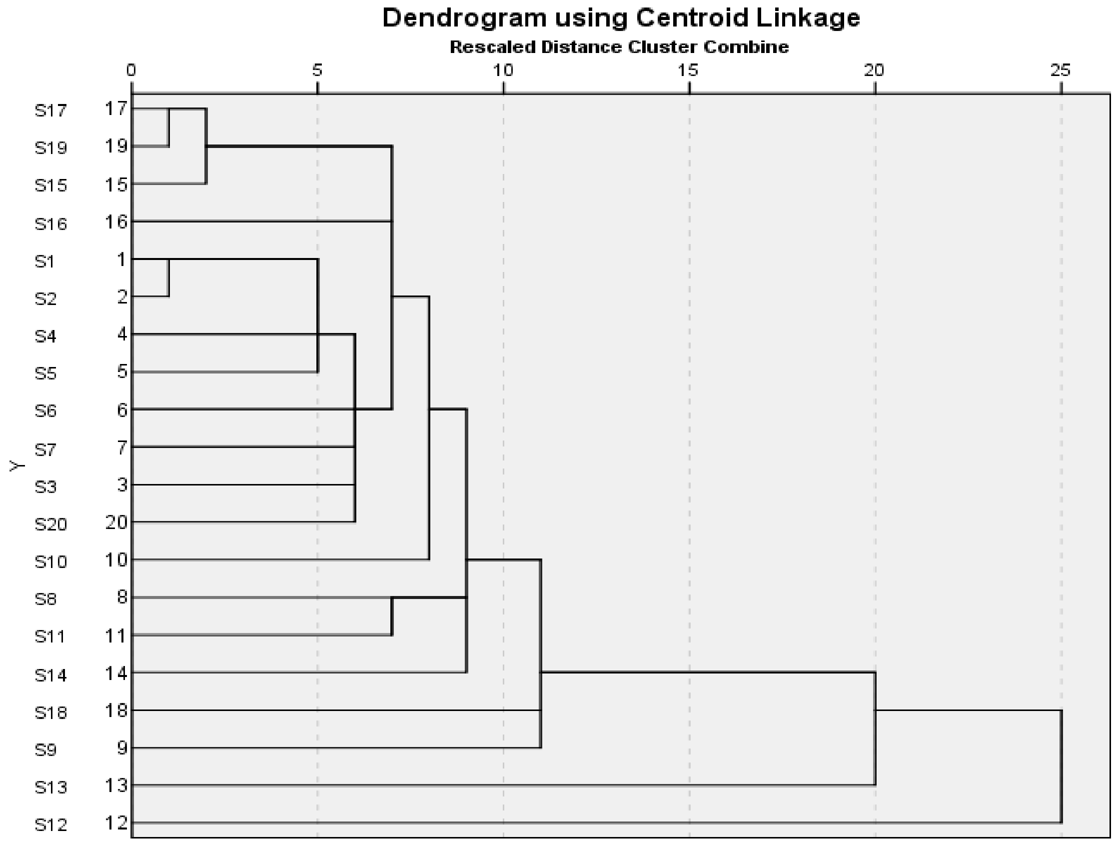

Fig 4.86. Hierarchical cluster analysis during post-monsoon second year (January, 2017)

Pre-monsoon (May, 2016)

Similarly the hierarchical cluster analysis was performed for pre-monsoon first year to highlight the spatial inter-relationships and similarities as per the sedimentchemistry of the selected parameters between the sampling locations of the lake (Figure 4.87). Three clusters were formed showing different sites along with their pollution potential on sediment quality. Sites from S16 to S18 comprises cluster 2 and cluster 3 comprises S19 and S20. The rest sites formed cluster 1.Sites S16 and S18 are located in North-west near village Chadwana and sites S19 and S20 are present near Sahjanpur village (near wetland entrance) north-east direction

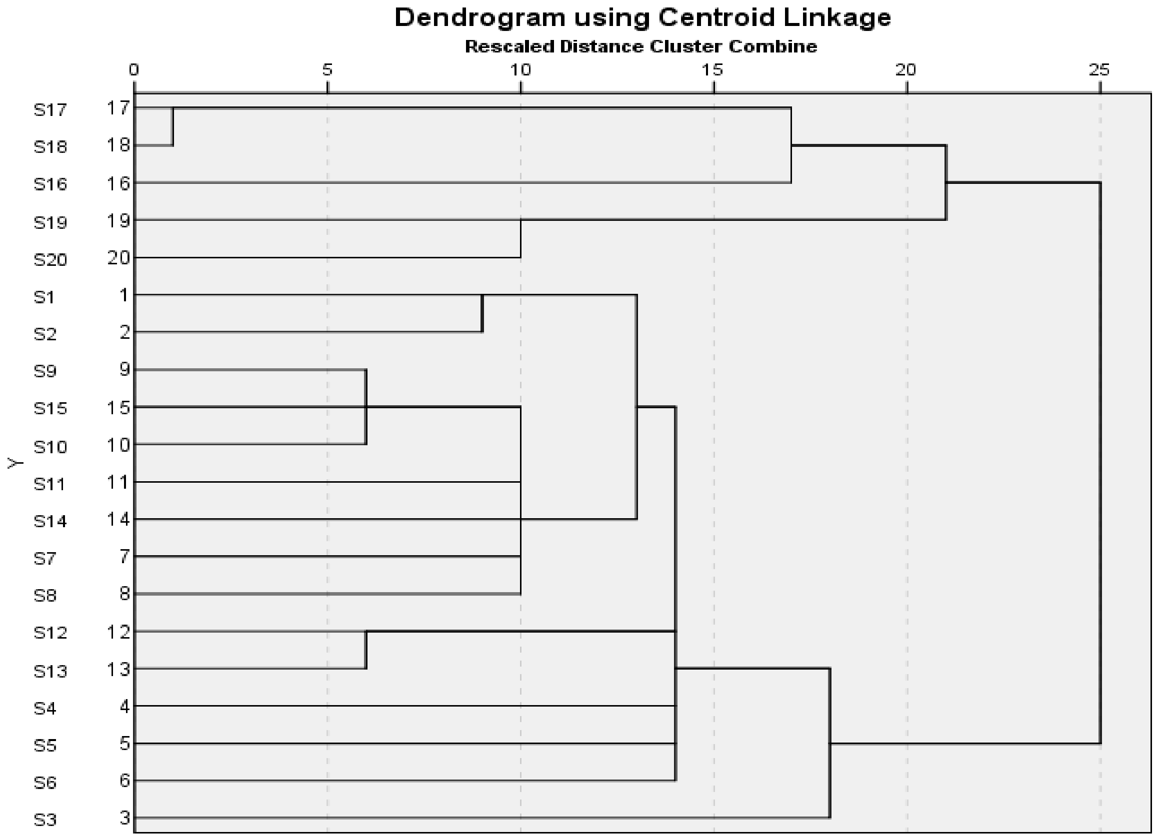

Fig 4.87. Hierarchical cluster analysis during pre-monsoon first year (May, 2016)

Pre-monsoon (May, 2017)

Similarly the hierarchical cluster analysis was performed for pre-monsoon second year to highlight the spatial inter-relationships and similarities as per the sediment chemistry of the selected parameters between the sampling locations of the lake (Figure 4.88). Three clusters were formed showing different sites along with their pollution potential on sediment quality. Sites from S1 to S8 and S13 formed cluster 1, whereas the remaining sites formed cluster 2 except S16 (cluster 3). Cluster 1 having sampling sites possess similar source of pollution and sampling sites S16 is present in cluster 3 as it is located away from inlet, near village Chadwana (north-west).

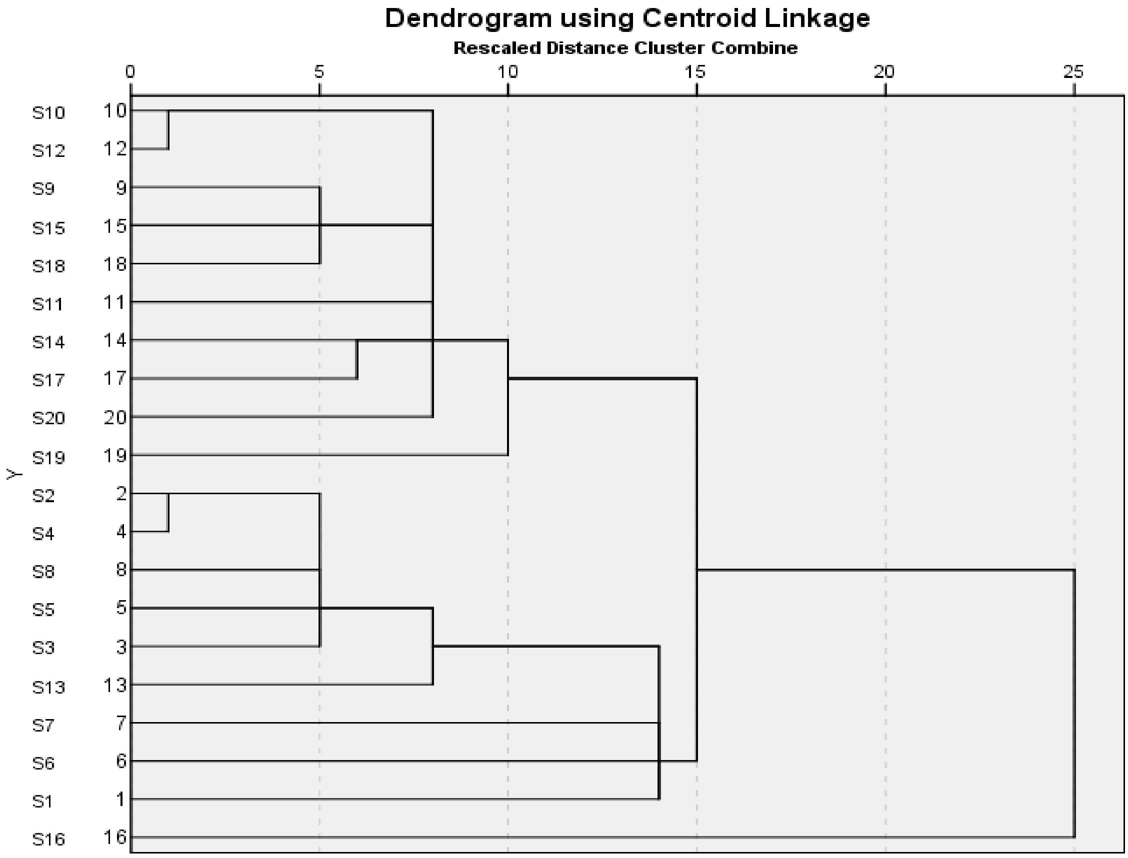

Fig 4.88. Hierarchical cluster analysis during pre-monsoon second year (May, 2017)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The present study determined the water quality status of Bhindawas wetland by characterising various physicochemical parameters viz. temperature, pH, EC, TDS, TSS, DO, ORP, BOD, COD, DOC, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, PO_4^{3-}, NO_3^-, NH_3-N and TKN at twenty different locations, alongwith inlet and outlet in three different seasons (Monsoon, Post-monsoon, Pre-monsoon) for two successive years (September, 2015 to May, 2017).

The present study deals with the nutrient loading and water quality assessment of Bhindawas wetland water quality . Based on this study following conclusions are drawn :

1. Seasonal trend for major pollutants in wetland was observed with their decreasing concentration as pre-monsoon > monsoon > post-monsoon confirming that excessive evaporation from wetland surface will concentrate the water with inorganic salts and nutrients.
2. Comparatively higher concentration of heavy metals Cd, Cr, Fe, Ni, and Zn was found in post-monsoon- ascribed to flushing and pumping of runoff from nearby fields. As prominent effect was seen after the end of monsoon.
3. Low to medium degree of pollution based on various HPI, HEI and Cd reveals good quality of water for irrigation and aquatic life except of region adjoining rural habitation.
4. WQI significantly determined all sampling locations having value > 100, making it unsuitable for aquatic use throughout the study period.
5. Slightly acidic nature of wetland sediments as compare to wetland water due to breakdown of TOC under limited supply of oxygen.
6. Maximum mean value for total phosphate and TKN, was observed in post-monsoon and least value was observed in pre-monsoon.
7. Minimal to significant enrichment of sediments with Cd, Cr, Zn, Ni, Cu and Pb indicates anthropogenic source of pollution with respect to heavy metals and based on geo-accumulation index sediments are rarely found contaminated with heavy metals except

Cd, having high geo-accumulation index.

8. Degree of contamination below total number of heavy metal studied, confirms the low degree of contamination in wetland sediments from sediments. Based on Sediment Pollution Index, sediments are low to moderately contaminated with SPI in between 0 to 2, indicating their natural origin.
9. During the study the nutrient loading has been evaluated with respect to Total Nitrogen and Total Phosphorous concentration . The higher mean value for TN has been observed in post-monsoon followed by monsoon and pre monsoon for two consecutive years while excessive concentration of Total Phosphorous was observed in monsoon which creates nuisance in wetland ecosystem creating eutrophication conditions.
10. Carlson Trophic Status Index represented water of Bhindawas wetland hyper-eutrophic category with significant variation during the period of study.
11. Significant seasonal variation in productivity was observed with minimum in monsoon and maximum in pre-monsoon. Based on productivity, wetland was found highly polluted with NPP to CR ratio >1.
12. Wetlands sediments are found saturated with high phosphorus content in post-monsoon as compare to pre-monsoon may be due to the sedimentation, precipitation of phosphate after monsoon. Nitrogen concentration in wetland sediments was observed maximum during post-monsoon and minimum during pre-monsoon.
13. Seasonal analysis revealed that higher NO_3^--N and PO_4^{3-}-P concentrations removal was observed in summer whereas higher content of N and P in plant tissues were noted in winter followed by monsoon and pre-monsoon.
14. A hierarchical cluster analysis, determined the spatial inter-relationships and similarities as per the hydrochemistry of the selected physicochemical parameters and heavy metals and determined their potential pollution sources and nutrient load viz. agricultural run off and storm water from vast stretches of catchment area, backflow of polluted water from drain no. 8, sewage waste from human settlement near wetland area..
15. The present study revealed that the aquatic macrophytes acts as a nutrient sink in aquatic ecosystem and help in reducing excess nutrients in wetland.

5.2 RECOMMENDATION

Following recommendations are made from the study:

1. Data related to various physicochemical characteristics of water, sediment and nutrient loading of Bhindawas wetland can be utilized as a baseline and reference value for future research work.
2. Being shallow in nature, wetland is susceptible to internal nutrient loading from bottom sediment and accumulation of sediments, nutrients from surrounding catchment and increased in productivity by excessive phytoplankton growth. So dredging of sediment from lake bed upto 10-20 cm is needed for removing nutrient and organic rich surface sediment layers.
3. Realizing the surrounding agricultural land to wetland proper management planning for control of soil erosion and nutrient removal catchment area need to be undertaken on a priority basis.
4. Increased nutrient input, shallow depth and high Chl-a content leads to highly eutrophic status of wetland which leads to water quality deterioration .Need for alternative fertilizers and pesticides in agricultural field is required to be explored. Proper flushing of wetland water with time to time is needed to reduce the affect of increased nutrient input.
5. There is high need of construction of sewage treatment plant in villages located around wetland to reduce organic waste loading in wetland.
6. Excessive growth of weeds like *Water hyacinth* and *Salvinia molesta* lead to deterioration of the water quality, shrinkage of lake area and loss of native species. There is need for continuous monitoring of the lake ecology for the evaluation of the pollution level in order to promote better ecosystem health and living conditions around the lake. Excessive weed growth should be controlled to further contamination of wetland water with plant residue. For this physical and chemical methods should be used.
7. Proper implementation of rules and laws, and various awareness programmes should be introduced for conservation and management of wetland water quality and nutrient abatement.

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Annexure I

LIST OF PUBLICATIONS

A. International Journals:

1. A.K., Haritash, Vandana Shan, Priyanka Singh, S.K. Singh (2015) **Preliminary investigation of environmental status of Bhindawas Bird Sanctuary,** International Journal of Engineering Research & Technology. 4(3), pp.53-56

2. Vandana Shan, A.K., Haritash, S.K. Singh (2017**) Major ions chemistry of surface water in Bhindawas Wetland, Haryana,** International Journal of Advance Research and Innovation, 5(1), pp.117-121

B. Communicated Research Articles

(i) Vandana Shan, S. K. Singh, A. K. Haritash, **Preliminary analysis of water quality and metal contamination in Bhindawas wetland, India** in Applied Water Science

(ii) Vandana Shan, S. K. Singh, A. K. Haritash, **Statistical assessment of heavy metal contamination in tropical wetland sediments in Bhindawas Bird Sanctuary, Haryana, India** in Environmental Science and Pollution Research.

C. International Conferences:

1. Vandana Shan, S. K. Singh, A. K. Haritash (2017) **Water quality indices to determine the surface water quality of Bhindawas Wetland** during International Conference on Emerging Areas of Environmental Science & Engineering, Guru Jambheshwar University of Science and Technology, Hisar held on February, 16-18,2017.

2. Vandana Shan, S. K. Singh, A. K. Haritash (2018) **Preliminary assessment of Water quality of Bhindawas wetland for irrigation, Haryana**, India. 3rd Go Green Summit, 23rd-24th March, 2018 at Manila, Philippines

D. Poster Presentation

1. Vandana Shan, A. K. Haritash, S. K. Singh (2019) **Nutrient Removal Potential of Selected Aquatic Macrophytes in Tropical Wetland**. 2nd International conference on Sustainable Technologies for Environmental Management (STEM-2019) held during 25th-26th March, 2019.