WATER QUALITY DETERMINATION AND MODELLING OF NATURAL LAKES

Thesis submitted in fulfillment of the requirements for the Degree of

DOCTOR OF PHILOSOPHY

By

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Month December, Year 2021

Dedicated to

My

Beloved Parents

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DECLARATION BY THE SCHOLAR

I hereby declare that the work contained in the Ph.D. thesis entitled **"Water Quality Determination and Modelling of Natural Lakes"** submitted at **Jaypee University of Information Technology at Waknaghat, India** is an authentic record of my work carried out under the supervision of **Dr. Rajiv Ganguly**. I have not submitted this work elsewhere for any other degree or diploma. I am fully responsible for the content of my Ph.D. thesis.

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SUPERVISOR'S CERTIFICATE

This is to certify that the work reported in the Ph.D. thesis entitled **"Water Quality Determination and Modelling of Natural Lakes"**, submitted by **Prachi Vasistha** at **Jaypee University of Information Technology at Waknaghat, India,** is a bonafide record of her original work carried out under my supervision. This work has not been submitted elsewhere for any other degree or diploma.

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ABSTRACT

Water is an essential commodity for humans, plants and animals. Many civilizations have settled along the banks of rivers; confirming water to be an important part of daily requirements. There are large numbers of water resources available on earth but not all are fit for consumption. The qualities of the available water resources are dependent on natural as well as on different anthropogenic factors. These factors affect the quality of water, which in turn are affected both spatially and temporally, hence an enhanced quality determination is the need of the hour.

In this context, the current study focusses on determination of Designated Best Use representing current usage status, pollution source identification, quantification of existing water quality through conventional and proposed Water Quality Indices, evaluation of characteristics of water, soil and sediments through spectroscopic analysis, determination of complete water quality status spatially and temporally through modelling techniques and evaluation of best remediation techniques for Tehsil for two study lakes of Panchkula district in State of Haryana. The main aim of the study is to generate baseline information about the current practices at the study sites leading to the problem of pollution and suggest suitable remediation techniques after evaluation of the complete scenario.

The evaluation of the present usable status of the water was done using the Designated Best Use (DBU) technique based on guidelines of Central Pollution Control Board (CPCB). The main aim of the technique was to evaluate the usage of the water body based on certain set of predefined parameters and their comparison with standards prescribed for usage by CPCB. The twin lakes considered for the study were found to be fit for usage with treatment, for fisheries and development of wildlife, for irrigation and bathing but were unfit for direct usage mainly due to slightly high Biological Oxygen Demand (BOD) concentrations of 2.1 mg/L to 2.3 mg/L which exceeded the values of 2 mg/L as per standards and can be achieved with certain level of treatment.

The determination of the different parameters affecting the water quality was done based on application of Multivariate Statistical Analysis technique which correlates the parameters having similar characteristics using Pearson's Correlation Matrix. The Principle Composite Analysis (PCA) and Hierarchal Cluster Analysis (HCA) were used for identification and grouping of components respectively based on the level of effect created in terms of quality. Strong correlations were observed between pH, Ca, Mg, HCO_3, SO_4, TA, EC, COD, TP, NO_3 and TH indicating alkalinity, leaching of minerals, hardness, high inorganic content, eutrophication and effects of increased agricultural activities. The PCA analysis revealed a total cumulative variance for components of Lake 1 and Lake 2 as 89.32 % and 95.14% respectively. The major components in lake 1 were TA, HCO_3, pH, DO, Temperature EC, Turbidity, COD, TP SO_4, Ca, TH and Cl whereas lake 2 exhibited principal components such as BOD, EC, HCO3, NO3, TA, Temperature, SO_4, COD, TP, TDS, TSS, TH, Na, Cl, Ca and TH. The HCA clustered source contamination in Lake 1 as 15 sites with parameters such as DO, pH, Turbidity, NO_3, K, Temperature, Cl, Mg, COD, SO_4, TP, BOD, Na, Ca, TSS contributing to low pollution and 5 sites with parameters such as TDS, TH, TA, HCO_3, EC contributing to moderate pollution levels. Lake 2 exhibited 15 sites with parameters such as NO_3, TP, BOD, K, DO, pH, Mg, Temperature, Turbidity, Na, Cl, COD, SO_4, Ca, TSS contributing to low pollution and 5 sites with parameters such as TDS, TH, TA, HCO_3, EC contributing to moderate pollution levels in lake 2 respectively.

The prevailing water quality was studied spatially as well as temporally using traditional WQI techniques such as National Sanitation Foundation Water Quality Index (NSFWQI), Bureau of Indian Standards Water Quality Index (BISWQI) methodologies over the entire sampling period. Further, Heavy Metal Index (HMI) was evaluated for monsoon and pre monsoon seasons and Trophic State Index (TSI) was calculated on an average yearly basis using conventional method. Finally, a modified water quality index (MWQI) and modified heavy metal index (MHMI) considering the spatial and temporal variations of the pollutants were prepared for the study locations. NSFWQI and MWQI categorized both lakes as ‘Good’ in terms of water quality. BISWQI categorized both lakes as ‘Excellent’. HMI and MHMI categorization for lake 1 was ‘Good’ and lake 2 as ‘Poor’. TSI classification for both lakes were ‘Eutrophic’ in terms of productivity with nitrogen limitation. The spectroscopic analysis was carried out for soil of the watershed areas, sediments along with water samples of both the lakes at different depths.

The spectroscopic analysis was achieved through scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) along with X-Ray Diffractometer (XRD) to comprehend the morphological and elemental composition of the samples. The soil and sediments for both the lakes showed relatively high Cation Exchange Capacity (CEC) values and therefore implies it could retain and supply nutrients especially cations such as Ca, Mg, K, Al and H, which were present in the tested samples. Many elements and thereby their characteristic properties of soil, sediments and water from both the lakes were similar with slight changes observed in the

morphological structure. This may be attributed to geological and topographical features of the sites in the immediate vicinity.

GIS Modelling technique was used as a tool for attribute prediction at unsampled locations from pre-calculated values at sampled locations for both the lakes. The Interpolation method of Inverse Distance Weighing (IDW) was used for the modelling purpose. The aim of the current study was to predict the water quality in terms of parametric variations for three different seasons of winter, summer and monsoon. The temperature variations were observed to decrease with increase in depth for all seasons at all sampling points and depths for both the lakes. Further, seasonal, depth wise and point wise variations were observed for DO concentrations except for winter season possibly due to stratification effects. The NO_3 concentrations showed no depth wise variations for the entire monitoring campaign except winter wherein the concentrations increased with depth for both the lakes. This may be attributed to the fact that higher levels of DO favors nitrification in lakes rather than ammonification; and hence overall high concentration levels in winters were observed. Similarly, the Total Phosphorous (TP) concentrations showed no depth wise variations for the entire monitoring campaign except monsoons wherein the concentrations increased with depth for both the lakes. The loss of TP from water column in monsoon season due to overflowing and settlements into sediment beds during summer season due to low level of water in lakes might be the possible cause.

The lakes experience tremendous amount of sedimentation due to constant erosion from the shoreline and watershed areas due to increased deforestation along with expansion of agricultural activities. The study therefore focused on evaluation of best possible physical, chemical and biological remediation techniques for study sites. The techniques can be applied to shallow lakes and suited for the study locations. The techniques can be used stand alone or in collaboration with each other to achieve overall better remediation results. Additionally, a small-scale Water Treatment Unit for the population of nearby villages surrounding the lakes have been designed to use the sources as potential for drinking water. Physical remediation technique such as dredging, vegetative buffers and riparian zone stabilization are considered suitable methods for remediation of heavy sediments from the lakes and to avoid further washing off of sediments into it. The dredging measures can be applied to remove the already existing sediments and the vegetation of native plants along the shorelines and can prove to be beneficial in preventing soil erosion, promote infiltration and stop further sediment influx. Use of chemicals such as alum can be used for

flocking of turbidity, nitrates and phosphorous from sediments at neutral pH range of 6-8. The lakes can be considered as fresh water sources and could be utilized for drinking purpose but with suitable treatment therefore the water treatment unit can be considered to be a necessity at the place.

Keywords: Water Quality Index, Designated Best Use, Multivariate Statistical Analysis, Principal Component Analysis, Spectral Characterization, Remediation Techniques.

LIST OF ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
BIS	Bureau of Indian Standards
BISWQI	Bureau of Indian Standards Water Quality Index
BOD	Biological Oxygen Demand
CEC	Cation Exchange Capacity
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
DBU	Designated Best Use
DO	Dissolved Oxygen
EC	Electrical Conductivity
FESEM	Field Emission Scanning Electron Microscope
GIS	Geographical Information System
GOI	Government of India
HCA	Hierarchical Cluster Analysis
HMI	Heavy Metal Index
HTP	Human Toxicity Potential
IDW	Inverse Distance Weighing
ISQG	Interim Sediment Water Quality Guidelines
MHMI	Modified Heavy Metal Index
MSA	Multivariate Statistical Analysis
MWQI	Modified Water Quality Index
NSFWQI	National Sanitation Foundation Water Quality Index

OC	Organic Carbon
OK	Ordinary Kriging
OSEL	Ontario Severe Effect Level
PCA	Preliminary Composite Analysis
PC	Principal Components
PEL	Probable Effect Levels
SAR	Sodium Absorption Ratio
SD	Secchi Depth
SPCB	State Pollution Control Board
STP	Sewage Treatment Plant
TDS	Total Dissolved Solids
TEF	Toxic Equivalent Factors
TH	Total Hardness
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorous
TSC	Total Sanitation Campaign
TSI	Trophic State Index
TSS	Total Suspended Solids
XRD	X-Ray Diffraction
WQ	Water Quality

LIST OF SYMBOLS

AW	Assigned Weight
B	Bad
Ca	Calcium
°C	Degree Celsius
c_i	Concentration of parameter
CHL-a	Chlorophyll-a
Cl	Chloride
E	Excellent
G	Good
HCO_3	Bicarbonate
K	Potassium
Kg	Kilograms
LMH	Litres per square metre hour
LPCD	Litres per capita per day
M	Medium
m^3	Cubic Meter
meq	Milliequivalent
Mg	Magnesium
mg	milligrams
mg/kg	Milligram per kilogram
mg/L	Milligram per liters
M_i	Value of the evaluated parameter

ml	Millilitres
MPN	Most Probable Number
n	Total number of parameters
N	Nitrogen
Na	Sodium
NO_3	Nitrates
P	Poor
Ppm	Parts per million
Q_i	Quality rating value
RW	Relative Weight
s_i	Standard value as in BIS 10500 (2012)
SO_4	Sulphate
U	Unfit for drinking
µg/L	Microgram/Litres
VB	Very Bad
VP	Very Poor
Wi	Weightage assigned to parameter

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CHAPTER 1

Introduction

1.1 Background

Water is often called the tonic of life as it contains ingredients important for human beings [1]. Out of many sources of water available to human kind, there exists only 2.5% of fresh water sources on earth of which 1% is accessible to humans, the maximum volume being trapped in glaciers and snow peaks [2]. Lakes, rivers and springs are few of the most important surface water sources which supply fresh water for consumption [3]. The insufficiency in the surface water resources often makes groundwater sources impeccable for the regular water supply. In the context of surface water bodies, lakes are considered to be one of the most important water resources and are further classified as man-made or natural [4].

The overall water quality of surface sources is affected by geological structure of earth and on the different anthropogenic activities being carried out in its vicinity including construction, waste dumping, agriculture and other associated activities which in turn reduces the utility of the water from that particular source. [5, 6]. Natural processes include water percolating through the soil leading to the addition of large amounts of soluble and insoluble substances into itself thereby altering the properties of the water, which makes it less consumable and sometimes even unpalatable [7, 8]. The problem is quite explicit in the case of arid lakes where water is an important economic factor and the demand and supply balance mismatches can lead to fluctuations in the water supply.

In this context it becomes imperative for keeping an eye on the current and futuristic water quality trends and thereby through implementation of stringent policies and regulations improve the status of water quality of surface as well ground water sources to avoid the water scarcity issues as well as declining water quality standards of potable water.

1.2 Water: Global Scenario

Water resources are unevenly distributed around the globe, with the UN General Assembly of 2003 declared the period 2005-2015 as International Decade for Action ‘Water for Life’ so as to put efforts for the improvement of water characteristics and deal in issues related to water conservation [9]. It is estimated that about 40% of the population of world will be facing serious *'Water Stresses'* by 2035 [10]. The key factor to this is the ever-increasing global population, leading to varied but increased water consumption [11]. Further, the UN estimates that the global population will rise from 6 to 8 billion by 2025 [11] and about 9.7 billion by 2050 with double the population settling in urban areas [10] which would stress out the existing resources to the maximum. The fact that the water resources are unevenly distributed and the regional growth patterns vary across the globe, the water scarcity issues can vary greatly leading to an overall depletion of natural resources.

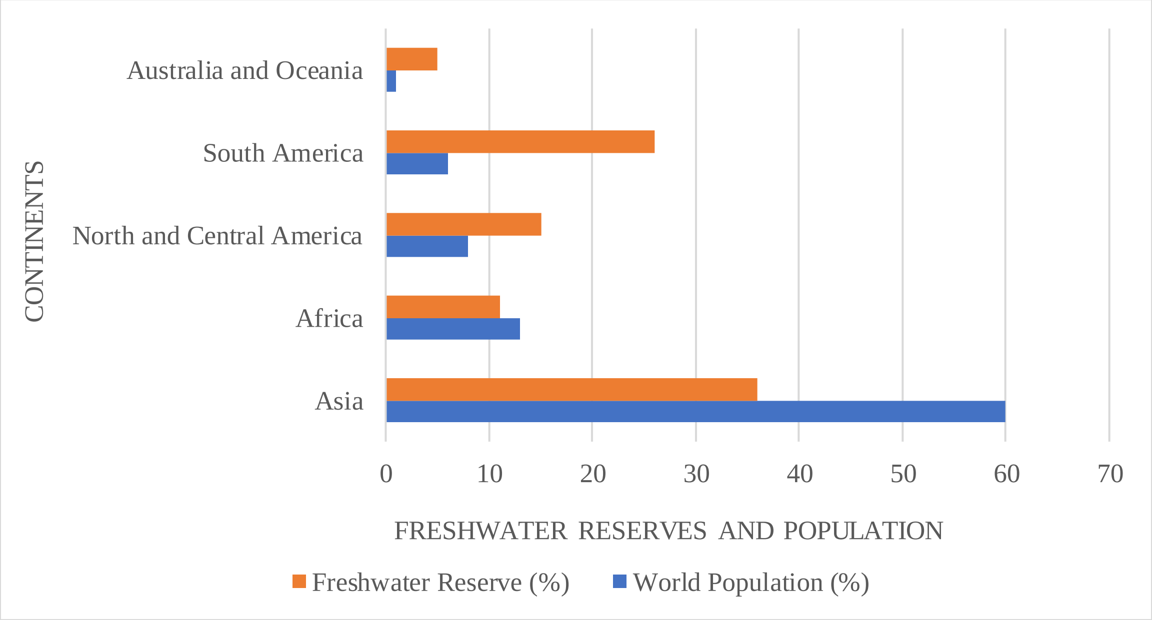

Figure 1.1: Spatial Variation in Fresh Water Reserves across Continents [22]

Figure 1.1 shows variation in the distribution of freshwater sources in comparison to the population across the different continents.

The other significant factor that significantly influences this issue is Global Warming. It has been reported that the mean temperature of surface has risen from 0.3 to 0.6 degrees due to ever increasing anthropogenic activities globally [11]. The ever-increasing global temperatures have a deteriorating impact on our natural resources and water cycles leading to a rise in unnatural climatic conditions, thermal expansion of sea waters resulting in droughts and floods which in turn severely affect water supplies. In this context, both quality and quantity of water supplies have been severely affected. About 663 million people around the globe do not have access to safe and potable drinking water since 2015 [12], the greatest example being the country Bangladesh where people are forced to drink water from sources rich in arsenic and exceed the prescribed WHO standards [13]. The global population has tripled but the demands for safe drinking waters will be six times by year 2050, with 400% for manufacturing and 130% for household usage [14].

The other sector that will be affected by the decreasing water quantity and quality is the Sanitation and Hygiene, with presently about 2.4 billion people lacking basic sanitation facilities [15]. 2 million tons of human waste is disposed of into water sources each day [11] leading to increased and severe pathogenic pollution of these sources, which affect about one-third of all global rivers. The organic pollution due to disposal of household wastes affects about one-seventh of rivers around globe [16]. The practice of haphazard disposal of wastes into the water sources leads to the development of water borne diseases like schistosomiasis, trachoma and intestinal worms affecting more than 1.5 billion people yearly specially children less than 5 years of age [15]. The lack of basic sanitation facilities leading to spread of diseases costs about 1863 million days of school attendance of the children globally [17].

The water scarcity and decreasing water quality is a global issue which can lead to a *'Global Pandemic'* like situations in near future. The ever-increasing water demand can lead to an exploitation of the surface water resources, as well as reduced co-ordination and co-operations between nations leading to conflicts over water usage issues which might deteriorate to *'water wars'*. The sustainable management of water resources varies among nations around the globe, but there is a serious need to address this problem because it could be a potential root cause of serious global issues. According to a 2016 study, the longer the government takes to address and scale-up the efforts the harder it becomes for the population to survive [18].

1.3 Water: Indian Scenario

India holds about 16 % of the world population which is greater than 1.3 billion of the total world population but occupies only 2% of earth's surface area which accounts to about 32,87,590 sq. km., so there lies a considerable difference in population to land ratio. The average annual runoff from rivers accounts to 4% of total surface runoff. The livestock population of India is about 500 million which is 20% of world livestock population [19]. The coastline of India extends to about 7500 Km, with 12 major rivers accounting to an area of 253 Mha of catchment area and 46 medium rivers accounting to total catchment area of about 24.6 Mha along with many other inland sources distributed unevenly across the country [20]. The thirteen river basins accounts to an area of greater than 20, 000 sq. km. which is about 82.4 % of total drainage basins contributing to 85% of total surface flow [21, 22]. India receives maximum amount of rainfall in monsoons (including snowfall), accounting to 3000 billion cubic meters with a wide spatial distribution across country [23]. The total of 690 billion cubic meters of surface water resources can be utilised [24]. Though, there is a plentiful of surface waters and rainfall, the water still remains a national concern. Rapid Urbanization, increased population growth and economics have led to an increase in the water demand of the country in various sectors.

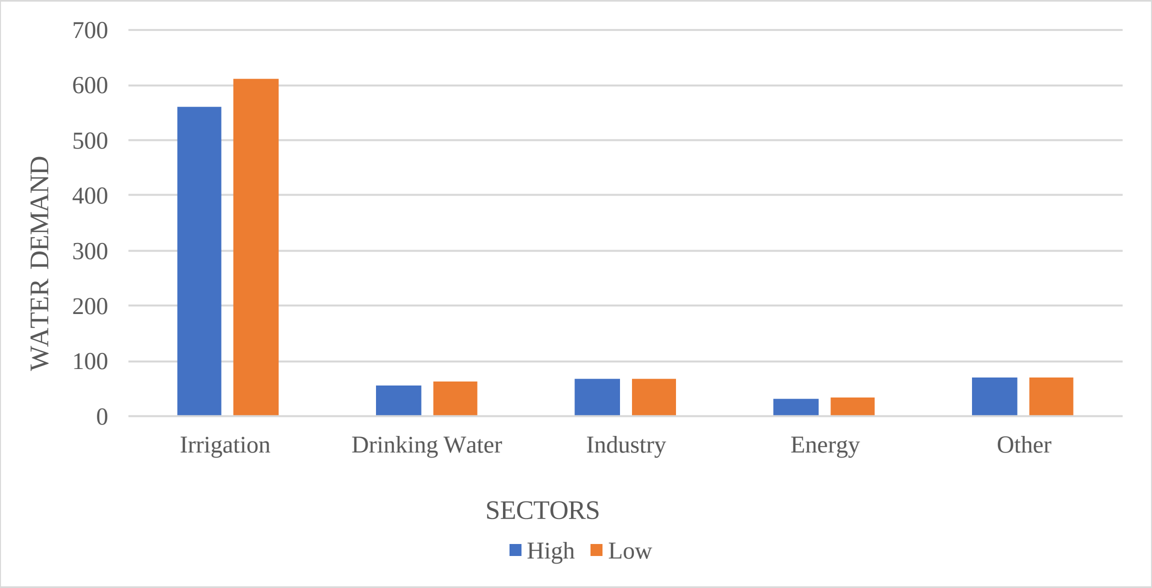

Figure 1.2: Projected Water Demand for India [22]

Figure 1.2 shows projected water demand for year 2025 in various sectors with water demand for irrigation being maximum. A considerable increase in the water usage can be observed due to changes in lifestyle, food habits and improved living standards due to modernization. In country like India, where the population is much higher and water reserves are much less, the country faces a serious water stress with a per capita water availability of 1545 m^3, projected to be 1401 m^3 by 2025 and 1191m^3 by 2050 [25, 19].

The main source of water availability in India is through surface and sub-surface but continuous and increased discharge of industrial wastes, agricultural refuse, and domestic waste has caused about 70% of surface sources to be polluted [22]. The major morbidity rate in India is contributed by Water Borne diseases [26]. Water Quality data from CPCB reports shows an alarming rate of increase of organic and bacterial pollution in lakes and rivers [27]. The concerns have led the government of India to implement some serious steps but the rate of improvement in the status is far from expectations. The National Water drinking mission by Government of India ensures 8 litres of safe water to be provided to every individual every day which must meet prescribed BIS standards [9]. The Total Sanitation Campaign (TSC), is another step, in collaboration with UNICEF to increase the awareness among rural population and generate awareness about the sanitation and sanitary facilities in India [9].

1.4 Water Quality Deterioration and its Environmental Impacts

The natural lakes are confined bodies of water which have a unique ecosystem lacking a continuous flow system for self-cleansing and therefore leading to the accumulation of heavy metals and nutrients [3]. High concentrations of heavy metals are dangerous for animal as well as human life and therefore need to be indexed thoroughly for proper evaluation and remediation. The nutrients on the other hand can enter into the lake water through input of human excreta or use of fertilizers which contain nitrogen, phosphorous and potassium which are primary sources for plant growth in lakes, the phosphorous being the major limiting factor for the growth of algae causing eutrophication in lake water. This effect is often assessed using the Trophic State Index (TSI) using Carlson’s formula. There are various kinds of modelling techniques which are used for prediction of future changes and thereby application of suitable feasibility solutions for remediation. The models include watershed models, ground water models and lake models that provide information for design of treatments.

1.5 Water Management Policies and Regulations in India

The Management of various water resources in India is governed by many bodies including Ministry of Environment and Forests, Water Resource Department, Jal Shakti Vibhaag, Central pollution control board (CPCB) and State Pollution Control Boards (SPCBs).

The Policies and rules relevant to Management and Supply of water in India are summarized below [28]:

National Water Mission -National Action Plan on Climate Change-Volume1 & 2 -Ministry of Water Resources (2008, 2009): This plan ensures conservation of water by minimizing wastage and ensuring equal distribution of water across and within the states through integrated approach.

National Water Policy- Ministry of Water Resources (2002): This policy addresses the water scarcity issue and the need to conserve these resources through sustainable means.

The Water (Prevention and Control of Pollution) Rules – Ministry of Environment and Forests (1974): It aims at prevention and control of pollution of water and thereby maintain its characteristics.

Guidelines for National Lake Conservation plan - Ministry of Environment and Forests (2008): It aims at restoration of water quality and lake ecology in different parts of nation.

The Water (Prevention and Control of Pollution) Cess Act- Ministry of Environment and Forests (1977): It aims at collection of cesses on water from persons owning industries to procure resources for central and state boards for preventing and controlling pollution.

National Water Policy: It aims at making framework for policies and creation of system for improvement of existing conditions keeping in view national perspective.

1.6 Need of the study

Water Quality Management is one of the most neglected and inattentive aspect in India’s environment. There is lack of awareness amongst people for the effectual management of water sources in India. The practice of water quality management in India has been suffering over the last few years. Only few sources have been managed and maintained appropriately as per requirements in Indian context. Inadequate management of water sources in India exists due to various reasons including the lack of appropriate monitoring technologies, resource allocations, awareness amongst local people and the inadequacy of government to maintain and develop sources. The major issues that arise from such negligence is improper usage of water resources most probably for a single purpose rather than their Designated Best Use (DBU).

Hence, in this aspect, the present study intends to have an elaborative view of water quality management aspects based on global and Indian scenarios. This would help to elaborate on the present status of Water and to ascertain such issues which hinders Quality Management techniques. Hence, the study elaborates on current status of water quality in two natural lakes in Haryana, identifying the sources of pollutants, their classification into different groups, enumerating the effects of anthropogenic activities on quality of lakes, it also models the Lakes through GIS modelling technique and based on the above recommends the remedial measures to improve the current and futuristic WQ status.

1.7 Objectives of the Research Work

The objectives of the present study are compiled as below:

1. Determination of the existing Designated Best Use (DBU) of the lakes covering one year sampling analysis representing any seasonal or annual variations.
2. Evaluation of spatial and temporal variations amongst concentrations of physico-chemical parameters using Multivariate Statistical Analysis.
3. Depth-Wise Quantification of above parametric analysis by using 3(a) Existing Water Quality Index (WQI) method, 3(b) Existing Heavy Metal Index (HMI) method, 3(c) Trophic State Index (TSI), 3(d) Proposing new and modified WQI and HMI technique to represent any changes in hydrological and limnological aspects of the lakes.
4. Determination of temporal variations in the water, soil of watershed area and sediment of lake bed using Spectral characterization techniques.
5. Application of suitable water quality prediction model for predicting status of lakes based on the evaluated water quality characteristics.
6. Theoretical evaluation of best possible remediation measures and prototype design for Water Treatment Unit.

1.8 Thesis Outline

The first chapter of the thesis gives a brief overview of the importance of water in daily life, its sources and importance and present status in terms of quality. Apart from this, the chapter also highlights the quality of water in context of Global and Indian Scenario and also the associated environmental impacts due to natural and anthropogenic causes. Further, the chapter also outlines steps taken by Government of India for Water quality restoration and maintenance. The chapter is the preliminary chapter and sets the premise of the study including the identification of the main objectives of the research work to be carried out.

The second chapter presents a comprehensive literature review including related studies carried out in Indian as well as global context to observe the significance of Water Quality determination through various aspects and its importance not only in present scenario but for future consideration as well. In particular, this chapter presents important facts of the research carried out earlier in context of the proposed research objectives.

The third chapter deals with the description of the study areas in Haryana state as well as the sampling methodology employed for determination of Designated Best Use (DBU) of the both the Lakes. The overall DBU was determined based on specific set of parameters as per Central Pollution Control Board (CPCB) guidelines over the entire sampling duration. Additionally, the DBU was also evaluated for seasonal variations for both the lakes. Further, the intended use of the water bodies has been specified through DBU evaluation rather than for any predefined single purpose.

The fourth chapter focuses on description of parameters utilized for study and their importance in terms of Water Quality determination, source identification and grouping of correlated physico-chemical parameters achieved through application of Multivariate Statistical Analysis techniques. Categorization of pollutants was achieved through Principal Component Analysis (PCA) and Hierarchal Component Analysis (HCA) used for grouping of sampled sites into Low, Medium and High pollution zones based on already determined physico-chemical parameters.

The fifth chapter deals with quantification of the physico- chemical parameters through Water Quality Indexing Techniques (WQI) for reduction and more precise description of the collected data at different depths. Different pre-existing techniques of indexing have been applied including '*National Sanitation Foundation Water Quality Index*' and '*Bureau of Indian Standards Water quality Index*' to evaluate the quality of water based on physico-chemical and biological parameters. '*Heavy Metal Indexing*' was used for determination of water quality based on heavy metals and '*Trophic State Indexing*' technique was utilized to determine the water quality in terms of nutrient status. In addition, two novel '*Modified Water Quality Index'* and *'Modified Heavy Metal Index'* were proposed during study to remove ambiguity arising from usage of different indexing techniques.

The sixth chapter deals with the spectroscopic analysis of soil of the watershed area, sediments of both the lakes and their comparison to determine spatial and temporal variations. The spectroscopic analysis was achieved through scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) and X-Ray Diffractometer (XRD) to comprehend the morphology and elemental composition of the samples.

The seventh chapter presents the usage of GIS as a tool for attribute prediction at unsampled locations from pre-calculated values at sampled locations. The Interpolation method of Inverse Distance Weighing (IDW) was used for achieving the objective. The aim of the current study was to predict the water quality in terms of parametric variations for three different seasons of *Winter, Summer and Monsoon*.

The eighth chapter presents the *Physical, Chemical and Biological* remediation techniques for study sites. The techniques can be applied to shallow lakes and for similar study locations. The techniques can be used stand alone or in collaboration with each other to achieve overall better remediation. Additionally, a theoretical design of a Water Treatment Unit for the population of nearby villages have been presented to use the source as potential for drinking water.

The ninth chapter focuses on comprehensive summary of the results and conclusions that are resultant from the overall study. However, some recommendations for upgrading current water quality management practices in Haryana along with promoting appropriate remediation techniques with the remarks of the future scope of the research work has also been included.

CHAPTER 2

Literature Review

The chapter enumerates a brief overview of the literature survey carried out for the entire study conducted. It provides necessary facts and draws relevant information from earlier reported scientific literature for effective management of surface water sources specially the natural lakes. It presents and summarizes the different approaches for appropriate lake water management studies carried out both globally and in an Indian context. Water is available to us in many forms but for human consumption the freshwater sources are of main importance [28]. The main sources of pollution that endanger these sources are effluents arising out of domestic and industrial wastes. The quality of the water source is a major issue since the water is not only used for drinking purpose but also for different other associated activities like agriculture, tourism, economic and human usage. Hence, it becomes imperative for conservation and management of this resource on a global scale. There are various kinds of pollution prevalent in the society, of which water pollution is of a significant concern and a major factor affecting sustainable development [29].

The Designated Best Use (DBU) criterion by CPCB in this context is a sustainable approach for classification of water bodies based on their intended usage. The DBU tables list predefined set of parameters and their prescribed limits which categorize the water bodies into various classifications such as Drinking water source with Chlorination (A), Bathing (B), Drinking water source with Treatment (C), Development of wildlife and Fisheries (D) and Irrigation (E). The parameters can be evaluated and compared with pre-defined set of parameters in each category to determine the present status of water source and its intended use can be assigned [30].

The quality of water is determined on the basis of physico-chemical and biological parameters. The spatial and temporal variations are also taken into consideration, since these variations can majorly affect the water quality making it difficult to interpret the current water quality status of source [31]. A process of continuous deterioration of a water source can lead to a complete and overall contamination therefore the restoration and its reuse becomes quite impossible. As such, systematic observations and regular monitoring of parameters can help in appropriate policy framing for restoration as well as determination of the best possible usage of these available sources. The quality determination is based on multiple chosen parameters and their possible interaction with each other. The agencies such as World Health Organization (WHO), Bureau of Indian Standards (BIS) and Central Pollution Control Board (CPCB) have given specific prescribed standards for assessing the water quality and determining the best usage of water bodies [32-35].

In regard of above, the parameters such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Organic Carbon (TOC) were assessed at 114 stations in watershed areas of Han river, Nakdong river, Geum river, Yeongsan river and 49 stations in various Lakes in South Korea [36]. The study presented a comparison between the analysis of these parameters and their interaction effects in estimation of organic components. The study utilized National Water Quality Monitoring Data collected over 5 years and determined that a high correlation of 0.87 and 0.66 existed between BOD and TOC in case of rivers and lakes respectively. Further, COD and TOC were also determined to have strong correlation values of 0.93 and 0.75 for rivers and lakes. The study concluded that determination of TOC alone can be beneficial rather than determining the parameters for BOD and COD.

A study conducted in the 4 lakes of Udaipur [37] primarily focused on the physico-chemical parameters. Random sampling was done for April 2014 and the parameters were analyzed through American Public Health Association (APHA) and the values were compared with standards prescribed by WHO and BIS. It was observed from the analysis that Biological Oxygen Demand (BOD) and Ammoniacal Nitrogen (NH_3-N) was found to be higher than prescribed limits thereby confirming bacterial input, organic matter and animal waste in the lakes. Amar Sagar (AS) and Dhani Sagar (DS) were found to be polluted mainly by canals carrying municipality waste, organic waste, disposal by residents and agricultural practices. The study concluded that an immediate remedial action needed to be undertaken to prevent the loss of lake water source

A similar study was carried out for Chandola Lake in Gujarat [38], wherein 10 monitoring sites were evaluated for 11 physico-chemical parameters (EC, TDS, pH, DO, Alkalinity, TH, Ca, Mg, NO_3, and BOD) over a sampling period of September 2013 to August 2014. Seasonal variation was also taken into consideration. The analysis of the samples revealed that concentrations of TDS, Alkalinity, pH, TH, and Ca were determined to be greater than the permissible standards prescribed by WHO and BIS particularly for summers and monsoon seasons rendering the water unfit for human consumption.

A study conducted on 28 freshwater lakes from the province of Serbia [39], physico- chemical parameters and nutrient concentrations were evaluated for the samples collected from these lakes. The value for most of the samples exceeded the values prescribed for drinking waters by WHO, Government of the Republic of Serbia and Water Act and Regulations. In particular, Lake Međuvršje showed high NH_4 concentration (28 mg/L), while samples collected from Lake Ovcar Banja reported high concentrations of phosphorous and nitrogen of 0.15 and 1.21 mg/L. The study concluded that the lakes in Siberia which were phosphorous limited due to input of nutrients from agricultural sources along with animal and human waste input and were concluded to be unfit for drinking purpose.

In a study conducted on 7 arid and semi-arid lakes in Xinjiang eco-region in China [40], TDS was found to have a significant role in algae growth in arid and semi-arid regions along with other parameters like TP, TN, Secchi Depth and Chlorophyll-a (CHL-a) due to input of organic matter with TDS. The Freshwater Lakes, Saltwater Lakes and Brine Lakes were concluded to be Oligotrophic and Mesotrophic respectively.

In a study conducted to determine the water quality in terms of Hardness, Alkalinity, Ca, Mg, BOD, COD, TDS, pH, Conductivity and Temperature in river waters of Kaushalya river of Parwanoo, Ghaggar river of Panchkula and Siswan nadi of Mohali around Chandigarh City by [41]. It was determined from the study that parameters of hardness, TDS and COD were found to exceed permissible limits prescribed by WHO and BIS. The authors concluded that there was an urgent need to check functioning of nearby Sewage Treatment Plant (STP's) and the quality of industrial effluent into the rivers. It was recommended by the authors that proper treatment was necessary before utilizing it as a source of water supply.

A study was conducted to determine the quality of water from West Bokaro coalfield [42] for its potential use for domestic and irrigational purposes. A total of 30 water samples were analyzed in terms of pH, EC, TDS, TH, cations, anions and dissolved silica. From the analysis conducted, it was determined that pH was seen to vary between neutral and alkaline nature. TDS was found to be in higher concentrations due to the lithographic and hydrological conditions of local areas. The major anions and cations were determined to be (SO_4, HCO_3) and (Ca, Mg) primarily due to rock dissolution from surrounding areas. The water was found to be in an overall good state for irrigation but in some areas due to higher salinity and Mg concentrations were unfit for irrigational activities.

A study was conducted from 2002 to 2003 in Shikoku region of Japan in three dam lakes to understand the effects of precipitation both directly and indirectly on eutrophication levels in the lakes by [43]. The Shikoku mountains were studied for high precipitation conditions whereas Sanuki mountain range was studies for low precipitation conditions. The dam lakes in Shikoku were classified to be oligotrophic to mesotrophic in eutrophic condition whereas the Sanuki mountain Lakes were classified mesotrophic to eutrophic in conditions. The precipitation was found to affect water quality in terms of high nitrogen, low DO, and therefore an overall increase in primary production in lakes. In case of Hypereutrophic Dam Lakes, under low precipitation condition the surface water flowed out and no DO water under thermocline rose to take its place resulting in anaerobic environment spreading across layers.

In a study conducted in the Yungui plateau in China [44], 24 lakes were assessed for water and sediment nature by describing their physical and chemical properties and the potential effects of anthropological and natural activities on their quality. It was observed from the study that there existed differences in water quality of the deep and shallow lakes in terms of nutrient content due to human interferences in watersheds and other associated anthropogenic activities. Increased non-carbonate and clastic sediments from watersheds induced low organic content in the sediments of all of the study lakes.

A study was conducted for determining seasonal variation in terms of physico-chemical parameters, at 5 selected sites of Parvara river in Maharashtra for purpose of irrigation [45]. A moderate variation in the concentration of parameters was observed for all seasons. Of the five selected sites, effluent concentrations of waste water from city at sites 3 and 4 led to pollution in the river during the monsoon season making it unfit for irrigation. In terms of irrigation quality Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) were determined and found to be within permissible ranges indicating good water quality.

This parameter detection can help in detection of pollution levels and can give a clear picture of status of water quality for the surface water bodies and hence help the regulatory authorities for framing of appropriate policies [46]. The sources which are detected to deviate from the prescribed limits are often rendered as polluted and unfit for human consumption, the prolonged usage of these sources can have ill effects on human health.

In the above context the identification of pollution sources and their grouping into different components is of utmost importance. Principal component analysis (PCA) and Hierarchical cluster analysis (HCA) are two such techniques which are used for source identification and component grouping. The source identification helps in clustering of components into groups or areas requiring major focus.

In lieu of these facts, in a study conducted in the Tricity region of North India for possible effects of groundwater contamination evaluated three non-engineered landfill sites at various downward distances through WQI analysis revealing improved groundwater quality [47]. PCA and HCA analysis was used for identification of groundwater sampling sites to low, moderate and high pollution zones. The study suggested conversion of sites into engineered landfill sites as well as consideration of new sites for landfill.

The evaluation of groundwater pollution potential through WQI, HMI and Leachate Pollution Index (LPI) was done by [48]. PCA technique was used for determination of components from either natural or anthropogenic sources. HCA analysis was used for grouping of these components into three major zones. The study detected most of the physico- chemical parameters in excess of prescribed limits in study areas.

The discharge of wastewaters from the neighboring town into the dam and agricultural area of Koudiat Medouar watershed led to heavy levels of anthropogenic pollution of the source. Multivariate Statistical Analysis (MSA) techniques were used for determination of spatial and temporal variability in the watershed [49]. The results from PCA revealed dominance in variability of Na, K and HCO_3 at first station, EC at second station and NO_3 and pH at third station. The HCA analysis exposed the anthropogenic activities and water -rock interactions as main cause in chemistry of major ions such as Mg, Ca, HCO_3, SO_4.

Sustainable use of water sources for different purposes is of primary need. A study evaluated the groundwater quality of Gaya region to demarcate the potential groundwater zones [50]. The cations followed order of Ca>Mg>Na>K whereas anions followed HCO_3>Cl> SO_4 >NO_3>PO_4. PCA analysis was used for determination of correlation and 7 major principal components (PC) were determined having variance > 80%. PC (1-3) reflected interrelationships with dissolution, weathering and anthropogenic activities being major phenomenon associated with the presence of ions whereas PC(4-7) showed independent and haphazard behaviors.

In a study involving the locations of Birimian, Cape Coast granitoid and the Densu River, the quality of the water and the different anthropogenic sources of pollution were evaluated using WQI and MSA [51]. It was observed from the results that the Cape Coast granitoid showed higher ionic concentrations due to dissolution of soil contents. Point sources of pollution such as input of organic waste, fertilizers and agrochemicals were found to have a deteriorating effect on water quality. PCA analysis revealed that 4 PC's were determined with variance > 73.16%. The factor plot score identified polluted areas, though major factor for deteriorating water quality was geological factor but, in some places, anthropogenic activities were found to take dominance.

The study conducted in Varanasi city of Uttar Pradesh utilized 23 samples collected from different locations covering dumping, roads and agricultural areas [52]. The study revealed that though the average concentration of all other heavy metals in road and dumping soil were found within permissible limits but the concentrations of Copper (Cu) and Lead (Pb) exceeded their limits due to contact with nearby roadside soil. The Integrated Pollution Index IPI varied between 0.59 to 9.94 due to the input of heavy Pb and Cu. The MSA revealed a significant level of co-relation amongst the two heavy metals. The result of PCA analysis revealed that PC1 was dominated by agrochemicals, PC2 was dominated by vehicular emissions, PC3 was dominated by waste dumping from steel industry and PC4 was dominated by lithogenic components such as parent material contributing various soluble and insoluble salts along with small amount of anthropogenic activities. Appropriate measures are suggested for avoiding ill effects on human health.

In a study conducted on Gomti River by [53], various MSA techniques were utilized in evaluating the spatial and temporal variations in a large water quality data set collected from 8 sites over 5 years of sampling duration in high, moderate and Low pollution zones. A total of 24 parameters were evaluated and the different MSA techniques involved use of PCA, HCA, Discriminant Analysis (DA) and Factor Analysis (FA) for studying these parameters. 6 PC's were determined through FA and PCA analysis with a variance of 71%. DA analysis conducted presented best results for variations and dimensionality reduction. 5 parameters (pH, Temperature, Conductivity, Total Alkalinity, and Magnesium) were determined optimum to represent temporal variations with 88% right assignations while for spatial variations were determined from 9 variables (pH, Temperature, Alkalinity, DO, Ca, BOD, Cl, SO_4 and TKN) with 91% accuracy. The study concluded that MSA is a useful tool in reduction of complex data sets for interpreting the results and thereby help in designing of effective management techniques.

In lieu of such above studies it often becomes difficult for regulatory authorities to describe these elaborative data sets and present to general public the results obtained in a concise and easy manner [54], since the continuous monitoring procedures can often lead to large data sets which are difficult to interpret [44]. The traditional methods of monitoring and sampling can be time consuming and often at times be ambiguous and complex. Many studies have reported the difficulties experienced by researchers in conducting laborious experimental procedures and application of conventional methodologies for water quality evaluation [55; 56]. Hence, there is a dire need of simple tools which would clearly describe the results to general public and regulatory bodies [39]. Water Quality Index (WQI) is another one such tool in which the parameters can be determined experimentally and then the appropriate WQI method can be chosen for representation and interpretation of results. The choice of selection of these WQI methods depend on evaluated parameters, the purpose of study and the best fitting Indexing technique [37;41].

The National Sanitation Foundation Water Quality Index (NSFWQI) was evaluated in Jajrood, Damavand River and Mamloo Dam using 14 WQ parameters (pH, EC, DO, BOD, TS, NO_3, PO_4, Turbidity, Temperature, Faecal Coliform (FC), Na, K, Ca, and Mg) [57]. The study concluded the NSFWQI values of Jajrood river, Damavand river were good (71.7) and medium (64.5) categories whereas the mixed waters near Mamloo Dam were of good classification (77.3). It was concluded from the study that the water quality determined for Jajrood river, Damavand river and mixed waters were suitable for drinking purpose with advanced treatment only whereas for Mamloo Dam the water can be used for drinking purpose with conventional treatment. The waters from all the sources can be used directly for irrigation.

In a study conducted on the water quality of Nile River at southern part of Aswan High Dam reservoir and Lake Nubia during low flood periods using NSFWQI for 3 consecutive years (2006-2008); the water quality was determined to vary from Excellent to Good due to spatial changes resulting from hydrological and morphological features [58].

In a similar study conducted in Anzali wetland located at southwest of Caspian Sea in Iran, the water quality was evaluated for the years 1985, 2007 and 2014 using weighted arithmetic $NSFWQI_a$ and Weighted Geometric $NSFWQI_m$ using 9 WQ parameters (pH, turbidity, Temperature, DO, NO_3, TS, PO_4, BOD and FC) at 8 different sampling stations. The mean of the indices was considered over a 3 years period and the WQ was determined to be better for western and central stations in comparison to other locations which experienced discharges of Industrial and Agricultural waste leading them to be classified as Poor [59]. The study concludes use of aggregation method for determination of WQ of ecosystem and its division accordingly.

Two Natural Lakes (Lake Zazari and Lake Petron) in Greece [60] were evaluated using the NSFWOI technique considering 14 WQ parameters. From the study it was concluded that the WQ for Zazari and Petron Lakes were Fair and Bad. The study concludes a need of special restorative measures to be undertaken for different areas in regard of individual WQ recorded at those points.

A study conducted considering 5 monitoring stations of Beheshtabad River in Iran at Chaharmahal and Bakhtiari Province used NSFWQI technique for classifying the water quality as the selected sites. The parameters considered for the study were (pH, EC, DO, BOD, TS, NO_3, PO_4, Turbidity, Temperature). It was concluded from the study that The WQI varied from Average to Good with the classification varying from upstream to downstream conditions. Effluent waste water and fertilizer discharges were main reasons for poor WQ. The authors [61] suggested the need of strict rules and guidelines for preservation of the Lake water.

The Temporal Variations in Lake WQ at Boukourdane dam in Northern Algeria was determined in a study [62] over 2-year period from January (2013-2015) at 4 different sampling sites. The WQ was determined using NSFWQI were categorized to be between Medium and Good with values varying between 60 to 72. The overall quality was classified as Medium with the decrease in quality noted during summer and autumn seasons. The degradation of organic matter led to variation in the nutrient concentrations in the seasons. The study concluded an establishment of regular and continuous monitoring system for restoration of wetland be set up.

Other studies utilized variable parameters such as Ortho-phosphate and TDS instead of widely used parameters to determine the NSFWQI for determining the change in the WQI for Sefidroud River in Iran [63]. A significant difference in WQ was observed, with original parameters, the WQ being classified as 'Bad Status' whereas using the variable parameters the status of WQ was determined to be 'Good'. The average WQ in both the cases were determined to be 'Medium' for Wet season and 'Bad' for Dry season. The study concludes a proper application of NSFWQI for water bodies while incorporating variable parameters.

In a study carried out in Chandola Lake of Gujrat in India, about 10 sampling locations within lake were analyzed for 11 physico-chemical parameters (pH, EC, DO, BOD, TDS, NO_3, Cl, Alkalinity, Total Hardness, Ca, and Mg) [38]. The study was carried out for 3 seasons of monsoon, winter and summer covering a total duration of a year. The water quality was reported using BISWQI and it was determined that the WQ of summer and monsoon seasons were unfit for drinking.

In a study conducted by [64] to determine the WQ of Sankey Tank and Mallathahalli lake in Bangalore region, 3 locations (A, B and C) were considered for sampling in Sankey Tank and Mallathahalli lake. The sections considered in the Mallathahalli lake were inlet, center and outlet zones. Study was carried out over a period of 3 months during March to May 2012. All major cations and anions were taken into consideration for determination of WQ apart from normal parameters generally included in determination of WQI like pH, EC, TDS, NO_3, K, Alkalinity, Total Hardness, Ca, Mg, Cl, SO_4, F, Fe and were compared with BIS standards. Further, SAR was determined to determine its suitability for irrigation purposes. The water was determined to be in the classifications of hard to very hard for both the sites. The WQI characterized Sankey Tank to Range '*Good*' with the value ranging from 50.34 to 63.38 whereas Mallathahalli Lake was categorized to be '*Poor*' with value ranging from 111.69 to 137.09.

A study was conducted in Bangladesh to determine the WQ of drinking water samples across the country in context of the Public Health Improvement [65]. Cross- sectional study was conducted at 24 random sites wherein measurements of parameters like pH, Arsenic, Fe, Mn and Salinity were recorded. The samples were found to be highly alkaline in nature and Mn concentrations were in medium range whereas Iron concentrations exceeded permissible limits at maximum sites. The WQI indicated that out of total sites considered for sampling, 33% sites had good quality drinking water with the remaining sites having poor quality of drinking water

A similar such study was carried out in Hemkund Lake in Uttarakhand State of India to determine its existing water quality by [66]. 19 physico-chemical parameters were evaluated and compared with BIS standards and the WQI was found to be categorized as 'Excellent' but the lake needed continuous monitoring for its proper conservation and management.

In the context of above prevailing studies, one of the potential issues underlying in determination of different WQI techniques are uncertainty and eclipsing which can lead to its limitations in terms of application and misinterpretations based on aggregation [40]. The ambiguity can be associated with the selection of parameters which is rigid in case of indexing and therefore the aggregation functions associated with one indexing technique cannot be applicable for the other [36; 67]. Keeping in view of these limitations, efforts have been made by different researchers to modify and improve the existing WQI determination leading to the formation of a modified version of WQI to overcome the existing difficulties.

In an assessment carried out to determine the quality of groundwater in Tumkur Taluk considering the physico-chemical analysis of the different parameters including pH, TH, Ca, Mg, HCO_3, Cl, NO_3, SO_4, TDS, Fe, Mn and F [68]. The WQI was determined in conjunction with regression models for future prediction of WQ based on the present status. The present WQ status revealed it to be categorized from good to unfit. The poor quality of water was due to high values of NO_3, SO_4, TDS, Fe, Mn, F, TH, HCO_3. The author concluded that the water needs to be treated to some degree before being utilized for drinking.

Another similar study reconsidered the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) to form an efficient Drinking Water Quality Index (DWQI) [69]. The aim of the modified index was to determine the drinking water quality of rural communities in Canada. In particular, rural provinces of Khuzestan were analyzed for the drinking water quality over the study period of four years from 2009-2013. The CCME WQI was modified for assignment of weight factors, input parameters, exclusion of carcinogens and bioaccumulates to reconsider the effects of unequal measurement for input parameters. The benchmarks were taken as criteria for categorizing the DWQI. The DWQI utilized 5 categories including Poor (0 to 54.9), Marginal (54.9-69.9), Fair (70-84.9), Good (85-94.9) and Excellent (95-100). The modified index was determined for spatial changes and not for temporal changes. Over the entire study period, the proportion for different categories could be summarized as excellent (6.7%), Good (59.1%), Fair (26.2%) and Poor (0.1%). Additionally, study also showed that the determined Turbidity Index (TI) and Ryznar Index (RI) used as basis for health and aesthetics had violations for 22.7% and 63.2% respectively of the total samples. It was concluded from the study that proposed DWQI were flexible, stable and reliable for WQ determination and can be used as an efficient tool for categorizing drinking water sources.

A study on Loktak Lake was carried out using the principle of WQI using 5 sampling locations, the location being a wetland dominated by anthropogenic activities [70]. 20 WQ parameters namely Temperature, pH, EC, Turbidity, DO, TH, Ca, Cl, F, SO_4, Mg, PO_4, Na, K, NO_2, NO_3, TDS, TC, BOD, and COD were determined through standard procedures. The parametric values were compared with BIS and WHO guidelines, to reveal the status of existing WQ. It was observed from the result that the parameter NO_2 was a major factor which affected the water quality. Unlike the standard procedure wherein the relative weights assigned to parameters are pre-determined in the BISWQI, the study utilized allocation of weightage to the different considered parameters based on averages accumulated through global literature. Utilizing this concept, the lake water was rendered unfit for drinking and other activities though it’s still being used by locals. It may be concluded that reassigning weightages to existing parameters for determination of water quality represented by WQI could be a great tool for policy makers for sustainable management of water body.

A study conducted at the mine site of Jharia Coal Fields [71] used the concept of WQI for determination of surface water contamination. Further, a Modified Water Quality Index was used for evaluation of existing status at the surface location. 18 surface samples were evaluated for 9 WQ parameters namely pH, TH, Ca, Mg, HCO_3, Cl, NO_3, SO_4, and TDS throughout the site. From the results it was concluded that samples were categorized to be 17 % as Good Category, 61% as Poor Category and 22% as Very Poor. The main reason for deterioration in the WQ was the presence of high concentrations of cations and anions. The authors concluded that majority of the parameters exceeded the permissible limits prescribed by BIS and hence unsafe for human consumption.

The industrialization and urbanization along with other increased anthropogenic activities has led to increased input of toxic pollutants into the water body which ultimately leads to a reduction in the quality of water. The ever increasing population has led to an increase in the demand of water but the addition of these toxic pollutants leads to decrease in the quality of water thereby putting a lot of pressure on the existing resources leading to its over utilization. The accumulation of toxic metals in water body needs to be determined through measurement of their concentrations in the water bodies [72; 73]. The accumulation in large amount can often lead to harmful effects on humans, plants and other organisms. Therefore an extensive study of the toxic characteristics of water bodies is considered necessary for complete water quality assessment

Several studies in the above context have been carried out. A study evaluating heavy metals in sediments of freshwaters in Serbia were carried out [74]. The heavy metals considered for the study were Cd, Cu, Co, Mn, Cr, Pb and Zn. The study utilized the concepts of Enrichment factor (EF), Correlation Analysis and box Plot methods to determine the effects of these metals. The results for the study revealed selective contamination of the freshwater watersheds with heavy metals. The EF suggested none to moderate enrichments for most elements except Cd, Cu and Zn which showed severe enrichment due to prevailing anthropogenic activities around the sampled sites. The study concluded that elements used in the study can be utilized for anthropogenic estimation except Co which can be used for normalization.

Another similar study was carried out to determine toxicity, Heavy Metal Pollution and Ecological Risk Assessment for sediments of Haihe Basin in China covering a total of selected 220 sampling sites [75]. From the sampling analysis conducted, the average concentrations of Cr, Cu, Ni, Pb and Zn in sediments were determined to be 129, 63.4, 36.6, 50 and 202 mg/kg respectively. The results for Geo- Accumulation Index and Pollution Load Index indicated that the sediments were heavily affected by the selected heavy metals considered for the study. The enrichment levels were maximum for Cu and least for Ni with determined values of 3.27 and 1.44 respectively. The mean index value of 38.9 indicated that the sediments showed low potential ecological risk but biological toxicity and therefore heavy metals pollution should be addressed at study site during development of ecological restoration strategies.

A study was undertaken to evaluate Akkulam-Veli Coastal Lake in Kerala for heavy metal contamination in sediments [76]. Heavy metals such as Cadmium, Copper, Lead, Manganese, Nickel and Zinc were used to determine the Contamination Factor (CF), Pollution Load Index and Geoaccumulation Index (I_{geo}). The results indicated contamination with Cu, Pb and Zn maybe attributed to effluent sewage disposal, other wastewater discharges and land run- off. The study was carried out in 2 seasons namely pre-monsoon and monsoon. Results obtained from the pre-monsoon and monsoon season showed sediment contamination due to high clay and silt content respectively in upstream sections of Lake. The study concludes lake restoration works to be carried out for treating clay and silt fractions for both seasons as remedial measure.

A study was conducted on Harike Wetland through an integrated approach of pollution indices as well as statistical analysis to assess the contamination due to industrial discharge, rapid urbanization and dumping of solid waste [77]. Heavy metals considered for the study were lead, chromium, iron, copper, nickel, zinc and cadmium and were studied for their toxic effects. The results concluded that the heavy metals were present in higher concentrations when compared to international standards at the wetland study site. Further, the quality of water was determined to be unfit for human drinking, irrigation and other aquatic usage and hence conservation and management of water body was necessary to prevent further degradation.

The natural lakes are stationary water bodies lacking appropriate air rotation and turbulence motion. The lack of inflow and outflow leads to increased nutrient status of lakes. The large amount of pollutant influx particularly nutrients in lakes can lead to eutrophication which in turn leads to reduced DO concentrations leading to deterioration of lake water quality [78]. This problem of eutrophication has led to a decrease in classification of water for its use. Therefore, water quality determination must also involve measure and control of nutrients and must explain their role for the same.

In the above context, a trophic state index was proposed for representing the nutrient status of a lake [79]. In particular, Secchi disk transparency, chlorophyll and phosphorous were the majorly used indicators. A scale of 0-100 was used for relating the trophic status of lakes. Each division indicated doubling of algal mass. The index serves as a tool for trophic status evaluation.

Several studies have been conducted to determine the Trophic State Index of a lake. In a comparative study conducted on Lake Victoria, Lake Superior, Lake Nipigon and Lake Malawi in East Africa to Arctic and North Atlantic oceans, the authors [80] found high concentrations of Total Nitrogen (TN) and Total Phosphorous (TP) in the oceans in comparison to lakes. A relation in concentration of TN and TP was found in Lakes where an increase in TP led to an increase in TN concentrations but no such relationship existed in oceans. Chlorophyll -a was found to be strongly correlated to TP but not TN for both lakes and oceans. The TN:TP can be used for detecting the limiting growth nutrient in lakes and oceans. The N and P limitation of algal growth is dependent on concentration of TN and TP as well as their product irrespective of freshwater or marine conditions.

A study was conducted in the Dianchi lake of China which had lost the capacity of self-purification due to changes in the environmental conditions in lake [81]. Different restoration methods were implemented but were unsuccessful due to heavy pollution loads leading to excessive and uncontrollable eutrophication. A comprehensive lake model consisting of six major projects covering (i) Lakeside pollution interruption and treatment of wastewater (ii) ecological restoration by construction of wetland (iii) Pollution control in relation to non-point sources in rural areas (iv) restoration of river environment (v) removal of sediment and algae (vi) water diversion were indicative to comprehend ecological functions in lake and also a decrease of domination was imperative.

A study showed an extensive increase in the concentration of nutrients in the flowing waters of US. Nitrogen (N) alone or with Phosphorous (P) was considered as strong responses for heterotrophic and autotrophic processes. Determination of N and P were considered as an apt procedure for determining the eutrophication rate. It was concluded from the study that the increase in Nitrogen and Phosphorous concentrations in the lakes may be attributed to different anthropogenic activities being carried out in the vicinity of the lake. [82].

The study of soil minerals is imperative in terms of investigating major soil forming compounds and its determination of fate of minor and trace elements. The effects of these minerals need to be identified not only for soil-plant interaction but for getting an insight of the interactions and its effects on nearby sediments, lake waters. In the above context, a study was conducted in G.B. Pant

University of Agriculture and Technology in Pant Nagar, Uttarakhand wherein X-ray diffraction (XRD) and PCA analysis were used for determining the minerals present in the soil [83]. From the samples collected, 17 elements were determined by Energy Dispersive X-ray fluorescence (EDXRF) technique along with application of XRD. Peak overlapping and micro-abrasion were omitted by removal of silica by polytetrafluoroethylene (PTFE) and churning with alcohol. Atomic absorption spectroscopy (AAS) and Sequential extraction procedure for metal speciation were applied on soil samples to determine the concentrations of metals in elemental and bound form. The study confirms applications of the above techniques for successful identification of minerals in the soil.

A study investigated the nature of sediments of Tapti River utilizing Scanning Electron Microscopy (SEM) and XRD techniques [84]. From the sediment samples collected, the minerals identified were Quartz, Kaolinite, Calcite, Vermiculite, Palygorskite, Micas and Gibbsite. It was inferred that the possible source pathway of these minerals in the soil might be due to weathering from rocks and different anthropogenic activities such as manufacturing processes along the banks which leads to adsorption and desorption in sediments.

A SEM based method was applied by on various samples of suspended particles collected from Amazonian rivers to identify the mineralogy [85]. A total of 2,04,000 samples were analyzed using Energy Dispersive X-ray Spectroscopy (SEM-EDAX). It was inferred that 15 distinct mineral phases group were present in the samples analyzed. SEM was used for revealing the size distribution of particles. The results revealed that the study was well suited and consistent mineralogy was identified in accordance to previous studies conducted. The method enabled hydrodynamic sorting for evolution of grain size throughout the water column varying from fine to course particles. It was concluded that the application of these instrumental methods were apt in determining sediment nature in the rivers.

In a study conducted at Chiba Prefecture in eastern Japan and in Fukuoka, Hiroshima, Hyogo, and Tottori prefectures in western Japan; 26 samples of soil were analyzed for mineralogical properties using semi-automated system of SEM- EDS to reveal their chemical components. Chi Squared tests were run to discriminate among different minerals and soil samples as well [87]. The methods classified samples with same parent population and also discriminated between different parent populations. The method was successful in identification of almost all soil samples and therefore concluded that as soil adheres to everything of forensic interest therefore the method can be applied in field of forensic sciences.

In a study conducted in the Solan and Mandi district of Himachal Pradesh spectral analysis of Aerobic compost of for assessment of suitability of its use were determined using SEM, EDS and XRD techniques [86]. The study concluded the compost of Solan to be low fertilizing for usage as fertilizer but the method could still be used for waste processing option and reduction of weight of organic waste on landfill site.

The changes in the climatic conditions and other environmental issues across the globe has led to use of simulation and prediction models for determination of present status as well as prediction of the futuristic changes in the lake water body [88; 90]. The application of these models have tremendously increased so that appropriate policies can be developed and maintained by the policy makers through the evaluation of the results obtained through the simulations. The seasonal and annual variations are also taken into account for model development, which in turn are highly cost effective and accurate (once calibrated) in comparison to traditional methods of water sampling and testing which are based on parameter evaluation [91]. Application of predictive modelling technique in Environmental sciences and engineering fields specially water quality management is widely used for determination and restoration of existing status of water quality, obtaining the baseline data through combination of modelling and use of traditional

GIS is a tool that can serve as a great potential for solving problems related to field of environment where attributes can be predicted through interpolation at unsampled locations from attributes determined at sampled locations. Geo statistical Analysis can be used for predicting values at definite time or space and can be used for creation of models and maps.

The techniques such as Inverse Distance Weighing (IDW) and Ordinary Kriging (OK) employed in GIS has been efficiently used in interpolation of lake water quality status throughout the lake spatially and temporally through the pre-determined water quality data generated through various sampling and testing procedures. Such techniques can serve as a useful tool for water quality prediction and futuristic modelling from a limited data set available.

In the above context, a study conducted in lake Kastoria in the Region of Western Macedonia, Greece compared two GIS Interpolation methods of Inverse Distance Weighing (IDW) and Ordinary Kriging (OK) for modelling [92]. The main parameters considered for the study were Temperature Variation, DO, NH_4-N, NO_3-N and PO_4-P for both winter and summer seasons of year 2005 and 2006 respectively. Five scattered sampling points were taken in Lake for the analysis. It was inferred from the modelling results that IDW method of interpolation was better for formulation of equipotential curves of selected parameters. Thematic maps were generated for all of the pollutants considered for the study indicating the most potential pollution sources along with their geographic distribution throughout the lake. The authors concluded that monthly monitoring system of data recording may miss out on crucial data related to extreme events and therefore daily monitoring was suggested to have a confirmed water quality status for proposing suitable management strategies.

In a study conducted at Vedaranyam wetland for surface water evaluation using water quality parameters of Temperature, Salinity, pH, Chlorophyll-a and Suspended Sediments for comparison between monsoon and summer seasons using the Ordinary Kriging (OK) method [93]. The kriging method was used for mapping of spatial dispersion patterns in water quality parameters. The results revealed high saline conditions around aquaculture area and lagoon along with high suspended sediment loads due to river runoff in monsoon season [93].

A similar such study used the application of remote sensing and GIS in monitoring of water quality parameters such as SS, Turbidity, Phytoplankton and Dissolved Organic Matter for study location in Peninsular Malaysia, Sabah and Sarawak [94]. Application of Remote sensing and GIS based tools were found to be highly effective in management and operation of water quality monitoring in the country. The application of such a tool could promote a concept of sustainable water resource management. The authors concluded that the collaboration of GIS technologies with computer modelling can be used successfully for future planning and management of water resources especially in formulation of water quality policies.

In a study conducted in Lake Tianyinhu from January 1, 2012 to December 31, 2012, a 3-D hydrodynamic-water quality model for investigation of water quality modelled under extreme hydrological conditions and sewage leaks were established in [95]. The calibration and validation of the model was carried out using observed data and the use of statistical parameter Room Mean Square Error [RMSE] for comparing observed and predicted data. It was observed from the study that the RMSE values were around 0.33. It may be inferred from the results that the lake was dominated by nutrient loads due to extreme rainfalls and limited water storage capacity of lake. The model showed negative effects associated with sewage leaks and therefore it becomes imperative to inspect and prevent any leakage from sewage pipes around lake. The study therefore can be beneficial for protection and management of similar hydrological ecosystems and urban lakes.

The limitation of the water resources and the alarming population increase as described in the above paragraphs poses a serious threat to the existing water resources [96]. There is an immediate need for management of water resources along with measures to determine the present and future scenarios pertaining to water quality. This accounts for making of appropriate policies in regards to the deteriorated water quality conditions in lake water body. The retreating water resources may become a vector for disease causing organisms due to constant dumping of agricultural and municipal waste, stormwater, grey water, and industrial wastes [97; 98]. The pollution sources around the water bodies can lead to high influx of sediments, organic matters and nutrients into water bodies which causes its deterioration and therefore remediation is of utmost importance [99]. Remediation of the water bodies can be carried out by in-situ or ex-situ measures which can utilize combination or separate application of physico-chemical and biological methods [100; 101]. The remediation techniques can be used alone or in combination with others depending on the extent of pollution levels

In-lieu of the above facts, a study was conducted in the Nanjing province of China which utilized the in-situ method of immobilization used in geo-engineering for eutrophication control in lake water bodies [102]. The method aims at reduction of internal phosphorous from sediments through chemical applications. A comprehensive study was carried out on selection of appropriate chemicals and their dosage for effective control and stability. The chemicals were categorized into nine different categories and their physico-chemical and ecological responses were reviewed. The study also considered the challenges faced during practical application and used them while proposing future recommendations.

A similar such study was conducted to propose suitable remediation measures for eutrophic shallow lakes of Portugal to meet Water Frame Directive (WFD) requirements related to control of external loading [103]. From the study, it was observed that the reduction in external loads did not prove to be efficient for returning the lake to the original state and therefore application of restoration measures were necessary for improving the water quality in lakes. The study also focused on the chemical approaches for phosphate inhibition in respect to their capacity and application along with their collaboration to physical treatment measures for effectiveness. The study concluded these measures to be effective but resulting in potential adverse ecological effects. Therefore it is imperative to consider cost, application strategy, and effects on humans before application.

In regards of selection of appropriate technology thorough reviews of different technologies that can be applied for river restoration were conducted [96]. Aeration was found to a suitable physical measure which was sustainable and effective that primarily focused on reduction of organic loading. Other physical remediation techniques like water diversion, mechanical algae removal, hydraulic structures and dredging are cost effective but may prove detrimental in the long-run. Chemical treatments are effective but are short lived and costly for treating both primary and secondary problems. Constructed wetlands, microbial dosing, ecological floating beds and biofilm technologies are some of the widely used biological and ecological measures which do not lead to any secondary pollution but their application efficiency is variable in terms of results observed.

A study carried out by [104] focused on the development and usage of 3 remediation techniques of application inclusive of physico-chemical and biological methods for improvement and control of eutrophication. It was inferred that physico-chemical methods are suitable for small scale usage and are effective to a certain extent but fail to completely remove the problems of eutrophication often leading to secondary pollution. Further, continuous application of these treatment methods leads to increased costs. They are best suited for application in emergency situations. The biological methods are highly cost effective and sustainable but the results are often achieved late. The study therefore concludes the need of application of combination of these technologies to restore ecosystem.

Summary

It was assessed from the literature review that Water Quality Determination and Management is the need of the hour and a principal responsibility of all concerned regulatory agencies. One of the major goals involved in WQ management is to reduce the contamination potential in the surface water bodies. The literature studies revealed that water resources are of finite capacity in comparison to the ever increasing population and hence must be preserved and used judiciously. Further, the quality of these existing water resources are also diminishing due to constant contamination arising out of different anthropogenic activities including dumping of untreated wastes, industrial effluents, sewage, agricultural waste, storm water and grey water. Such increased anthropogenic activity has the potential to cause serious health issues in the society and may lead to overall degradation of environmental quality. Additionally, the lack of knowledge and awareness amongst general public regarding sanitation, waste management and dumping further leads to problems with management of water resources.

The problem of water quality management is of global concern, however many developed countries have already put in the required management steps to deal with the crisis but with increasing population, globalization and lack of new resources developing countries are more critically affected by this issue. In the context of India, various parts of the country are experiencing acute water shortage like Gurugram, Shimla and Bangalore. This makes it more important to conserve the existing water quality of the sources and also to improve the quality of those which are poor in nature and hence are not in use so that they can be reused again.

The above literature survey summarizes the inadequacy in management of the water resources leading to critical effects on the potable water sources. The physico-chemical characteristics of the water, soil and sediments evaluated through sampling and testing procedures showed higher values than standards when compared to prescribed limits by WHO and BIS due to inadequacy in management of these resources in most of the studies referred. The traditional water quality management practices of sampling and laboratory testing needs to be collaborated with advanced systems such as remote sensing and GIS to have daily telemetric monitoring values rather than monthly and bi- monthly records to avoid missing on major and extreme environmental events. A major portion of the contamination of the water bodies may be attributed to the different human anthropogenic activities with a small portion being due to natural causes (like weathering of rocks and soil erosion). Due to variability in the problems associated with different water resources, the government bodies and policy makers needs to take immediate and appropriate steps for proper management of the water bodies.

The conclusion drawn from literature survey is delay in appropriate management of water bodies might have a detrimental effect on the humans as well as on the surrounding environment leading to loss of major water reserves feeding the exploding population. The degrading of water quality can lead to a reduction in potability and worth of these water sources for its capacity to be used. Henceforth, there is a dire need of improvement in the existing water quality management scenario. Water should be evaluated for its existing status and steps should be implemented to ensure daily telemetric monitoring to have an elaborate view of the complete and futuristic trends in water quality scenario at considered locations. The water body needs to be evaluated for existing problems and therefore appropriate policies need to be framed to remediate the water body and its nearby environment.

Hence, in a nutshell, it may be inferred that background study and characterization of water body is very helpful for the appropriate management and to maintain WQ. The various Water Quality Indexes (NSFWQI and BISWQI) , Heavy Metal Indexes and Trophic State Index used for water bodies globally can prove to be beneficial tools not only to analyze the present status of water quality but for allocating appropriate DBU status and also in suggesting appropriate remediation and control measures for improving the quality of water resource.

Therefore, in this work an attempt has been made for characterization of water body according to its Designated Best Use, application of multivariate analysis to determine the potential pollution sources, determination of existing water quality of the lakes using different indexing techniques, spectral characterization of soil, water and sediment to reveal the extent of effects of pollutant loads, GIS Interpolation Modelling of Lakes to evaluate the complete water quality status at surface and at different depths through already determined data values, selection of appropriate remediation measures for lake remediation at the selected study sites. Since, there is no baseline data available for selected study sites, the detailed water quality analysis carried may prove helpful for the development and management of water quality in the study locations.

CHAPTER 3

‘Designated Best Use’ (DBU) Determination For Twin Lakes

3.1 Introduction

Water is important for sustenance on earth as it contains necessary nutrient and minerals necessary for living beings [1]. Rivers, lakes and springs are a few significant surface water sources [3]. The quality of water body depends on earth’s geology along with different anthropogenic activities being carried out around it, namely agriculture, construction and industrialization and other such actions [5; 105] which affect its overall water quality [106]. As the water flows through soil layer, it gets absorbed with large concentrations of suspended and dissolved impurities rendering it unfit for use and in some cases making it non- palatable [7]. It can be thereby concluded that the physico-chemical properties of water vary both spatially and temporally [107]. The lakes being the most important fresh water source is generally distinguished into man-made and natural [4] and since water scarcity has grown to be an alarming environmental issue, the primary focus is often on characterization of these lakes for quality enhancement and regeneration [108].

The categorizations of water quality are defined on the basis of physico-chemical and biological parameters [109]. The values of these parameters determine the present scenario and can be used to forecast the future hydrological variations in water bodies [45]. The purpose of determination of the water quality of any such bodies is determined on its necessity in immediate vicinity.

In above context, the Designated Best Use (DBU) is one of the most widely used methods in India which categorizes the characteristic usage of the water body based on the measured physico-chemical and biological parameters. The measured parameters are suitably compared with the DBU criteria as specified by CPCB [30]. The current study utilizes the DBU criteria for the study lakes to determine their usage. The purpose of this classification is to determine the best usage of surface water body based on determined parameters and also to set targets for improvement in water quality of such sources. In the present study, the sites were analyzed for both seasonal and annual variations in terms of parameters determined and compared with DBU criteria specified by CPCB and were classified accordingly.

3.2 Methodology

3.2.1 Site locations

Lake 1

Lake 1 lies in the geographical coordinates of 30° 42’N 77°5’E, is a natural lake which is primarily used for recreational activities. It is 550m in length and 460 m in width with a depth of about 5-6 m as measured in the center of lake. The depth of the lake has considerably reduced in past few years due to continual silt and soil load input from the surrounding watershed area.

Lake 2

Lake 2 is also located at geographical location of 30° 42’N 77°5’E in close vicinity to Lake 1. The lake is considered to be a sacred spot with a temple built along its edge where daily offerings are made. The lake has dimensions of 365 m by 365 m by 4-5 m respectively. Similar to Lake 1, continuous siltation and soil loadings from the surrounding watershed area have considerably reduced its depth.

The lake was earlier being used by Fisheries department of Haryana for pisciculture but presently is used for religious activities and unauthorized irrigation by locals. There is a significant volume of water in the lake throughout the year. The source of water is located at a hill nearby in form of a waterfall which remains functional from August to December. The study locations have been shown in Figure 3.1.

Though some form of usage of the water in these lakes is in practice, the actual suitability status is still unknown, since no water quality assessment studies have been carried out.

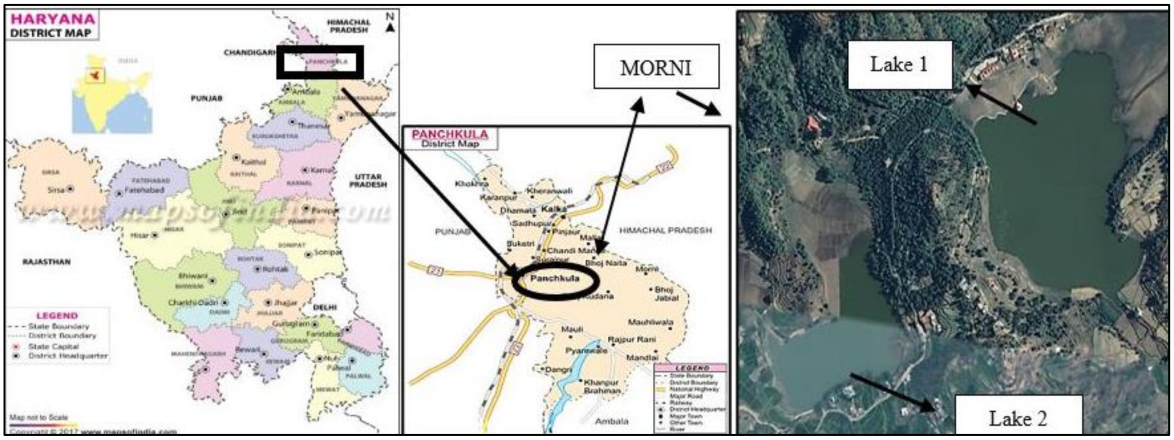

Figure 3.1: Location of study regions

3.2.2 Morphology and Climatic Conditions

The location of the study lakes experiences warm temperatures with overall ranges varying from 20 to 30^0C with an annual average of 25^0C. The average annual rainfall is about 792 mm. The topography surrounding the lakes is moderate to highly dissever with mild steep slopes. Additionally, the soil types are mix of clay loam and are rich in nutrients and thereby fertile.

3.2.3 Site Sampling

The sampling was carried out based on the CPCB guidelines [30] for Lake Water Quality monitoring which specifies minimum sampling duration to be 4 times in a year. Sampling was carried out in the months of August 2019, October 2019, December 2019, February 2020 and June 2020. Depth Integrated Grab sampling technique was used for the sampling of lakes. The samples were collected with the help of Water Depth Sampler which is about 2.5 l capacity. The sampler is immersed in the water body at the fixed depth in the lake from where the samples are to be taken. The sampler is held stationary at the desired depth with the help of ropes tied to the two hooks at the top of the sampler. The third rope is tied at the center of the sampler which has a movable rod that is used for creating the vacuum. The rod is pulled upward which creates vacuum at the bottom hole of the sampler which pushes the water upward in the sampler. The sampler is kept inserted in the lake until the bubble formation in the lower portion of the sampler vanishes which confirms the complete filling of sampler. It takes 2-3 minutes for the water samples to fill completely in the sampler. The sampler should be kept stationary at the fixed depth for complete filling of sampler. For our study, the water samples were taken at depths of 2, 3 and 4 m respectively from Lake 1 and at 1, 2 and 3 m from Lake 2.

Figure 3.2 shows the sampler used for Lake sampling.

Figure 3.2: Sampler used for Lake Sampling

The sampling was done by accessing the sampling locations through boats available on- site. The collected samples were stored in PVC bottles and tested for physico-chemical and biological parameters as per CPCB guidelines for DBU determination. The parameters tested were namely pH, BOD, DO, Total Coliform, Ammonia, Electrical Conductivity and Sodium Absorption Ratio (SAR). The values for pH, Electrical Conductivity (EC) and Dissolved Oxygen (DO) were measured on site using a portable water quality testing kit (Hanna H19811-5). The temperature of the selected samples was determined using a Celsius Thermometer. Chemical parameters like Bicarbonates, Hardness, Sulphates, Chlorides, Iron and BOD were evaluated using the standard methodology [110] in the laboratory. Hardness was determined by EDTA Titration method [110] while Iron and sulphates were determined using spectrophotometer at absorbance of 508 nm and 420 nm respectively. Chlorides were determined using the Argentometric Titration method using $AgNO_3$ as titrant while BOD was determined using the modified Winkler's Method [110]. Chlorophyll-a were determined using the acetone method along with spectrophotometer while Total Phosphorous was evaluated using 4500-P method of APHA 2012, Secchi Disk was used for getting the value of lake transparency. All the parameters were expressed in standard unit of mg/L except pH and also EC which were expressed as µs/cm. the other remaining parameters were measured as per the standard procedure outlined by American Public Health Association (APHA) [110]. The samples were analyzed over the sampling periods which were used to represent the seasonal variations and the averages of the results were considered to be the annual representation of the DBU of the study lakes. The seasonal variations were determined to give a more elaborative view of the water quality status of the lakes which might experience spatial and temporal variations due to natural and anthropogenic activities.

Lake 1

Since the characteristics of DBU are determined from the sampling carried out at the surface of the water body, for Lake 1 the samples were collected from 4 sampling locations marked S1-S4 to cover the *accessible lake area as per government regulations for safety*. Hence to summarize, the nomenclature pattern followed was that S1 signifies sampling location 1 at a depth of 2 m from the surface of the lake. Similarly, S3 signifies sampling at location 3 with a depth of 2 m from the surface. Figure 3.3 shows the Lake 1 and the selected points for Sampling for DBU determination.

Figure 3.3: Sampling locations at Lake 1 for determination of DBU

Lake 2

A similar sampling strategy was adopted for Lake 2 wherein samples were taken from 3 sampling points marked as D1, D2 and D3 respectively in the Lake 2 to cover the *accessible areas of the lake as per government regulations for safety*. However, sampling was carried out at these locations at depth of 1 m from surface of the lake.

Figure 3.4 shows the Lake 2 and the selected points for Sampling for DBU determination.

Figure 3.4: Sampling locations at Lake 2 for determination of DBU

3.3 Determination of Designated Best Use (DBU)

The criteria for water quality are based on the intended use of the waterbody and hence it varies for different sources. For example, a particular water source might be fit for bathing or recreational activity but may not be suitable for human consumption; therefore, CPCB developed the concept of Designated Best Use (DBU) with list of certain pre-defined parameters along with their prescribed limits to be categorized under a specified water use category.

In general, they are classified into categories such as Category A i.e., potable source without treatment but chlorination, Category B i.e., outdoor bathing source, Category C or potable source with treatment, Category D i.e., propagation of fishes and other wildlife, Category E i.e., irrigation and other industrial uses. The parameters pre-defined by CPCB for categorization of surface water body include a combination of physical, chemical and biological parameters set according to the category of use. Table 3.1 describes the DBU criteria for the characterization of a water body so that the water body can be employed to its best use. For being categorized into a particular class (A to E) all the parameters must be satisfied confirming the fitness in the particular category.

Table 3.1: DBU Determination Criteria for Characterization of Water Bodies [30]

Designated Best Use (DBU)	Water Quality Class	Water Quality Criteria
Drinking water source without treatment but with chlorination	A	1. Total coliform (MPN/100 ml) organism shall be 50 or less. 2. pH between 6.5-8.5. 3. Dissolved Oxygen (D.O.) – 6 mg/L or more. 4. Biological Oxygen Demand (BOD) <2 mg/L.
Outdoor bathing (organized)	B	1. Total coliform (MPN/100 ml) organism shall be 500 or less. 2. pH between 6.5-8.5. 3. Dissolved Oxygen (D.O.) – 5 mg/L or more.

		4. Biological Oxygen Demand (B.OD.) <3 mg/L.
Drinking water source with conventional treatment	C	1. Total coliform (MPN/100 ml) organism shall be 5000 or less. 2. pH between 6.5 & 9. 3. Dissolved Oxygen (D.O.) – 4 mg/L or more. 4. Biological Oxygen Demand (B.OD.) 3 mg/L or less.
Propagation of Wildlife and fisheries.	D	1. pH between 6.5 & 9. 2. Dissolved Oxygen (D.O.) – 4 mg/L or more. 3. Free Ammonia (as N) – 1.2 mg or less.
Irrigation, Industrial Cooling and controlled Disposal.	E	1. pH between 6.0 & 8.5. 2. Electrical Conductivity less than 2250 micro mhos/cm. 3. Sodium Absorption Ratio (SAR) less than 26. 4. Boron less than 2 mg/L.

3.4 Results and Discussions

3.4.1 Seasonal Variations

The seasonal variations were determined based on the list of parameters given by CPCB and analyzed for the months of August 2019, October 2019, December 2019, February 2020 and June 2020.

The parameters analyzed for Lake 1 showed seasonal variations for almost the entire study duration. The pH varied from 7.1 to 8.82 lying in the near-neutral range. In particular, the water was determined to be in neutral range for Autumn, Monsoon and Spring but were slightly alkaline for Winter and Summer. The possible reason for the transition was the lack of input of fresh water into the lake from either the water source which feeds water into it from August till November or the absence of rain water which increased the concentrations of salts into the lake making it alkaline. A low DO concentration was observed for the monsoon season which might be attributed to the flowing of organic matter into the lake from the watershed area along with rain water. The condition was seen to improve from autumn to spring. The stratification in lakes in winters leads to reduced DO concentrations which increase in spring due to overturning effects. The DO levels declined in summers due to lack of input of fresh water into lake. Further, BOD is inversely related to DO and therefore BOD was found to increase with decrease in DO for all the sampling periods around the year [30]. Similar observations were made from Table 3.2 where high BOD levels were seen in accordance to the low DO levels throughout the study duration. The input of freshwater in Monsoon leads to low levels of Turbidity and Total Dissolved Solids (TDS) leading to low conductivity in Monsoons as compared to Summers (June) which is generally marked with low water levels and high TDS and turbidity. Ammonia was measured for winter season to assess the possible stratification effects in the lakes along with high pH levels which favored ammonification in lakes, however some ammonia concentrations were observed in Lake 2 for autumn season as well possibly due to higher temperatures in autumn along with stratification effects [111] which favored ammonification due to decomposition of organic matter present in waters which is confirmed by high BOD levels in Lake 2 for autumn season [112]. The Total coliform count remained less than 50 for the entire sampling period and therefore based on this parameter the water was found to be fit for each category from A to E for all seasons. Similar results were observed for Lake 2 with the exception that the ammonia concentrations were also observed in Autumn season possibly due to stratification effects in the lake 2 in Autumn. The parametric value of different parameters utilized for determination of DBU over the sampling seasons for Lake 1 and 2 have been summarized in Tables 3.2 and 3.3 respectively.

In the above context, it may be mentioned that the lake water is affected by seasonal variations and hence it is important to determine the seasonal effects while characterizing the water body for its intended use based on the CPCB criteria for DBU determination.

Table 3.2: Seasonal Variation in parameters for DBU determination for Lake 1

Parameters	August, 2019 (Monsoon)	October, 2019 (Autumn)	December,2019 (Winters)	February, 2020 (Spring)	June, 2020 (Summer)
Total Coliform (No.)	20	15	5	10	12
pH	7.53	7.1	8.1	7.75	8.82
DO (mg/L)	4.08	6.9	8.53	9.67	6.78
BOD (mg/L)	2.4	1.55	1.6	1.02	3.5
EC (µmhos/cm)	256.3	273.5	263.5	379	320.5
NH_3 -N (mg)	0	0	0.35	0	0
SAR	NA	NA	NA	NA	NA
Boron (mg/L)	NIL	NIL	NIL	NIL	NIL

Table 3.3: Seasonal Variation in parameters for DBU determination for Lake 2

Parameters	August, 2019 (Monsoon)	October, 2019 (Autumn)	December, 2019 (Winters)	February, 2020 (Spring)	June, 2020 (Summer)
Total Coliform (No.)	20	38	26	30	40
pH	7.31	7.2	8.09	8.17	7.83
DO (mg/L)	3.75	6.25	8.8	9.09	6.63
BOD (mg/L)	7.46	2.76	0.73	0.26	0.6
EC (µmhos/cm)	159.3	230.57	215.3	225.67	296.4
NH_3 -N (mg)	0	0.70	0.28	0	0
SAR	NA	NA	NA	NA	NA
Boron (mg/L)	NIL	NIL	NIL	NIL	NIL

3.4.2 Overall DBU Determination

The DBU status for both the lakes confirmed that they were fit to be used for *'Categories B to E'* since all the specific parameters in these categories was satisfied. However, the study lakes were *not fit for 'Category A'* which signifies that the lake water could not be used as potable water source with just chlorination but would require some additional treatment. It may be observed from Table 3.4 that both the lakes fail in conforming to *DBU 'category A'* by a very fine margin [(2.02 mg/L > 2 mg/L) for lake 1; (2.36 mg/L > 2 mg/L for lake 2]. The overall DBU determination for intended use of the Lake 1 and Lake 2 has been reported below in the Tables 3.4 and 3.5.

Table 3.4: Overall DBU classification for Lake 1 [149]

Designated Best Use (DBU)	Water Quality Class	Average parameter value	Water Quality Criteria	Status
Drinking water source without treatment but with chlorination	A	1. Total Coliform – 12.4/100 ml	1. Total coliform (MPN/100 ml) organism shall be 50 or less	OK
		2. pH- 7.73	2. pH between 6.5-8.5.	OK
		3. DO- 7.19 mg/L	3. Dissolved Oxygen (D.O.) – 6 mg/L or more.	OK
		4. BOD- 2.014 mg/L	4. Biological Oxygen Demand (BOD) <2 mg/L.	NOT OK
Outdoor bathing (organized)	B	1. Total Coliform – 12.4/100 ml	1.Total coliform (MPN/100 ml) organism shall be 500 or less.	OK
		2. pH- 7.73	2. pH between 6.5-8.5	OK
		3. DO- 7.19 mg/L	3. Dissolved Oxygen (D.O.) – 5 mg/L or more.	OK
		4. BOD- 2.014 mg/L	4. Biological Oxygen Demand (B.OD.) <3mg/L.	OK
Drinking water source with conventional treatment	C	1. Total Coliform – 12.4/100 ml	1. Total coliform (MPN/100 ml) organism shall be 5000 or less.	OK
		2. pH- 7.73	2. pH between 6.5 & 9.	OK
		3. DO- 7.19 mg/L	3. Dissolved Oxygen (D.O.) – 4 mg/L or more.	OK

		4. BOD- 2.014 mg/L	4. Biological Oxygen Demand (B.OD.) 3 mg/L or less.	OK
Propagation of Wildlife and fisheries.	D	1. pH- 7.73	1. pH between 6.5 & 9.	OK
		2. DO- 7.19 mg/L	2. Dissolved Oxygen (D.O.) – 4 mg/L or more.	OK
		3. NH_3 (as N)- 0.35 mg	3. Free Ammonia (as N) – 1.2 mg or less.	OK
Irrigation, Industrial Cooling and controlled Disposal.	E	1.pH- 7.73	1. pH between 6.0 & 8.5.	OK
		2. E.C. – 298.56 micromhos/cm	2. Electrical Conductivity less than 2250 micro mhos/cm.	OK
		3. SAR- NA	3. Sodium Absorption Ratio (SAR) less than 26.	OK
		4. Boron- NIL	4. Boron less than 2 mg/L.	OK

Table 3.5: Overall DBU classification for Lake 2 [149]

Designated Best Use (DBU)	Water Quality Class	Average parameter value	Water Quality Criteria	Status
Drinking water source without treatment but with chlorination	A	1. Total Coliform – 30.8/100 ml	1. Total coliform (MPN/100 ml) organism shall be 50 or less	OK
		2. pH- 7.72	2. pH between 6.5-8.5.	OK
		3. DO- 6.90 mg/L	3. Dissolved Oxygen (D.O.) – 6 mg/L or more.	OK
		4. BOD- 2.36 mg/L	4. Biological Oxygen Demand (BOD) <2 mg/L.	NOT OK

Outdoor bathing (organized)	B	1. Total Coliform – 30.8/100 ml	1. Total coliform (MPN/100 ml) organism shall be 500 or less.	OK
		2. pH- 7.72	2. pH between 6.5-8.5	OK
		3. DO- 6.90 mg/L	3. Dissolved Oxygen (D.O.) – 5 mg/L or more.	OK
		4. BOD- 2.36 mg/L	4. Biological Oxygen Demand (B.OD.) <3mg/L.	OK
Drinking water source with conventional treatment	C	1. Total Coliform – 30.8/100 ml	1. Total coliform (MPN/100 ml) organism shall be 5000 or less.	OK
		2. pH- 7.72	2. pH between 6.5 & 9.	OK
		3. DO- 6.90 mg/L	3. Dissolved Oxygen (D.O.) – 4 mg/L or more.	OK
		4. BOD- 2.36 mg/L	4. Biological Oxygen Demand (B.OD.) 3 mg/L or less.	OK
Propagation of Wildlife and fisheries.	D	1. pH- 7.72	1. pH between 6.5 & 9.	OK
		2. DO- 6.90 mg/L	2. Dissolved Oxygen (D.O.) – 4 mg/L or more.	OK
		3. NH_3 (as N)- 0.20 mg	3. Free Ammonia (as N) – 1.2 mg or less.	OK
Irrigation, Industrial Cooling and controlled Disposal.	E	1.pH- 7.72	1. pH between 6.0 & 8.5.	OK
		2. E.C. – 225.45 micromhos/cm	2. Electrical Conductivity less than 2250 micro mhos/cm.	OK
		3. SAR- NA	3. Sodium Absorption Ratio (SAR) less than 26.	OK
		4. Boron- NIL	4. Boron less than 2 mg/L.	OK

Summary

The study revealed that the lake waters are affected by seasonal variations due to both anthropogenic and natural causes. The seasonal variations showed high variability in pH, DO and BOD with seasons. The pH was seen to vary from neutral to alkaline for both the lakes with change of seasons especially during summers which marked fluctuations in water levels and parameter concentrations. The highest and lowest DO concentrations were observed in Spring and Monsoons due to overturning effects and high input organic and inorganic content from watershed area respectively. The DO and BOD concentrations were inversely proportional to each other and were observed throughout the sampling period.

The overall DBU status confirms the use of Lake water directly from *category B to E*, but not for *category A* which clearly means that the water can directly be used for irrigation, development of wildlife, outdoor bathing activities and drinking water usage but there is a requirement of small scale or an intensive treatment before being able to be used as a potable water source.

Detailed water quality assessment of these lakes has not been conducted and reported previously and hence the present study has been undertaken for determination of DBU and to note any existing seasonal variations in the water quality of the lakes based on the sampling durations. Further, the lakes are a large fresh water source and therefore it becomes imperative in evaluating the suitable use of this natural lake ecosystem which in turn will help to develop suitable policies for improving the lake water quality and to save the lake ecosystem from degradation.

In the above context, it may be mentioned that detailed seasonal characterization of the lake water will be necessary to determine its further use. The following chapter (Chapter 4) discusses the detailed characterization of water quality parameters and calculation of different water quality indices.

CHAPTER 4

Multivariate Statistical Analysis For Twin Lakes

4.1 Introduction

Water quality is an important criterion for determination of human well-being through evaluation of human poverty, wealth and education levels [70]. The water from lakes and rivers contributes in different ways to human welfare [113]. Rapid increase in modernization and industrialization has increased the use of water causing a strain in its resources and also deterioration of its quality. Therefore, apart from researching new water sources, improving the quality of water in existing sources is important for sustainable development. The water quality restoration through source identification and control has become an important step for an overall improvement in the quality of the water source [114]. The variables for pollution source identification show high variability among parameters due to both increased anthropogenic activities as well as natural influences [115]. The discharges through anthropogenic activities however form a constant pollution source and thereby cause a considerable decline in the water quality in comparison to natural factors. The lakes ecosystem has different physico-chemical and biological parameters pertaining to it and its overall water quality depends on their interactions with each other [61]. The parameters show interdependencies and therefore a slight change in one parameter may induce changes in the other associated parameters [3]. The concentration values for different parameters considered for the study over the entire monitoring campaign have been summarized in Tables A1 to A10 in the Appendix A.

In above context, the application of Multivariate Statistical Analysis (MSA) is one of the most useful methods which categorizes the pollution sources and helps in parametric analysis of water samples by co-relating the parameters having similar characteristics according to their chemical compositions [48]. The multivariate statistical methods such as Pearson’s correlation coefficient analysis, Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) are impartial methods that are broadly used to indicate associations between different samples and their variables [47].

4.2 Materials and methods

4.2.1 Lake water sampling and analysis

The sampling methodology is similar to the process explained in *chapter3; section 3.2.3.* Sampling at both the lakes was carried out at predefined locations and depth as mentioned earlier in *section 3.2.3*. Depth Integrated Grab sampling technique was used for lake sampling and the samples taken from different points were analyzed separately. The average of these results over the entire monitoring campaign were taken for determination of Pearson's Correlation matrix analysis, Principal component analysis (PCA) and Hierarchical cluster analysis (HCA).

4.2.2 Multivariate Statistical Analysis

Multivariate statistical analysis is an useful tool which is often used for reduction of dimensionality and biasness associated with assessment of data and hence preferred in environmental monitoring assessments [116]. It reduces large complex data sets into defined ones which are useful in terms of water quality assessment. This unbiased method is used for determination of relations between samples or parameters. The present study utilizes three multivariate statistical methods includes Pearson's correlation matrix analysis, Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) by using software IBMSPSS statistics V 22.0. These statistical tools help in evaluation of various measured parameters through analysis of their variability from permissible limits and thereby impact on the overall water quality [47]. The study was conducted on a total of 20 evaluated parameters namely pH, DO (mg/L), Temperature (°C), EC (µmhos/cm), Turbidity (NTU), TDS (mg/L), Nitrates (mg/L), BOD (mg/L), COD (mg/L), Ca (mg/L), Mg (mg/L), Cl (mg/L), HCO_3 (mg/L), SO_4 (mg/L), TA (mg/L), TH (mg/L), TP (mg/L), TSS (mg/L), Sodium (Na) (mg/L), Potassium(K) (mg/L).

4.2.2.1 Pearson's Correlation

Pearson's correlation coefficient represents the linear association of one variable with another [115]. The correlation coefficient value measured as +1 represents a good positive relationship between variables whereas a correlation value as -1 represents a good but inverse relationship between variables, the value of 0 represents no relation between variables [115]. The coefficient value as $r > 0.7$ is considered as a strong correlation, r value between 0.5 & 0.7 is considered as moderate correlation and $r > 0.5$ is considered as low correlation [117]. The matrix is representative of dependency of parameters on each other. Irrespective of the correlation value (whether positive or negative), any correlation number signifies that the origins of both the pollutants are from the same sources.

4.2.2.2 Principal Component Analysis (PCA)

Principal component analysis (PCA) is used as a source identification tool for identification of smaller variables called as '*principal components'* from large data sets [118]. The components are used for analysis of relationships among observed variables which also helps in identification of variance in data set [47; 48]. The analysis is suitable for explanation of maximum variance in sample values [47]. The components with eigen values greater than unity is taken into consideration. Rotated component matrix is used for maximization of variance sum for those coefficients which influence the aquatic systems [117]. PCA analyses are beneficial for undertaking Eigen vector problems [48]. It is a data alteration method and can reveal simple primary structures which are assumed to present within data sets [120].

4.2.2.3 Hierarchal Cluster Analysis (HCA)

Hierarchal Cluster Analysis (HCA) is an important statistical method used for data analysis in field of environmental engineering [47; 49; 116]. HCA follows an algorithm that associates together identical objects into clusters usually based on their similar chemical composition [48; 122]. It is a technique which is used for reduction of data by interlinking inter-sample similarities forming a cluster tree or dendrogram [119]. The clustering can help in setting a scale or level appropriate for the study purpose [47; 121]. The clusters can represent different interpretations and thereby decide the level or scale of clustering as low, moderate and high. The HCA utilises entire data set unlike PCA which utilizes only limited number of components [47].

4.3 Results and Discussions

4.3.1 Pearson's Correlation Matrix

The correlation was determined between the different physico-chemical parameters of water samples of both the study lakes.

4.3.1.1 Lake 1

The correlation matrix for lake 1 covering the entire monitoring campaign has been presented in Table 4.1.

The results obtained from the correlation matrix for Lake 1 revealed that parameters such as DO, pH, Temperature, Turbidity, TA, HCO_3, COD and K were found to have a significant correlation with each other and to a certain degree with other parameters. DO showed the positive significant correlation with pH (r = 0.94), Temperature (r = 0.67), TA (r = 0.74) and HCO_3 (r = 0.63) but a significant negative correlation with turbidity (r = -0.61). The high positive correlation with temperature was attributed to the fact that the saturation of DO is temperature dependent and a shift in temperature can lead to change in DO concentrations. Further, potential shift in the redox reactions which decrease the pH also affect the DO concentrations. The significant negative correlation of turbidity with DO was due to the presence of organic and inorganic particles contributing to turbidity in the lake which in turn leads to a decline in DO levels; leading to an inverse relationship between DO and turbidity.

EC was found to have high positive correlation with turbidity (r = 0.63) and BOD (r = 0.58) confirming an increase in the value of EC due to presence of high turbid and organic particles. Ca ions were observed to have a significant positive correlation with TH (r = 0.68) and COD (r = 0.63) thereby leading to an increased alkalinity in lake water. Mg ions were observed to have a significant positive correlation with HCO_3 (r = 0.70) promoting hardness in water due to formation of $Mg(HCO_3)_2$.

HCO_3 and TA were also found to have significant positive correlation (r = 0.96) describing the hardness in water to be positively related to the alkalinity levels in lake. TP and SO_4 were found to have a high positive correlation with each other (r = 0.98) both contributing to eutrophication in lake. COD was found to have negative correlation to DO as they are inversely related to each other.

Further, no significant correlation between COD and BOD values reveals that the major portion is non-biodegradable and might be due to leaching of natural and agricultural pollutants into lake water [115;123]. K was found to have significant positive correlation to TDS (r = 0.70) and turbidity (r = 0.70) due to leaching of mineral from nearby sedimentary rocks and soil erosion from water shed areas leading to input of K ions along with soil particles into the lake.

Table 4.1: Pearson's Correlation matrix for Lake 1

	DO	pH	Temp.	EC	TDS	Turb.	TA	Ca	Mg	NO_3	TSS	SO_4	HCO_3	BOD	COD	TP	TH	K
DO	1	0.94	0.67	-0.16	-0.28	-0.61	0.74	-0.19	-0.30	-0.19	-0.22	0.17	0.63	0.31	-0.37	0.06	-0.43	-0.53
pH	0.94	1	0.63	-0.25	-0.35	-0.56	0.65	-0.02	-0.30	-0.14	-0.17	0.13	0.57	0.18	-0.26	0.05	-0.33	-0.50
Temp.	0.67	0.63	1	-0.05	-0.20	-0.50	0.65	-0.42	-0.42	-0.28	0.07	0.34	0.57	0.34	-0.35	0.20	-0.69	-0.44
EC	-0.16	-0.25	-0.05	1	0.42	0.63	0.29	-0.01	-0.39	-0.38	-0.11	0.35	0.29	0.58	0.50	0.24	-0.25	0.44
TDS	-0.28	-0.35	-0.20	0.42	1	0.42	0.06	0.45	-0.35	0.05	0.68	0.29	0.09	0.32	0.52	0.32	0.39	0.70
Turb.	-0.61	-0.56	-0.50	0.63	0.42	1	-0.25	0.17	0.04	0.08	0.02	0.05	-0.20	0.15	0.57	0.04	0.21	0.70
TA	0.74	0.65	0.65	0.29	0.06	-0.25	1	0.06	-0.60	-0.34	0.09	0.18	0.96	0.44	-0.04	0.01	-0.39	-0.20
Ca	-0.19	-0.02	-0.42	-0.01	0.45	0.17	0.06	1	-0.38	0.27	0.57	-0.15	0.22	-0.32	0.63	-0.08	0.68	0.41
Mg	-0.30	-0.30	-0.42	-0.39	-0.35	0.04	-0.60	-0.38	1	0.03	-0.48	-0.53	-0.70	-0.14	-0.48	-0.46	0.33	-0.26
NO_3	-0.19	-0.14	-0.28	-0.38	0.05	0.08	-0.34	0.27	0.03	1	0.18	-0.48	-0.22	-0.60	0.41	-0.40	0.30	-0.07
TSS	-0.22	-0.17	0.07	-0.11	0.68	0.02	0.09	0.57	-0.48	0.18	1	0.25	0.18	-0.11	0.33	0.30	0.32	0.50
SO_4	0.17	0.13	0.34	0.35	0.29	0.05	0.18	-0.15	-0.53	-0.48	0.25	1	0.14	0.41	-0.05	0.98	-0.46	0.48
HCO_3	0.63	0.57	0.57	0.29	0.09	-0.20	0.96	0.22	-0.70	-0.22	0.18	0.14	1	0.23	0.08	-0.02	-0.28	-0.12
COD	-0.37	-0.26	-0.35	0.50	0.52	0.57	-0.04	0.63	-0.48	0.41	0.32	-0.05	0.08	-0.01	1	-0.03	0.23	0.49

BOD	0.31	0.18	0.34	0.58	0.32	0.15	0.44	-0.32	-0.14	-0.60	-0.11	0.41	0.23	1	-0.01	0.29	-0.41	0.05
TP	0.06	0.05	0.20	0.24	0.32	0.04	0.01	-0.08	-0.46	-0.40	0.30	0.98	-0.02	0.29	-0.03	1	-0.33	0.54
TH	0.43	0.33	-0.69	-0.25	0.39	0.21	-0.39	0.68	0.33	0.30	0.32	-0.46	-0.28	0.29	0.23	-0.33	1	0.31
K	-0.53	-0.50	-0.44	0.44	0.70	0.70	-0.20	0.41	-0.26	-0.07	0.50	0.48	-0.12	0.50	0.49	0.54	0.31	1

4.3.1.2 Lake 2

Table 4.2: Pearson's Correlation matrix for Lake 2

	pH	DO	Temp.	EC	Turb.	TDS	NO_3	BOD	COD	Ca	Mg	HCO_3	SO_4	TA	TH	TP	TSS	K
pH	1	0.80	0.66	-0.21	-0.45	-0.03	-0.24	0.44	-0.15	-0.54	-0.21	0.17	-0.09	0.09	-0.53	-0.27	0.35	0.58
DO	0.79	1	0.43	-0.69	-0.54	-0.50	-0.61	-0.07	-0.18	-0.54	-0.01	-0.29	0.26	0.10	-0.44	-0.41	0.33	0.61
Temp.	0.66	0.43	1	-0.18	0.11	0.00	-0.09	0.12	-0.17	-0.51	0.46	0.38	-0.59	-0.54	-0.18	0.04	0.59	0.82
EC	-0.21	-0.69	-0.18	1	0.30	0.60	0.87	0.72	-0.05	0.30	-0.40	0.56	-0.32	0.16	0.15	0.13	-0.05	-0.33
Turb.	-0.45	-0.54	0.11	0.30	1	-0.01	0.21	-0.21	-0.46	-0.09	0.42	0.17	-0.35	-0.38	0.40	0.11	0.13	0.18
TDS	-0.03	-0.50	0.00	0.60	-0.01	1	0.52	0.48	0.55	0.37	-0.32	0.35	-0.40	-0.25	-0.08	0.52	-0.27	-0.45
NO_3	-0.24	-0.61	-0.09	0.87	0.21	0.52	1	0.56	-0.11	0.56	-0.08	0.60	-0.45	-0.03	0.48	-0.07	0.27	-0.17
BOD	0.44	-0.07	0.12	0.72	-0.21	0.48	0.56	1	0.01	0.03	-0.66	0.68	-0.33	0.31	-0.22	-0.13	0.16	-0.05

COD	-0.15	-0.18	-0.17	-0.05	-0.46	0.55	-0.11	0.01	1	0.22	-0.26	-0.08	-0.06	-0.24	-0.37	0.68	-0.47	-0.54
Ca	-0.54	-0.54	-0.51	0.30	-0.09	0.37	0.56	0.03	0.22	1	0.00	0.26	-0.19	0.01	0.73	-0.17	-0.01	-0.58
Mg	-0.21	-0.01	0.46	-0.40	0.42	-0.32	-0.08	-0.66	-0.26	0.00	1	-0.03	-0.31	-0.60	0.48	0.04	0.39	0.49
HCO_3	0.17	-0.29	0.38	0.56	0.17	0.35	0.60	0.68	-0.08	0.26	-0.03	1	-0.83	-0.12	0.31	-0.18	0.47	0.13
SO_4	-0.09	0.26	-0.59	-0.32	-0.35	-0.40	-0.45	-0.33	-0.06	-0.19	-0.31	-0.83	1	0.66	-0.35	-0.04	-0.60	-0.33
TA	0.09	0.10	-0.54	0.16	-0.38	-0.25	-0.03	0.31	-0.24	0.01	-0.60	-0.12	0.66	1	-0.18	-0.35	-0.41	-0.39
TH	-0.53	-0.44	-0.18	0.15	0.40	-0.08	0.48	-0.22	-0.37	0.73	0.48	0.31	-0.35	-0.18	1	-0.45	0.41	-0.05
TP	-0.27	-0.41	0.04	0.13	0.11	0.52	-0.07	-0.13	0.68	-0.17	0.04	-0.18	-0.04	-0.35	-0.45	1	-0.60	-0.35
TSS	0.35	0.33	0.59	-0.05	0.13	-0.27	0.27	0.16	-0.47	-0.01	0.39	0.47	-0.60	-0.41	0.41	-0.60	1	0.78
K	0.58	0.61	0.82	-0.33	0.18	-0.45	-0.17	-0.05	-0.54	-0.58	0.49	0.13	-0.33	-0.39	-0.05	-0.35	0.78	1

The correlation matrix for Lake 2 has been shown in Table 4.2 below. The results obtained from the correlation matrix for Lake 2 revealed that parameters such as DO, Temperature, EC and BOD were found to have a significant correlation with each other and other parameters as well. DO showed the positive significant correlation with pH (r = 0.80) and a significant negative correlation with EC (r = -0.69) [124]. The high positive correlation between Temperature and pH (r = 0.66) and also with K (r = 0.82) could be attributed to the fact that the input of sewage waste does not affect temperature [124]. Potassium ions are contributed excessively either by weathering of rocks or by use of fertilizers containing potassium and nitrates as elements. Since the K was found to have a significant positive correlation with TSS (r = 0.79) it may be inferred that they were majorly contributed by weathering of rocks and its erosion into lake waters. EC was found to show high positive correlation with NO_3 (r = 0.87) and BOD (r = 0.72) which might be due to input of inorganic dissolved solids from the use of fertilizers in agricultural fields into the lake leading to increase in EC and also promoting high BOD [125].

A high negative correlation of EC was found to exist with DO (r = -0.69), due to increased salinity in water during stratification in shallow lakes which leads to increase in EC but reduces the DO in water due to stratification effects in shallow lakes. Ca ions showed high positive correlation with TH (r = 0.73) contributing to increased hardness in lake water [48]. Mg was found to be highly positively correlated to TA (r = 0.60) promoting overall alkalinity in lake water [47]. HCO_3 and SO_4 were highly negatively correlated to each other (r = -0.83). TP was found to show high positive correlation with COD (r = 0.68) which might be due to the fact that the TP was contributed due to flow of soil due to erosion from watershed area into lake increasing TP in lake waters. TSS was found mainly in lake waters due to high level of soil erosion and weathering of rocks containing K ions and therefore a high positive correlation was found between K and TSS (r = 0.78) [117].

These high correlations among the parameters lead to overall change in characteristics of the lake water due to interdependency among parameters, which means variation in one parameter leads to variation in other.

4.3.2 Principal Component Analysis (PCA)

Principal Component Analysis is built on the Kaiser normalization which enumerates those components with Eigen values greater than unity are considered [48]. Six components were obtained for *Lake 1* and *Lake 2* with Eigen values greater than unity having a total variance of 89.32% and 95.14 % respectively. The PCA analysis revealed six components in all with first 3 components representing maximum amount of variance and therefore the rotated component plot prepared in 3-D was plotted between the major 3 components representing PC1 to PC3 as represented in Figure 4.1 and Figure 4.2 for both lake 1 and lake 2 respectively.

4.3.2.1 Lake 1

The matrix was plotted between the different physico-chemical components. The 3 major components representing the highest variances have been depicted in a 3-D plot in rotated space in Figure 4.1. The Rotated Component Matrix obtained from PCA analysis for Lake 1 has been shown in Table A11 in Appendix A.

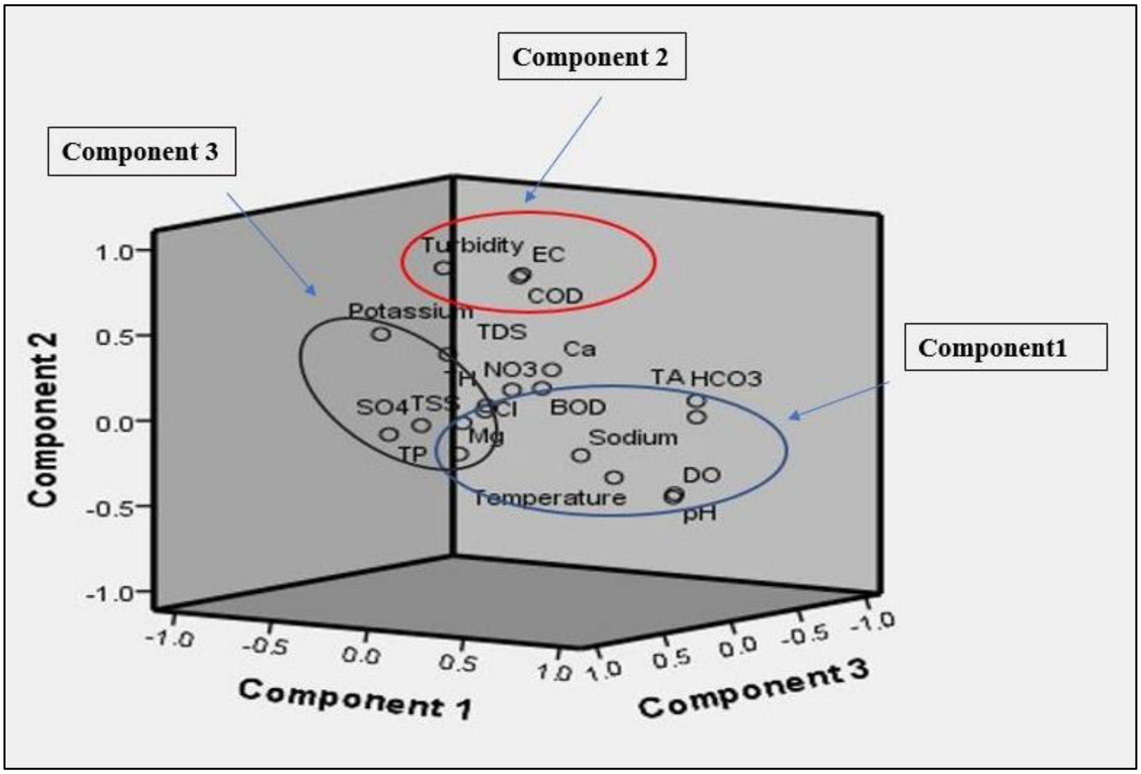

Figure 4.1: Component plot in rotated space for Lake 1

Component 1

Component 1 obtained from the PCA analysis of Lake 1 showed a variance of 23.39 % and was dominated by high positive loadings in TA, HCO_3, pH and DO. Moderate positive loading was exhibited by Temperature whereas a moderate negative loading was observed for Mg. Presence of TH in the form of HCO_3, Ca and Mg in water samples can be attributed to the leaching of the minerals and anthropogenic factors which are dominant controlling factors of the high positive loading of loading TA, HCO_3, pH, also the high TA loadings pushed the pH towards alkalinity [117; 124;125]. The magnesium and phosphorus have negative correlation with each other whereas alkalinity and pH are positively correlated.

Component 2

The second major component in water samples of Lake 1 represented a variance of 15.84 % and was dominated by high positive loadings in EC, Turbidity and COD. Moderate positive loading was exhibited by K. The high turbidity input from the watershed area contributes to high inorganic content in lake and therefore is positively corelated to COD and EC [47; 48; 117]. Further, the K ions along with other inorganic content contributes to high EC levels in lake water.

Component 3

The third component in water samples of Lake 1 showed a variance of 15.54 % and was dominated by high positive loadings in TP and SO_4. Moderate positive loading was exhibited by K. The high dominance of TP is attributed to the increased agricultural activities in the vicinity of lake and the possible use of phosphate-based fertilizers in the farms which enter lake water increasing TP levels. The SO_4 in the lake waters might be the result of leaching of mineral from nearby rocks [117].

Component 4

The fourth component in water samples of Lake 1 showed a variance of 15.15 % and was dominated by high positive loadings from TH and Ca. Moderate positive loading was exhibited by TSS and TDS. The high dominance of Ca ion leads to increase in hardness of water and therefore is highly correlated with TH, both showing high dominance. The TSS and TDS are contributed by extreme level of soil erosion from watershed area into the lake water.

Component 5

The fifth component in water samples of Lake 1 represented a total variance of 11.64 % which was due to high positive loadings in NO_3 and moderate positive loading in Na. The high dominance of NO_3 is due to use of nitrate based fertilizers in the agricultural fields.

Component 6

The final component in water samples of Lake 1 showed a variance of 7.76 % and was dominated by high negative loadings in Cl and moderate positive loading in BOD. The high dominance of Cl is due to the leaching of minerals from nearby sedimentary rocks as well as soil erosion from watershed area due to irrigational and agricultural activities adding up to Cl loadings.

4.3.2.2 Lake 2

The matrix was plotted between the different physico-chemical components. The three major components representing the majority of the percentage variation in the variance (PC1-PC3) have been depicted in a 3-D plot in rotated space in Figure 4.2. The Rotated Component Matrix obtained from PCA analysis for Lake 2 has been shown in Table A.12 in the Appendix A.

Component 1

The first component in water samples of Lake 2 represented a variance of 22.01 % which was indicative of high positive loadings in BOD, EC and HCO_3. Moderate positive and negative loading were exhibited by NO_3 and Cl respectively. Presence of BOD confirms organic content in the lake which might be in relation to presence of NO_3 which enters the source via irrigational activities in agricultural field leading to an increase BOD levels. The high dominance in EC was due to presence of HCO_3 and Cl ions in lake waters.

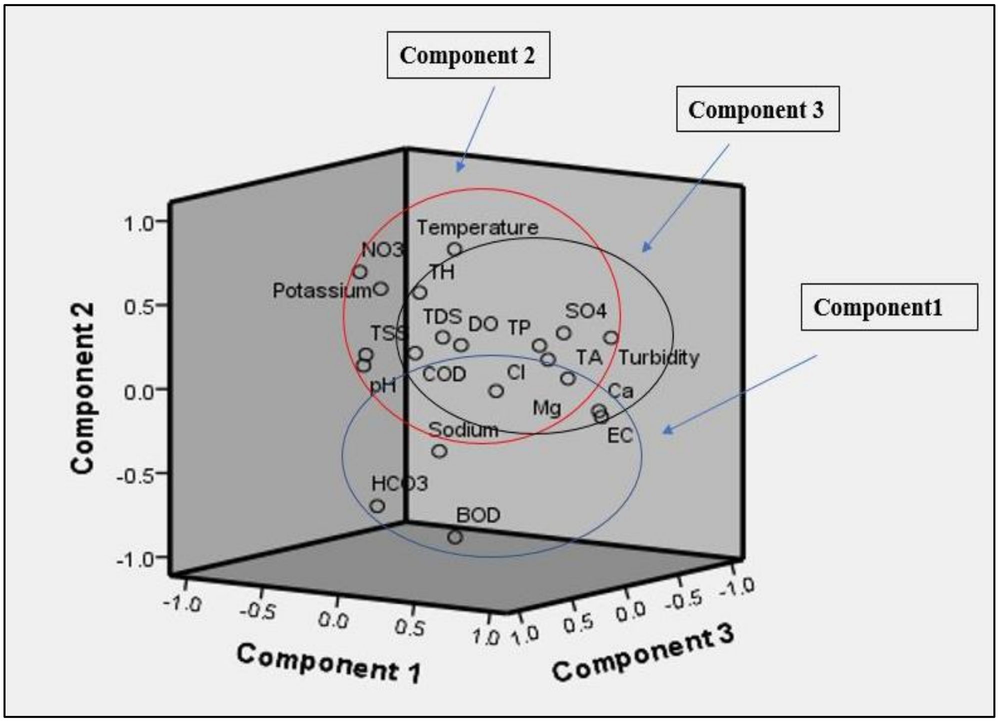

Figure 4.2: Component plot in rotated space for Lake 2

Component 2

The second component in water samples of Lake 2 showed a variance of 19.27 % which were attributed to high positive and negative loading in Temperature, TA and SO_4 respectively. Moderate positive loading was exhibited by Mg and K. The TA and SO_4 are highly correlated to each other as SO_4 is responsible for high alkalinity in lake waters. Further the concentrations of

Mg and K increases in the lake water due to leaching of minerals along with inorganic content due to erosional activities around lakes.

Component 3

The third component in water samples of Lake 2 showed a variance of 17.27 % and was dominated by high negative loadings in TP and COD. Moderate positive and negative loading were exhibited by TSS and TDS respectively due to high input of soil from erosion in watershed areas into the lake water. The dominance of TP and COD is attributed to the increased erosional activities due to heavy irrigation from agricultural fields leading to high concentrations of COD and TP levels in lake water. Further, the moderate loading in TSS confirms that there is a strong correlation between TSS, COD and TP.

Component 4

The fourth component in water samples of Lake 2 represented an overall variance of 15.78 % and was dominated by high positive loadings in TH and Ca along with moderate negative loading was exhibited by pH. The high dominance of Ca ion leads to increase in hardness of water and therefore is highly correlated with TH, both showing high dominance.

Component 5

The fifth component in water samples of Lake 1 represented variance of 12.74 % and were indicative of high positive loadings in Turbidity and moderate negative loading in DO and pH respectively. The high dominance of Turbidity is due to high erosional activities surrounding lakes. The moderate negative loading in DO is attributed to high BOD levels and increased pH which reduces the aquatic plant growth and thereby directly affects the DO in lake leading to reduced concentrations.

Component 6

The sixth component in water samples of Lake 2 showed a variance of 8.08 % and was due to high positive loadings in Na and moderate positive loading in Cl. The correlation of Na and Cl is due to the leaching of minerals from nearby sedimentary rocks as well as soil erosion from water shed area due to irrigational and agricultural activities adding up to Na and Cl concentrations.

4.3.3 Hierarchal Cluster Analysis (HCA)

Hierarchal Cluster analysis is represented in form of Dendrogram which is based on arrangement of clusters formed by hierarchical clustering technique [48]. *Two* clusters were obtained for *Lake 1* and *Lake 2* with Euclidian distance less than five taken as a criterion for cluster formation. A total of 15 concerned parameters contributing to low pollution sources and 5 parameters contributing to medium pollution sources were obtained in both the lakes [47; 48].

4.3.3.1 Lake 1

The HCA analysis was applied to different physico-chemical parameters considered in the study. 2 clusters were obtained for Lake 1 wherein cluster 1 and 2 represented low and medium pollution sites components respectively. The dendrogram has been represented in Figure 4.3 below.

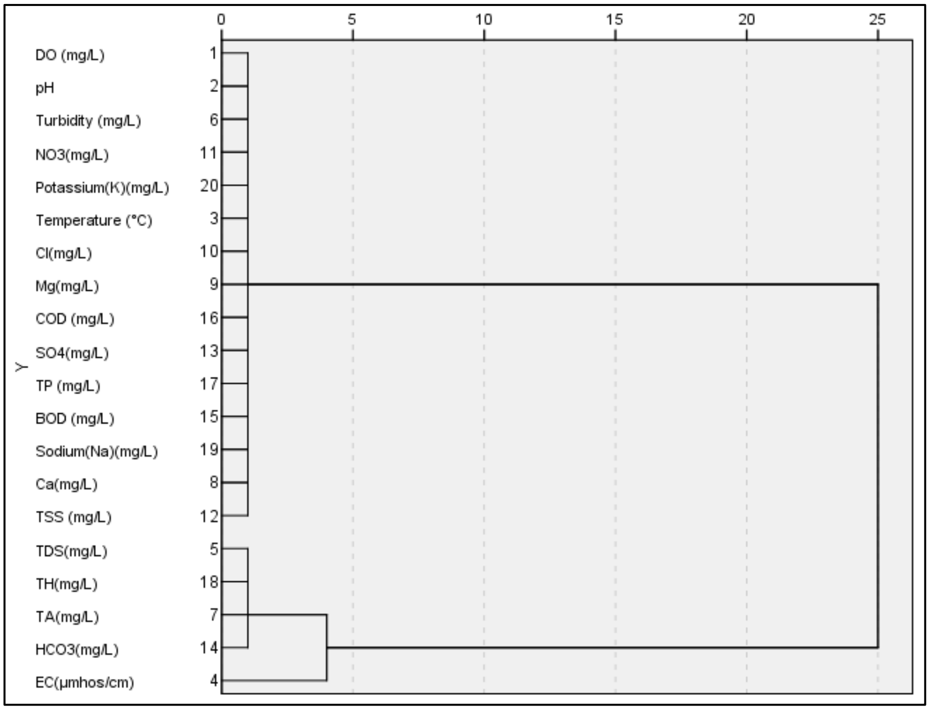

Figure 4.3: Dendrogram for Ward Linkage for Lake 1

Cluster 1

Cluster 1 grouped parameters 1-3, 6, 8-13, 15-17, 19-20 into low pollution zones dominated by parameters such as DO, pH, Turbidity, NO_3, K, Temperature, Cl, Mg, COD, SO_4, TP, BOD, Na, Ca, TSS contributing to low pollution in lake waters. The high levels of turbidity and TSS contribute to high inorganic content in the lake waters and high COD levels. The ions such as Cl, Mg, K, Na, Ca are accountable for high ionic concentrations and grouped together leads to high

EC in lake waters. The high TP and NO_3 levels in lake water induces high BOD levels and thereby low DO concentrations in lake. The SO_4 is accountable for high alkalinity and increased pH levels.

Cluster 2

Cluster 2 grouped parameters 4-5, 7, 14, 18 into medium pollution zones dominated by parameters such as TDS, TH, TA, HCO_3, EC contributing to moderate pollution levels in lake waters. The high level of TDS from the erosional activities along lake banks and watershed areas along with high ionic concentrations contributed to high EC levels. The TH was contributed by HCO_3 and SO_4 reactions with Ca and Mg in lake water which increased the TA increasing the pH thereby making it alkaline.

4.3.3.2 Lake 2

The HCA analysis was applied to different physico - chemical parameters considered for the study. Similar to the above, 2 clusters were obtained for lake 2, wherein Cluster 1 and 2 represented low and medium pollution zones respectively. The dendrogram has been represented Figure 4.4 below.

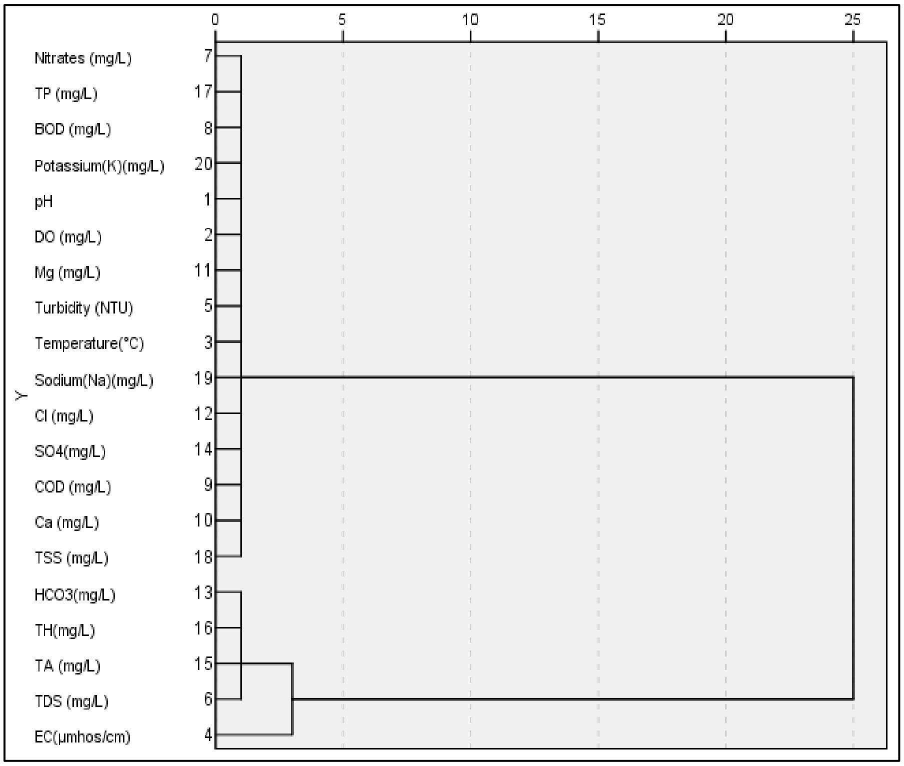

Figure 4.4: Dendrogram for Ward Linkage for Lake 2

Cluster 1

Cluster 1 grouped parameter 1-3, 5, 7-12, 14, 17-20 into low pollution zone dominated by parameters such as NO_3, TP, BOD, K, DO, pH, Mg, Temp., Turb., Na, Cl, COD, SO_4, Ca, TSS contributing to low pollution levels in lake waters. The results obtained were similar to cluster 1 from lake 1

Cluster 2

Cluster 2 grouped parameters 4, 6, 13, 15-16 into medium pollution zone dominated by parameters such as EC, TDS, HCO_3, TA, TH contributing to moderate pollution levels in lake waters. The results obtained were similar to cluster 2 of lake 1.

Summary

The present chapter focussed on the source identification and classification of pollutants based on the analysis of physical, chemical and biological parameters of both the lakes using Multivariate Statistical Analysis of water samples.

The Pearson's correlation matrix established a strong correlation between the various parameters considered for both the lakes wherein, high turbidity was found to be positively correlated to EC and COD which indicated a heavy amount of soil erosion from watershed areas and along lake banks which led to input of heavy sediments into lakes. Further, strong correlation was observed between pH, Ca, Mg, HCO_3, SO_4, TA and TH which also indicated an increase in alkaline nature of water due to high TA increasing the pH values., Concentrations of Ca, Mg, HCO_3 and SO_4 indicated leaching of minerals from nearby sedimentary rocks which led to formation of $CaSO_4$, $CaHCO_3$, $MgSO_4$ and $CaSO_4$ thereby increasing the hardness of water. The strong correlation between TP, NO_3 and BOD revealed that the organic content in the lakes was contributed by increased agricultural and irrigational activities in vicinity which led to increased TP and NO_3 concentrations in lake waters promoting slight eutrophication.

The PCA analysis revealed different principal components of source pollution in both the lakes. Six major components were determined in both the lakes respectively. The total cumulative variance for components of Lake 1 and 2 were determined to be 89.32% and 95.14% respectively. The principal components determined for Lake 1 showing maximum variance were TA, HCO_3, pH, DO, Temperature EC, Turbidity, COD, TP SO_4, Ca, TH and Cl. The Lake 2 exhibited principal components such as BOD, EC, HCO_3, NO_3, TA, Temperature, SO_4, COD, TP, TDS, TSS, TH, Na, Cl, Ca, TH to have maximum variance. These components were seen to have a deteriorating effect on the existing water quality in lakes.

The HCA analysis was used for determining the parameters related to source contamination by grouping them together into clusters depicting similar characteristics and effects. Lake 1 exhibited 15 parameters such as DO, pH, Turbidity, NO_3, K, Temperature, Cl, Mg, COD, SO_4, TP, BOD, Na, Ca, TSS contributing to low pollution and 5 parameters such as TDS, TH, TA, HCO_3, EC contributing to moderate pollution levels. Lake 2 exhibited 15 parameters such as NO_3, TP, BOD, K, DO, pH, Mg, Temperature, Turbidity, Na, Cl, COD, SO_4, Ca, TSS contributing to low pollution and 5 parameters such as TDS, TH, TA, HCO_3, EC contributing to moderate pollution levels in Lake 2.

The parameters studied and reported in this chapter are widely used for monitoring of water quality for lakes. However, certain parameters such as DO, BOD, TP, NO_3 and Temperature have more significance than others such as TDS, in the context of their effect on the existing water quality. The water quality indexing is an useful tool which utilizes all these parameters and assigns suitable weightages to each of them for determining the overall water quality. The following chapter uses these parameters for determining Water Quality Indexing (WQI) using different techniques and its overall classification for their use.

CHAPTER 5

Determination of Spatio-Temporal Quality variations in Lake Water Bodies using Indexing Methods

5.1 Introduction

Water quality is not only dependent upon the geology of the earth surface but also on different anthropogenic activities happening in its vicinity [126; 106]. As such, the physical, chemical and biological properties of water vary both spatially and temporally [107]. In agrarian regions, contaminations due to pesticides and fertilizers can lead to eutrophication [127]. The human welfare and aquatic system are majorly affected by water quality [113]. Water quality is often assessed based on physico-chemical, heavy metals, eutrophication potential and other associated parameters ascertaining the use of the water body for different purposes including for agriculture, industrial, recreational and drinking [128;129]. Water quality determination is associated with measurement of different parameters and their evaluation that creates enormous data sets which are often complex. The variability of parameters is often associated with natural and anthropogenic factors [130]. Further, with multifarious parameters being assessed for monitoring water quality it becomes tedious for the regulatory bodies in classification of existing water quality in lucid terms which could be easily understood by general public. In this context, the use of water quality indices (WQI) is one such tool which can help in reporting the existing water quality which is easily understood by both authorities and general public [131]. There are different number of water quality indices available and in practice such as BIS (Bureau of Indian Standards), NSFWQI (National Sanitation Foundation Water Quality Index), Oregon Water Quality Index, Canadian Water Quality Index for irrigation purpose, Fuzzy Logic Water Quality Index and a variety of other such localized water quality indices. The parameter selection is based on methodology described in the concerned water quality indexing method and also the necessary mathematical calculations are carried out to obtain the suitable single value for the water quality based on which the categorization of the water is carried out. The method to be chosen is dependent upon the parameters monitored and the probable use of the water source.

However, there exist some concerns about the evaluation of WQI. The main problems associated with WQI are obscuring and uncertainty which raises concerns about the opacity and also creates misunderstandings in application of WQI which are generally associated with aggregation methods [132]. The ambiguity relates to spatial measurements since they are generally not included in determination of WQI [133]. Rigidity in selection of parameters is one such problem which creates a lack of flexibility in selection and utilization of parameters in calculation of the concerned WQI [134]. Considering these major issues associated with traditional WQI methods, a Modified Water Quality Index (MWQI) method could be a better approach which not only lays emphasis on reducing ambiguity but also concentrates on elimination of rigidity in concerned water quality index.

The main aim of the chapter is to determine the prevailing water quality of the study lakes, both spatially and temporally and to ascertain their quality for utilization using traditional WQI techniques such as NSFWQI, BISWQI methodologies over the entire sampling period. Further, Heavy Metal Index (HMI) is evaluated for monsoon and pre-monsoon seasons and Trophic State Index (TSI) is determined on average yearly basis using conventional methods. Finally, a modified water quality index (MWQI) and modified heavy metal index (MHMI) considering the spatial and temporal variations of the pollutants have been prepared for the study locations.

5.2 Materials and methods

5.2.1 Lake water sampling and analysis

The sampling methodology is similar to that explained in *chapter 3 section 3.2.3.* Samples were collected at predefined locations and depths as mentioned earlier in *section 3.2.3;* using depth integrated grab sampling technique for both the lakes. The samples taken from different points and depths, were analyzed separately and the results were evaluated on depth, point, seasonal and average annual basis for the entire sampling months of August 2019, October 2019, December 2019, February 2020 and June 2020.

5.2.2 Water Quality Indexing

Water quality indexing (WQI) is a simple method for determining existing quality of a water body [135]. The results of WQI are in form of a single numerical value that are suitable in categorizing the water body and if required provide indication in taking necessary actions for restoration of deteriorating water bodies [47;48]. In principle, the determination of WQI is based on evaluation of physical, chemical and biological parameters where in these parameters are allocated a suitable weightage (sub-index) as per their importance in affecting the existing water quality. Thereafter, using suitable aggregation method an aggregation of sub index function is calculated using mathematical expressions [29]. The following indices have been used for calculating the WQI of both the lakes.

5.2.2.1 National Sanitation Foundation Water Quality Index (NSFWQI)

The NSFWQI is determined based on pre-decided nine water quality parameters with weightage already assigned to them. The parameters and weightage for determining NSFWQI are DO (0.17), Fecal coliform (0.15), pH (0.12), BOD (0.10), Total Phosphorous (0.10), Temperature (0.10), Nitrates (0.10) Turbidity (0.08) and TSS (0.08). The summation of all the weightage ($\sum$ Wi) comes out to be 1. The WQI is calculated as shown in eq. 5.1 below.

$$NSFWQI = \frac{\sum_{i=1}^{n} Wi * Qi}{\sum_{i=1}^{n} Wi} \quad (5.1)$$

Where,

W_i= weightage assigned to the parameters

Q_i= quality rating value obtained from quality rating curve

$\sum_{i=1}^{n} Wi$= summation of assigned weights which should be 1

The final categorization of the water quality based on NSFWQI has been summarized in Table 5.1.

Table 5.1: Rating table for NSFWQI [136]

Range	Category
0-25	Very bad (VB)
26-50	Bad (B)
51- 70	Medium (M)
71-90	Good (G)
91-100	Excellent (E)

5.2.2.2 Bureau of Indian Standard Water Quality Index (BISWQI)

The index is based on the comparison of determined parametric values with standards prescribed in Bureau of Indian Standards BIS 2012 (IS: 10500) [137].

The first step is determination of parametric values of pH, EC, TDS, TA, Ca, Mg, Cl, NO_3, SO_4, HCO_3 through standard procedures as mentioned in mentioned in APHA [110].

The second step is allocating the weights (wi) to each of the measured parameters on 1-5 scale with 1 as lowest impact and 5 as highest one based on relative importance of these parameters in water quality [138;139].

The third step is associated with relative weightage (Wi) calculation based on eq. 5.2 below.

$$W_i = w_i / \sum_{i=1}^{n} wi \quad (5.2)$$

Where,

W_i = relative weight to be calculated

w_i = weight of concerned parameters

n = total number of parameters

The fourth step includes determining rating scale 'qi' which is generally calculated by division of its concentration obtained by testing procedures by the standards prescribed by BIS 10500 (2012). The eq. 5.3 below shows calculation procedure for 'qi'.

$$q_i = (c_i / s_i) * 100 \quad (5.3)$$

Where,

q_i = quality rating scale

c_i = concentration of parameter (mg/L)

s_i = standard value as in BIS 10500 (2012)

The fifth step is calculation of sub index function for parameter individually for the final calculation of WQI. The sub index function or '*SI*' is calculated as in eq. 5.4 below.

$$SI_i = \mathrm{W}_i * q_i \quad (5.4)$$

Where,

SI_i = Sub Index function for i_{th} parameter

W_i = relative weight of the parameter

q_i = quality rating scale

The final step is the calculation of final WQI using method as in eq. 5.5 below.

$$BISWQI = \sum_{i=1}^{n} SI_i \quad (5.5)$$

The categorization of water bodies is summarized in Table 5.2 [47].

Table 5.2: Rating table for BISWQI [71]

Range	Category
<50	Excellent (E)
50-100	Good (G)
100-200	Poor (P)
200-300	Very Poor (VP)
>300	Unfit for drinking (U)

5.2.2.3 Modified Water Quality Index (MWQI)

The Modified Water Quality Index (MWQI) is an indexing method proposed to determine the WQ of the lakes by eradicating rigidness related to traditional WQI methods. The weightage of associated parameters that affect the water quality are often different and dependent on the method used for determining the WQI and therefore is often difficult to interpret the actual importance of the considered parameter. Further, the parameters evaluated by the prevailing WQI methods are often insufficient. The NSFWQI utilizes only 9 parameters while BISWQI also utilizes a limited set of parameters in deciding the overall WQ of any water body. The proposed MWQI gives flexibility in selection of parameters to be considered for the study.

The context of the proposed MWQI is defined in steps below:

Step 1

The first step is to determine the values of parameters such as pH, EC, TDS, TA, Ca, Mg, Cl, NO_3, SO_4, HCO_3 through standard procedures as mentioned in APHA [110].

Step 2

The second step is related to assigning of weightage to different parameters selected. The weightage assigned to each of the parameters was the average of weights of parameters as in reported scientific literature (25) and has been shown in Appendix-A (Table A13). The relative weights for each parameter were obtained through eq. 5.6 below.

Relative Weight (RW) = Assigned weight (AW) / Sum of Assigned Weights (AW)

$$RW = AW / \sum_{i=1}^{n} AW \quad (5.6)$$

Where,

AW = Assigned Weights (Taken from expert ratings evaluated through scientific literature)

RW = Relative Weights

n= number of parameters taken

Step 3

The third step includes determining of quality assessment of selected parameters in relation to BIS 105000, 2012 as evaluated in eq. 5.7.

$$Q_i = (C_i / S_i) * 100 \quad (5.7)$$

Where,

Q_i = Scale for Quality assessment

C_i= Evaluated parametric concentration

S_i = Standard parametric concentration as per BIS 10500, 2012

The above Eq. (5.7) is modified for two parameters namely pH and DO due to significant effects on water quality. Since the optimum pH of water should be 7 and DO saturation is 100% at DO concentration of 14.6 mg/L at 23°C, the quality assessment scale for the parameters varies slightly as shown in Eq. 5.8.

$$Q_i = \left(\frac{C_i - V_i}{S_i - V_i}\right) * 100 \quad (5.8)$$

Where, V_i = ideal value of parameters (pH = 7, DO = 14.6 mg/L) and other terms have same meaning as described in eq. 5.7.

Step 4

This step involves determination of sub-index factor for all parameters, which is determined as the product of the quality assessment factor (Qi) with respect to relative weight of the concerned parameters. The final WQI value is determined as the summation of the different sub-index values for concerned parameters represented in eq. 5.9 and eq. 5.10 respectively.

$$SI_i = RW * Q_i \quad (5.9)$$

Where, SI_i = Sub Index function for I^{th} parameter, and

$$MWQI = \sum_{i=1}^{n} SI_i \quad (5.10)$$

The methodology mentioned above is very similar to reported scientific literature [70] for determination of MWQI for Loktak Lake in India. However, there are certain distinctions in our study. For example, in our study we have evaluated the relative weight of the concerned parameters utilizing larger number of scientific literatures (25) than [70] in which only 13 scientific reported literature values were utilized. The utilization of a greater number of scientific literatures leads to more robustness to the determined values of relative weights. Further, extra parameters were utilized for determination of MWQI which presents more potent results than earlier reported study [70].

The final categorization of the water body is based on Table 5.3 and follows the similar classification system as BIS 2012 (IS: 10500).

Table 5.3: Rating table for MWQI [68]

Range	Category
< 50	Excellent (E)
50-100	Good(G)
100-200	Poor (P)
200-300	Very Poor (VP)
> 300	Unfit for drinking (U)

5.2.2.4 Heavy Metal Index (HMI)

Heavy metals present in water bodies can severely affect the water quality and may have various health impacts. Hence, heavy metal determination is one of the important criteria for evaluation of water quality of a source [140]. The accumulation of heavy metals in the water body may be attributed to natural or anthropogenic factors.

The heavy metals considered for the study were Arsenic (As), Cadmium (Cd), Mercury (Hg), Zinc (Zn), Chromium (Cr), Lead (Pb), Nickel (Ni), Iron (Fe). The Atomic Absorption Spectrum (AAS) technique was applied for determination of heavy metals in water samples at different wavelengths after suitable digestion with nitric acid and the concentrations are generally reported in µg/l [141].

The first step to determination of HMI includes assigning unit weights W_i to each heavy metal as in eq. 5.11

$$W_i = K / s_i \qquad (5.11)$$

Where,

W_i = unit weights or weightage.

K = constant of proportionality generally taken as 1.

S_i = standard value of I^{th} parameter as in BIS 10500 (2012).

The second step includes calculating Q_i or the sub-index function usually related with the quality rating of parameters as in eq. 5.12 below.

$$Qi = \sum_{i=1}^{n} \frac{M_i(-)I_i}{S_i - Ii} \times 100 \qquad (5.12)$$

Where,

Q_i= Sub Index value

M_i = Value of the evaluated parameter

I_i= permissible value as in IS 10500 (BIS 2012)

S_i= Highest permissible value as in IS 10500 (BIS 2012)

(-) = the sign confirms the difference is free of any algebraic sign

The HMI is then calculated through the eq. 5.13 below.

$$HMI = \frac{\sum_{i=1}^{n} W_i Qi}{\sum_{i=1}^{n} W_i} \qquad (5.13)$$

Where,

Q_i= Sub Index value of I^{th} parameter

W_i = unit weight or weightage of I^{th} parameter

n = number of parameters taken

A HMI value greater than 100 was determined to be unfit for drinking purposes [141]. The scale for suitability as drinking water presented Table 5.4 below [124].

Table 5.4: Rating Table for HMI [124]

Range	Category
0-25	Excellent (E)
26-50	Good (G)
51-75	Poor (P)
75-100	Very Poor (VP)
>100	Unfit for drinking (U)

5.2.2.5 Modified Heavy Metal Index (MHMI)

The methodology mentioned for Modified Heavy Metal Index (MHMI) is similar to that used for determination of MWQI as in section *5.2.2.3 Modified Water Quality Index (MWQI)* where similar scientific literatures was considered for assigning weights to the considered heavy metals for the study. The calculation of relative weights for heavy metals is done through eq. 6 *section 5.2.2.3 Modified Water Quality Index (MWQI)*, where the relative weights were taken from the global literature (25). The relative weights were taken as an average of ratings provided in the global literature considered for the study.

Further, all the other steps utilized for calculation of MHMI were similar to that followed for calculation of HMI as mentioned in *section 5.2.2.4 Heavy Metal Index (MWQI)*, from eq. 12 till eq.13. The final aggregation of MHMI was done through table 5.4 as mentioned above.

5.2.2.6 Trophic State Index (TSI)

The Trophic status implies the productivity of a water body due to various biological and chemical activities in water and is an indirect measurement of water quality related to nutrient concentrations [142]. The Carlson's TSI is based on measurement of nutrient levels (in form of total phosphorous) which causes change in biomass concentrations (measured in form of chlorophyll-a) and leads to change in transparency of lake [143]. Carlson's TSI is the most suitable method for classification of lakes based on trophic status [144].

The methodology for calculation of Carlson's TSI involves determination of Secchi Depth (SD), Total Phosphorous concentration (TP) and concentration of Chlorophyll-a (CHL) using eqns. 5.14-5.16 as below [145; 146].

$$\text{TSI (SD)} = 60 - 14.41 \text{ Ln } [\text{SD(m)}] \qquad (5.14)$$

$$\text{TSI (CHL)} = 9.81 \text{ Ln } [\text{CHL } (\mu\text{g/L})] + 30.6 \qquad (5.15)$$

$$\text{TSI (TP)} = 14.42 \text{ Ln } [\text{TP } (\mu\text{g/L})] + 4.15 \qquad (5.16)$$

If the three TSI values are not similar, [143] there exist a possibility that algal growth may be light or nitrogen limited and other factors are not considered. The lakes can therefore be classified based on Table 5.5 below as below.

Table 5.5: Rating Table for TSI [58]

Range	Category
< 40	Oligotrophic (O)
40-50	Mesotrophic (M)
50-70	Eutrophic (E)
>70	Hypereutrophic (H)

Carlson's TSI average is recommended as an indicator for trophic status of water bodies in general.

5.3 Results and Discussions

The following section deals with results calculated for NSFWQI, BISWQI, MWQI, HMI, MHMI and TSI for of the monitoring campaigns conducted in the months of August 2019, October 2019, December 2019, February 2020 and June 2020for both the study sites. The values utilized for the calculation of the various WQI as obtained from sample collection and testing have been shown in Appendix A (Table A1-A5) for lake 1 and Appendix A Table (A6-A10) for lake 2 respectively.

Lake 1

The various WQI evaluated for different sampling durations for Lake 1 were determined point wise, depth wise, seasonal and average yearly basis. Point wise evaluation was carried at 4 points in lake 1 denoted by S1 – S4. The depths taken into consideration for evaluation for Lake 1 were 2m, 3m and 4m respectively from surface towards lake bed. The seasonal variations were evaluated in months of August 2019 (Monsoon), October 2019 (Autumn), December 2019 (Winter), February 2020 (Spring) and June 2020 (Summers). In principle, a weighted average system was employed to determine the overall WQI at each of the sampling locations S1-S4 for Lake 1.

Lake 2

Lake 2 was evaluated based on similar methodology as Lake1 above but pointwise evaluation was carried at three sampling locations in lake 1 i.e., D1 – D3. The depths taken into consideration for evaluation for Lake 2 were1, 2 and 3 m respectively from surface towards lake bed.

5.3.1 National Sanitation Foundation Water Quality Index (NSFWQI)

The water quality index utilizing the NSFWQI methodology has been summarized for both the lakes in Tables 5.6 and 5.7 respectively. The NSFWQI was determined for the sampling month of August 2019, October 2019, December 2019, February 2020 and June 2020 for both the lakes. The NSFWQI clearly shows a variation of water quality with depth as can be observed for the different sampling locations S1-S4 (Table 5.6) and D1-D3 (Table 5.7) [147].

The change in water quality with increase in depth was observed for the month of August 2019 and October 2019 in both the lakes with better water quality observed at surface and a decline in the quality depth wise. For lake 1, the NSFWQI for months of August 2019 at *S1(a)* showed an index value of '*87',* a value of *'83'* at *S1(b)* and*'74'* at *S1(c)*, likewise pattern was observed for other points S2, S3 and S4 as well. Similarly for lake 2, the NSFWQI for sampling during months of August 2019 at *D1(a)* showed an index value of '*80'*, a value of *'79'* at *D1(b)* and *'78'* at *D1(c)* with a likewise pattern observed for other points D2, and D3 as well. In this context, it may be summarized that depth wise variation of water quality for both sampling months at all of the sampling locations in both the lakes may be attributed to the decrease in concentration of DO due to reduction in sunlight conditions with depth which creates anaerobic conditions in the lake resulting in degradation of water quality [149]. The month of August 2019 i.e. monsoon marks influx of freshwater into the lakes due to monsoon season but also leads to increased influx of sediments along with it into the lakes leading to decrease in transparency, lower temperature values and therefore a decrease in DO concentrations at lower depths in spite of influx of freshwater into lakes [150].

The pattern of depth wise variation was observed for all of the remaining sampling period for both the lakes but the trend of decline in water quality was not significant as observed for August 2019 and October 2019. The main reason for this variation may be attributed to the facts that December 2019 i.e. winter is marked with stratification effects, the month of February 2020 marks spring season and overturning in the shallow lakes due to temperature variations, the month of June 2020 marks summer season and therefore a considerable increase in temperature is experienced along with no freshwater influx [149]

December 2019 showed a little haphazard pattern in water quality trend depth wise due to stratification effects in winters as observed for point with value of '*85'*at *S4 (a), '84'* at *S4(b)* and *'87'* at *S4 (c)* in lake 1 and a value of *'88'* at *D2 (a), '86'* at *D2 (b)* and*'87'* at *D2 (c)* in lake 2. The haphazardness in the depth wise trends was observed to increase in February 2020 due to change in the temperature in lakes and totally variable values were observed in the month with almost no significant pattern depth wise. For example a value of '*79'* at *S1(a),'83'* at *S1(b)* and '*78'* at *S1(c)* was observed in lake 1 and a value of '*81'*at *D1(a), '82'*at *D1(b)* and *'81'*at *D1(c)* for the month of February 2020 due to overturning in the lakes as a result of temperature variation among different layers [149]. Sampling carried out in June 2020 showed a decline in water quality due to low influx of freshwater which would have been significant but due to lockdown effects and no tourist influx, the water quality categorized as '*Good (G)' or 'Excellent (E)'* for all the points but the depth wise trend still showed a haphazard pattern due to seasonal and lockdown effects [149].

Some interesting results further observed in detailed assessment of point wise, depth wise, seasonal and an overall yearly NSFWQI determination, included *'Spill over effects'*. For example, NSFWQI of some sampling locations in lake 1 such as *S3 (b)* during the October 2019 and *S4 (a)* during June 2020 yielded a WQI value of '*91'* and '*89'* respectively which is at the threshold range (71-90) of the category '*Good'* and (91-100) of the category '*Excellent'* as per NSFWQI and likewise for other points in lake 2 as well specially in October 2019 for the points 'D1' and 'D2' at all relevant depths of 1m, 2m and 3 m respectively.

Sampling carried out in different months was also meant to represent seasonal variations in the water quality in both the lakes. For the sampling undertaken in August 2019 i.e. Monsoon season, the water quality was evaluated to be in category '*Good* ' with a value of '*79'* for *lake 1* and a value of '*76'* for *lake 2* due to influx of freshwater and heavy inflow of soil and silt particles from watershed area leading to an overall decline in water quality in comparison to other seasons. However, it was observed that in water sampled in both the lakes in October 2019 i.e. Autumn season showed a considerable improvement in the quality with an average value of '*88'* for *lake 1* and a value of *'90'* for *lake 2*, the categorization still remained *'Good'*. This maybe primarily attributed to a decrease in temperature leading to an increase in DO concentration [148]. Sampling carried out in month of December 2019 i.e. Winter season showed an increment in water quality value with a value of '*84'* for *lake 1* and *'85'* for *lake 2* but the categorization remained constant at *'Good'*. The possible factor may be biological and chemical processes, solids and temperature which were well within permissible range in winters [107] leading to a considerable improvement in DO concentrations and therefore a better water quality. This was validated by the interrelationships between different parameters discussed in earlier sections in Chapter 4. The month of February 2020 i.e. Spring season marks a considerable shift in temperature after winters with increased temperature of lake waters due to spring season which leads to slight overturning effects in lakes and therefore a decline in water quality was observed with a value of '*82'* for *lake 1* and '81' for *lake 2* with category *'Good'*. The month of June 2020 i.e. Summer season generally marked low influx of freshwater due to summers but due to lockdown effects an early monsoon rain was observed in sampling month of June 2020 leading to an influx of freshwater, high DO concentrations and therefore an improved water quality in respect to other months with a value of *'90'* for *lake 1 and '82'* for *lake 2 but* with category *'Good'.*

The overall water quality for the entire sampling duration was observed to be in category *'Good'* with a value of '*85'* for *lake 1 and '83'* for *lake*.

Table 5.6: Determined values of NSFWQI for Lake 1

Points in Lake 1	August 2019	October 2019	December 2019	February 2020	June 2020	Overall Weighted Average NSFWQI August 2019	Overall Weighted Average NSFWQI October 2019	Overall Weighted Average NSFWQI December 2019	Overall Weighted Average NSFWQI February 2020	Overall Weighted Average NSFWQI June 2020	Overall NSFWQI at sampling points (Yearly Basis)
S1(a)	87 (G)	88 (G)	88 (G)	79 (G)	93 (E)	S1= 83 (G)	S1=87 (G)	S1=86 (G)	S1=80 (G)	S1=92 (E)	S1= 86 (G)
S1(b)	83 (G)	85 (G)	86 (G)	83 (G)	*91 (E)*						
S1(c)	74 (G)	87 (G)	84 (G)	78 (G)	*92 (E)*						
S2(a)	78 (G)	87 (G)	85 (G)	85 (G)	*91 (E)*	S2 = 76 (G)	S2=87 (G)	S2=86 (G)	S2=84 (G)	*S2=89 (G)*	S2= 84 (G)
S2(b)	74 (G)	87 (G)	86 (G)	84 (G)	*92 (E)*						
S2(c)	72 (G)	88 (G)	86 (G)	82 (G)	83 (G)						
S3(a)	78 (G)	95 (E)	79 (G)	85(G)	93 (E)	S3 = 79 (G)	S3=90 (G)	S3=78 (G)	S3=82 (G)	*S3=91 (E)*	S3=84 (G)
S3(b)	79 (G)	*91 (E)*	79 (G)	82 (G)	88 (G)						
S3(c)	79 (G)	79 (G)	77 (G)	75 (G)	*89 (G)*						
S4(a)	80 (G)	*91 (E)*	85 (G)	81 (G)	*89 (G)*	S4 = 79 (G)	S4=87 (G)	S4=85 (G)	S4=81 (G)	*S4=90 (G)*	S4=84 (G)
S4(b)	79 (G)	*89 (G)*	84 (G)	81 (G)	*90 (G)*						
S4(c)	74 (G)	77 (G)	87 (G)	82 (G)	*89 (G)*						
						79 (G)	**88 (G)**	**84 (G)**	**82 (G)**	***90 (G)***	**85 (G)**

Table 5.7: Determined values of NSFWQI for Lake 2

Points in Lake 2	August 2019	October 2019	December 2019	February 2020	June 2020	Overall Weighted Average NSFWQI August 2019	Overall Weighted Average NSFWQI October 2019	Overall Weighted Average NSFWQI December 2019	Overall Weighted Average NSFWQI February 2020	Overall Weighted Average NSFWQI June 2020	Overall NSFWQI at sampling points (Yearly Basis)
D1(a)	80 (G)	92 (E)	86 (G)	81 (G)	79 (G)	D1= 79 (G)	*D1=91(E)*	D1=84(G)	D1=81(G)	D1=80(G)	D1= 84 (G)
D1(b)	79 (G)	*90 (G)*	86 (G)	82 (G)	83 (G)						
D1(c)	78 (G)	*90 (G)*	81 (G)	81 (G)	78 (G)						
D2(a)	79 (G)	92 (E)	88 (G)	81 (G)	85 (G)	D2 = 76 (G)	*D2=91(E)*	D2=86(G)	D2=80(G)	D2=85(G)	D2= 84 (G)
D2(b)	75 (G)	*91 (E)*	86 (G)	81 (G)	85 (G)						
D2(c)	75 (G)	*90 (G)*	87 (G)	79 (G)	86 (G)						
D3(a)	75 (G)	*90 (G)*	88 (G)	84 (G)	79 (G)	D3 = 74 (G)	D3=88(G)	D3=85(G)	D3=83(G)	D3=82(G)	D3= 81 (G)
D3(b)	74 (G)	89 (G)	84 (G)	82 (G)	84 (G)						
D3(c)	*71 (G)*	86 (G)	84 (G)	82 (G)	82 (G)						
						76 (G)	***90 (G)***	**85 (G)**	**81 (G)**	**82 (G)**	**83 (G)**

5.3.2 Bureau of Indian Standards Water Quality Index (BISWQI)

The BISWQI determined for Lake 1 and Lake 2 has been summarized in Tables 5.8 and 5.9 respectively. The BISWQI was determined for the entire monitoring campaign. Overall, it was observed that there exist no significant variation of water quality with depth for both the lakes as can be observed from the Tables 5.8 and 5.9 respectively [147].

Further, the pattern of depth wise variation was observed to be haphazard with no clear trends for the entire monitoring campaign for both the lakes. The results obtained from BISWQI were similar to those of NSFWQI wherein no distinct pattern in the depth wise variations was observed.

Samples collected during the monitoring period of August 2019, October 2019 and December 2019, represented a better value of water quality in comparison to other monitoring periods with an overall value of '*37'*and *'25'* in *August 2019, '38' and '29'* in *October 2019 and '36'and '34'* in *December 2019* for lake 1 and lake 2 respectively being categorized as '*Excellent'.* For February 2020 in *lake 1* , a change in categorization of water quality was observed with overall values of BISWQI being '*50'* and categorized as '*Good'* but with '*spillover effect*'. This also implies that small changes in concentrations (both less and more) may influence the final categorization of the water quality in Lakes. The overall BISWQI for *Lake 2* was determined to be *'44'* categorized as *'Excellent'.* It may be inferred that though the categorization of lake 2 remained same, the numerical value has increased depicting the variations in concentrations of parameters, however the overall categorization of the water quality was same . The overall water quality determined from samples collected in June 2020 was categorized as *'Excellent'* for both the lakes with overall BISWQI values of *'45'* and *'36'* for lakes 1 and 2 respectively. The possible changes in water quality observed over the entire monitoring campaign has already been discussed for NSFWQI, the same reasons may be attributed while determining the BISWQI.

It may be further summarized that there was no significant change in water quality as observed from the seasonal characterization. The only major change was observed for Lake 1 during the monitoring campaign carried out during February 2020 wherein the water quality categorization changed from *'Excellent'* to *'Good'* but for all other monitoring periods considered for the study, the water quality remained Excellent for both the lakes.

Table 5.8: Determined values of BISWQI for Lake 1

Points in Lake 1	August 2019	October 2019	December 2019	February 2020	June 2020	Overall Weighted Average BISWQI August 2019	Overall Weighted Average BISWQI October 2019	Overall Weighted Average BISWQI December 2019	Overall Weighted Average BISWQI February 2020	Overall Weighted Average BISWQI June 2020	Overall BISWQI at sampling points (Yearly Basis)
S1(a)	38 (E)	40 (E)	39 (E)	49 (E)	53 (G)	S1= 37 (E)	S1=39 (E)	S1=38 (E)	S1=49 (E)	S1=49 (E)	S1= 43 (E)
S1(b)	36 (E)	38 (E)	38 (E)	47 (E)	45 (E)						
S1(c)	38 (E)	40 (E)	35 (E)	*51 (G)*	44 (E)						
S2(a)	37 (E)	37 (E)	36 (E)	54 (G)	43 (E)	S2 = 36 (E)	S2=36 (E)	S2=36 (E)	S2=52 (G)	S2=43 (E)	S2= 41 (E)
S2(b)	36 (E)	36 (E)	36 (E)	*51 (G)*	41 (E)						
S2(c)	37 (E)	37 (E)	35 (E)	*50 (G)*	44 (E)						
S3(a)	38 (E)	38 (E)	36 (E)	52 (G)	42 (E)	S3 = 38 (E)	S3=38 (E)	S3=36 (E)	*S3=51 (G)*	S3=44 (E)	S3=42 (E)
S3(b)	38 (E)	37 (E)	36 (E)	49 (E)	48 (E)						
S3(c)	38 (E)	41 (E)	36 (E)	*51 (G)*	45 (E)						
S4(a)	37 (E)	38 (E)	36 (E)	48 (E)	44 (E)	S4 =37 (E)	S4=38 (E)	S4=36 (E)	S4=49 (E)	S4=43 (E)	S4=41 (E)
S4(b)	36 (E)	36 (E)	36 (E)	49 (E)	44 (E)						
S4(c)	38 (E)	41 (E)	38 (E)	*50 (G)*	40 (E)						
						37 (E)	**38 (E)**	**36 (E)**	***50 (G)***	***45 (E)***	**41 (E)**

Table 5.9: Determined values of BISWQI for Lake 2

Points in Lake 2	August 2019	October 2019	December 2019	February 2020	June 2020	Overall Weighted Average BISWQI August 2019	Overall Weighted Average BISWQI October 2019	Overall Weighted Average BISWQI December 2019	Overall Weighted Average BISWQI February 2020	Overall Weighted Average BISWQI June 2020	Overall BISWQI at sampling points (Yearly Basis)
D1(a)	29 (E)	28 (E)	36 (E)	43 (E)	34 (E)	D1= 26 (E)	*D1=29(E)*	D1=35 (E)	D1=46 (E)	D1=34 (E)	D1= 34 (E)
D1(b)	25 (E)	29 (E)	35 (E)	49 (E)	34 (E)						
D1(c)	24 (E)	31 (E)	34 (E)	45 (E)	34 (E)						
D2(a)	23 (E)	27 (E)	36 (E)	46 (E)	32 (E)	D2 = 23 (E)	*D2=28(E)*	D2=36 (E)	D2=44 (E)	D2=37 (E)	D2= 33 (E)
D2(b)	23 (E)	28 (E)	36 (E)	45 (E)	38 (E)						
D2(c)	24 (E)	28 (E)	34 (E)	40 (E)	41 (E)						
D3(a)	27 (E)	30 (E)	32 (E)	43 (E)	33 (E)	D3 = 27 (E)	D3=29 (E)	D3=31 (E)	D3=43 (E)	D3=38 (E)	D3= 34 (E)
D3(b)	29 (E)	30 (E)	31 (E)	43 (E)	40 (E)						
D3(c)	24 (E)	29 (E)	30 (E)	44 (E)	41 (E)						
						25 (E)	***29 (E)***	**34 (E)**	**44 (E)**	**36 (E)**	**34 (E)**

5.3.3 Modified Water Quality Index (MWQI)

The results of the MWQI determined for Lake 1 and 2 has been presented in Tables 5.10 and 5.11 respectively. The MWQI values were determined for the entire monitoring campaign. It was observed from the analysis that there existed variations of water quality with depth for both the lakes [147].

In particular, samples analyzed for the months of August 2019 and October 2019 depicted sharp variations in water quality with depth. For example, the MWQI results for the month of August 2019 showed an index value of *'37' at S1(a), '39' at S1(b) and '52' at S1(c)* for Lake 1. A likewise pattern was observed for all the other sampling points for lake 1 during August 2019. Similar results were obtained for Lake 2 with MWQI values of *'66'* at *D3(a), '93'* at *D3(b)* and *'94'*at *D3(c)*. The pattern of change in water quality was observed at different sampling locations and depths for both the lakes over the entire monitoring campaign. The best water quality in Lake 1 was obtained in the months of *August 2019 (MWQI = 51), October 2019 (MWQI = 50)* and *June 2020 (MWQI = 61)*, this may be attributed to influx of freshwater during these sampling periods. However, the best water quality in Lake 2 was observed for *August 2019 (MWQI = 68)* and *December 2019 (MWQI = 65)*, the main reason for the variation was high influx of freshwater, low parametric concentrations [107;148]. However, water quality categorization for both the lakes was *'Good'*. Stratification effects for both the lakes were observed for samples collected in December 2019 due to winter conditions. For example, stratification was clearly observed at sampling locations *S1* and *S3* for *Lake 1* and at *D1* for Lake 2. Similar such trends were also observed for the sampling carried out in the periods of February 2020 and June 2020. Further, improved water quality was observed in June 2020 in comparison to December 2019 and February 2020 for Lake 1, due to lockdown effects but no such observations were made for lake 2 [61].

It was observed that only one significant change in categorization of water quality was observed from the seasonal characterization for Lake 1. The major change was observed for Lake 1 during the monitoring campaign carried out during *December 2019* wherein the water quality categorization was *'Good'* but value was towards higher side. No seasonal variation was observed in Lake 2 with the water quality being classified as *'Good'* over the entire monitoring campaign.

Table 5.10: Determined values of MWQI for Lake 1

Points in Lake 1	August 2019	October 2019	December 2019	February 2020	June 2020	Overall Weighted Average MWQI August 2019	Overall Weighted Average MWQI October 2019	Overall Weighted Average MWQI December 2019	Overall Weighted Average MWQI February 2020	Overall Weighted Average MWQI June 2020	Overall MWQI at sampling points (Yearly Basis)
S1(a)	37 (E)	62 (G)	66 (G)	83 (G)	60(G)	S1= 41 (E)	S1=63 (G)	S1=75 (G)	S1=87 (G)	S1=56 (G)	S1= 64 (G)
S1(b)	39 (E)	61 (G)	67 (G)	81 (G)	*50 (G)*						
S1(c)	52 (G)	65 (G)	103(P)	*100(P)*	54 (G)						
S2(a)	52 (G)	*50 (G)*	68 (G)	74 (G)	52 (G)	S2 = 57 (G)	S2=54 (G)	S2=69 (G)	S2=74 (G)	S2=65 (G)	S2= 64 (G)
S2(b)	60 (G)	*50 (G)*	68 (G)	73 (G)	52 (G)						
S2(c)	63 (G)	66 (G)	73 (G)	74 (G)	103(P)						
S3(a)	61 (G)	41 (E)	102 (P)	75 (G)	54 (G)	S3 = 56 (G)	*S3=50 (G)*	S3=149(P)	S3=80 (G)	S3=69 (G)	S3= 81 (G)
S3(b)	53 (G)	44 (E)	88 (G)	68 (G)	72 (G)						
S3(c)	48 (E)	76 (G)	305(U)	104(P)	96 (G)						
S4(a)	43 (E)	38 (E)	69 (G)	87 (G)	56 (G)	*S4 =50 (G)*	S4=45 (E)	S4=68 (G)	S4=84 (G)	S4=55 (G)	S4= 60 (G)
S4(b)	*51 (G)*	*49 (E)*	68 (G)	71 (G)	56 (G)						
S4(c)	61 (G)	56 (G)	67 (G)	90 (G)	*51(G)*						
						51 (G)	***50 (G)***	**90 (G)**	**81 (G)**	**61 (G)**	**67 (G)**

Table 5.11: Determined values of MWQI for Lake 2

Points in Lake 2	August 2019	October 2019	December 2019	February 2020	June 2020	Overall Weighted Average MWQI August 2019	Overall Weighted Average MWQI October 2019	Overall Weighted Average MWQI December 2019	Overall Weighted Average MWQI February 2020	Overall Weighted Average MWQI June 2020	Overall MWQI at sampling points (Yearly Basis)
D1(a)	61 (G)	53(G)	45 (E)	80 (G)	113 (P)	D1= 59 (G)	D1=57(G)	D1=68(G)	D1=80(G)	D1=97(G)	D1= 72 (G)
D1(b)	61 (G)	*49 (E)*	79 (G)	78 (G)	88 (G)						
D1(c)	55 (G)	70 (G)	80 (G)	80 (G)	89 (G)						
D2(a)	61 (G)	55 (G)	*51 (G)*	88 (G)	96 (G)	D2 = 62 (G)	D2=58(G)	D2=59(G)	D2=80(G)	D2=86(G)	D2= 69 (G)
D2(b)	59 (G)	57 (G)	54 (G)	75 (G)	74 (G)						
D2(c)	66 (G)	61 (G)	68 (G)	77 (G)	88 (G)						
D3(a)	66 (G)	57 (G)	57 (G)	82 (G)	109 (P)	D3 = 84 (G)	D3=58(G)	D3=69(G)	D3=83(G)	D3=91(G)	D3= 77 (G)
D3(b)	93 (G)	58 (G)	59 (G)	77 (G)	79 (G)						
D3(c)	94 (G)	58 (G)	92 (G)	89 (G)	84 (G)						
						68 (G)	**90 (G)**	**65 (G)**	**81 (G)**	**91 (G)**	**77 (G)**

5.3.4 Heavy Metal Index (HMI)

The Heavy Metal Index (HMI) was determined over the monitoring campaign conducted in August 2019 and June 2020 for samples collected point wise, depth wise, seasonally and annually for both the lakes which have been summarized in Tables 5.12 and 5.13 respectively.

It was observed from the analysis that there existed a variation of heavy metals with depth observed from both the lakes but the pattern of variation in HMI with depth was not significant for the months of August 2019 as was for June 2020. For example, only difference in categorization of HMI category occurred at depth '*S4 (b)'* for Lake 1 and no sampling locations in lake 2 for August 2019. However, significant variations in HMI leading to change in categorizations were observed at different sampling depths for both the lakes in June 2020. In particular, it may be highlighted that there existed almost no variations depth wise for samples collected in August 2019 and overall classification of HMI was *'Good' for both lakes with HMI value of '35' for lake 1 and value of '38' for lake 2.* However, samples collected in the month of the June 2020 showed an enormous decline in the water quality in context of Heavy Metals and the overall category was determined to be '*Poor*' and *'Very poor' with HMI values of* '*62' and '78' for Lake1 and Lake 2 respectively* making them unfit for use. Samples collected during the month of June 2020 was representative of summer month wherein high temperature led to increased evaporation and greater parametric concentrations of heavy metals [107; 148] as compared to monsoons which mark heavy rains, high water influx and overall dilution of heavy metals leading to a lower values of HMI. The overall HMI for the entire sampling duration was observed to be in category *'Good'* with a value of '*49'* for *lake 1* and in category *'Poor'* with value of *'58'* for *lake 2* but with *'spill over effects'* observed for few points.

Table 5.12: Determined values of HMI for Lake 1

Points in Lake 1	August 2019	June 2020	Overall Weighted Average HMI August 2019	Overall Weighted Average HMI June 2020	Overall HMI at sampling points (Yearly Basis)
S1(a)	41 (G)	85 (P)	S1= 36 (G)	*S1=76 (VP)*	S1= 56 (P)
S1(b)	30 (G)	78 (VP)			

S1(c)	34 (G)	57 (P)			
S2(a)	*26 (G)*	32 (G)	S2 = 32 (G)	S2=41 (G)	S2= 36 (G)
S2(b)	38 (G)	84 (VP)			
S2(c)	38 (G)	17 (E)			
S3(a)	39 (G)	10 (E)	S3 = 40 (G)	S3=97 (VP)	S3= 69 (P)
S3(b)	42 (G)	96 (VP)			
S3(c)	40 (G)	275 (U)			
S4(a)	41 (G)	37 (G)	S4 =36 (G)	S4=33 (G)	S4= 34 (G)
S4(b)	23 (E)	23 (E)			
S4(c)	38 (G)	33 (G)			
			35 (G)	**62 (P)**	**49 (G)**

Table 5.13: Determined values of HMI for Lake 2

Points in Lake 2	August 2019	June 2020	Overall Weighted Average HMI August 2019	Overall Weighted Average HMI June 2020	Overall HMI at sampling points (Yearly Basis)
D1(a)	37 (G)	48 (G)	D1 = 37 (G)	D1 = 64 (P)	*D1 = 50 (G)*
D1(b)	37 (G)	31 (G)			
D1(c)	36 (G)	111 (U)			
D2(a)	39 (G)	53 (P)	D2 = 40 (G)	D2 = 72 (VP)	D2 = 56 (P)
D2(b)	40 (G)	66 (P)			
D2(c)	39 (G)	97 (VP)			
D3(a)	38 (G)	114 (U)	D3 = 39 (G)	D3 = 97 (VP)	D3 = 69 (P)
D3(b)	38 (G)	14 (E)			
D3(c)	39 (G)	170 (U)			
			38 (G)	**78 (VP)**	**58 (P)**

5.3.5 Modified Heavy Metal Index (MHMI)

The Modified Heavy Metal Index (MHMI) were determined for samples collected during August 2019 and June 2020 point wise, depth wise, seasonally and annually for both the lakes which have been summarized in Tables 5.14 and 5.15 respectively.

It was observed from the analysis that there existed a variation of heavy metals with depth observed for both the lakes. For samples collected in August 2019, from lake 1 while no change in categorization on depth wise analysis of samples were observed at sampling locations S1 and S2, the same was not applicable for sites S3 and S4. Sites S3 and S4 of lake 1 showed significant change in Heavy metal concentration to alter the categorization depth wise at the sampling locations. However, no such depth wise variations were observed for sampling points considered for lake 2. It may also be mentioned that for August 2019 all of the site locations S1-S4 for lake 1 and D1-D3 for lake 2, the MHMI was categorized to be *'Good'*. The overall MHMI for the month of August 2019 was evaluated to be in category '*Good*' with a value of *'36'* for lake 1 and a value of *'42'* for lake 2.

Interestingly, results of MHMI observed from samples collected in June 2020 revealed that there existed significant variation in concentrations of heavy metals depth wise leading to different categorizations for sampling locations S2-S4 in lake 1. Similar depth wise variations in heavy metals concentrations and thereby MHMI index was also observed for sampling locations D1-D3 in lake 2.

On the basis of MHMI, sampling locations S1-S4 in lake 1 were categorized as *'Poor', 'Good', 'Very Poor', 'Good'* respectively. Similarly, for lake 2, sampling point D1-D3 were categorized as *'Poor', 'Poor', 'Very Poor'* respectively. The month of June 2020 showed an enormous decline in MHMI and the overall category was determined to be '*Poor*' with a value of '*55'* for lake 1 and a value of *'67'* for lake 2. The reasons for poor quality of water in both the lakes for samples collected in June 2020 have already been explained in *section 5.3.4 above*.

The overall MHMI for the entire sampling duration was observed to be in category *'Good'* with a value of '*46' for lake 1* and category *'Poor'* with value of *'55'* for *lake 2* but with *'spill over effects'* observed for few points.

Table 5.14: Determined values of MHMI for Lake 1

Points in Lake 1	August 2019	June 2020	Overall Weighted Average MHMI August 2019	Overall Weighted Average MHMI June 2020	Overall MHMI at sampling points (Yearly Basis)
S1(a)	44 (G)	72 (P)	S1= 41 (G)	S1 = 66 (P)	S1= 54 (P)
S1(b)	37 (G)	68 (P)			
S1(c)	40 (G)	54 (P)			
S2(a)	35 (G)	39 (G)	S2 = 38 (G)	S2=44 (G)	S2= 41 (G)
S2(b)	42 (G)	71 (P)			
S2(c)	42 (G)	30 (G)			
S3(a)	43 (G)	*24 (E)*	S3 = 33 (G)	S3=79 (VP)	S3= 56 (P)
S3(b)	24 (E)	78 (VP)			
S3(c)	23 (E)	190 (U)			
S4(a)	44 (G)	42 (G)	S4 =31 (G)	S4=31 (G)	S4= 31 (G)
S4(b)	14 (E)	21 (E)			
S4(c)	23 (E)	21 (E)			
			36 (G)	**55 (P)**	**46 (G)**

Table 5.15: Determined values of MHMI for Lake 2

Points in Lake 2	August 2019	June 2020	Overall Weighted Average MHMI August 2019	Overall Weighted Average MHMI June 2020	Overall MHMI at sampling points (Yearly Basis)
D1(a)	42 (G)	48 (G)	D1 = 41 (G)	D1 = 58 (P)	*D1 = 50 (G)*
D1(b)	41 (G)	39 (G)			

D1(c)	41 (G)	88 (VP)			
D2(a)	43 (G)	52 (P)	D2 = 43 (G)	D2 = 63 (P)	D2 = 53 (P)
D2(b)	43 (G)	60 (P)			
D2(c)	43 (G)	79 (VP)			
D3(a)	42 (G)	90 (VP)	D3 = 43 (G)	D3 = 81 (VP)	D3 = 62 (P)
D3(b)	43 (G)	27 (E)			
D3(c)	43 (G)	125 (U)			
			42 (G)	**67 (P)**	**55 (P)**

5.3.6 Trophic State Index (TSI)

The parameters used for determining TSI for Lake 1 and Lake 2 were determined over the entire monitoring campaign and was determined for average yearly basis as shown in Appendix-A, Table A13 and A14 respectively. TSI is determined on lake surface and are averaged annually to determine the final TSI values and thereby their categorizations as has been summarized in Tables 5.16 and 5.17 respectively.

Lake 1

The TSI (SD) values determined for Lake 1 were *‘69.36’* and *‘66.77’* and were categorized to be *‘Eutrophic’* for sampling carried out in months of August 2019 and October 2019 respectively. The main reason attributed to the eutrophic nature may be attributed to inflow of freshwater into lakes which reduces the turbidity thereby increasing the transparency and productivity. For sampling carried out in months of December 2019 and February 2020, the TSI (SD) was determined to be *‘73.2’* and *‘71.5’* respectively categorizing it to be *‘Hypereutrophic’*. This categorization was observed due to lack of inflow of freshwater in December 2019 and overturning effects in February 2020 leading to decrease in transparency and increased haziness. For sampling carried out in June 2020 the TSI (SD) value was determined to be *‘68.07’* and was categorized as *‘Eutrophic’*, which was resulted due to onset of early monsoons thereby allowing influx of clear water and improvement in transparency which in turn resulted a shift in categorization from *‘Hypereutrophic’* to *‘Eutrophic’*. The overall average category for TSI (SD) over the entire monitoring campaign for Lake 1 was determined to be *‘Eutrophic’* with a value of *‘69.65’*.

The TSI (CHL-a) values for Lake 1 were determined to be in category *'Oligotrophic'* with values of *'30.8', '29', '24.32' and '28.05'* for the sampling months of August 2019, October 2019, December 2019 and February 2020 respectively but for June 2020 the value was determined to be *'40.44'* and was categorized as 'Mesotrophic' which might be attributed to high influx of freshwater and nutrients in June 2020 due to early monsoons observed in lieu of lockdown effects leading to decrease in productivity level. The overall average for TSI (CHL-a) was determined to be with a value of *'28.72' and was categorized as 'Oligotrophic'*.

The TSI (TP) values of Lake 1 were determined to be *'66.01'* and *'68.61'* and classified as *'Eutrophic'* for the months of August and October 2019 respectively. The main reason attributed to the eutrophic nature is the inflow of freshwater into the lake which reduces the parametric concentrations and thereby decreases the value of TSI (TP). The TSI (TP) values for sampling carried out in December 2019 and February 2020 were determined to be *'85.34'* and *'81.30'* respectively categorizing it to be *'Hypereutrophic'.* This was due to lack of inflow of freshwater in December 2019 and overturning effects in February 2020 leading to increased concentration and increased TSI (TP). For sampling conducted in June 2020 the TSI (TP) value was determined to be *'52.17'* and categorized as *'Eutrophic'*, due to onset of early monsoon. The overall average category for TSI (TP) was determined to be *'Hypereutrophic'* with a value of *'74.95'*.

Table 5.16: Determined values of TSI for Lake 1

Months	TSI (SD) (m)	TSI(CHL-a) (µg/L)	TSI(TP) (µg/L)
August 2019	69.36 (E)	30.8 (O)	66.01 (E)
October 2019	66.77 (E)	29 (O)	68.61 (E)
December2019	73.2 (H)	24.32 (O)	85.34 (H)
February 2020	71.5 (H)	28.05 (O)	81.30 (H)

June 2020	68.07 (E)	40.44 (M)	52.17 (E)
Average Yearly	**69.65 (E)**	**28.72 (O)**	**74.95 (H)**
Overall Yearly	**57.77 (E)**		

Lake 2

The TSI (SD) for lake 2 was categorized as *‘Hypereutrophic’* over the entire monitoring campaign as observed from Table 5.17 with an average annual value of *’76.57’*. This may be attributed to excessive erosion from the banks of watershed area reducing transparency and increasing turbidity.

The TSI (CHL-a) values for Lake 2 were determined to be*‘43.67’* and *‘40.64’* and categorized as *‘Mesotrophic’* for sampling conducted in months of August 2019 and October 2019 respectively. This is due to inflow of freshwater into lakes which increases transparency and therefore photosynthetic activities promoting algal growth thereby increasing its productivity. The TSI (CHL-a) values for December 2019, February 2020 and June 2020 were determined to be *‘30.97’*, *‘32.48’* and *‘37.47’* respectively categorizing as *‘Oligotrophic’*. The overall average category for TSI (ChL-a) was determined to be *‘Oligotrophic’* with a value of *‘37.05’*.

The TSI (TP) for lake 2 were determined to be *‘56.20’*, *’56.20’* and *‘69.62’*and categorized as *‘Eutrophic’* in months of August 2019, October 2019 and December 2019 respectively. Input of freshwater into the lake which adds erosional silt particles carrying TP from agricultural area increases the TSI (TP). The TSI (TP) value for February 2020 was determined to be*‘70.5’* categorizing it to be *‘Mesotrophic’,* and is due to lack of inflow of freshwater. For June 2020 the value was determined to be *’34.15’* and category was *‘Oligotrophic’*, and was primarily due to onset of early monsoon leading to inflow of fresh water thereby decreasing TSI value. The overall average category for TSI (TP) was determined to be *‘Eutrophic’* with a value of *’61.83’*.

Table 5.17: Determined values of TSI for Lake 2

Months	TSI (SD) (m)	TSI(CHL-a) (µg/L)	TSI(TP) (µg/L)
August 2019	80.89 (H)	43.67 (M)	56.20 (E)
October 2019	72.85 (H)	40.64 (M)	56.20 (E)
December2019	75.7 (H)	30.97 (O)	69.62 (E)
February 2020	73.55 (H)	32.48 (O)	70.5 (M)
June 2020	78.30 (H)	37.47 (O)	34.15 (O)
Average Yearly	**76.57 (H)**	**37.05 (O)**	**61.83 (E)**
Overall Yearly	**58.48 (E)**		

The annual average TSI values were determined to be *'57.77'* for *lake 1* and *'58.48'* for *lake 2* and were categorized as *'Eutrophic'*. Since, the three TSI values are not similar to each other [144]. The possibilities include growth of algae to be light or nitrogen limited rather than phosphorous limitation and that the Secchi disk transparency is affected by erosional silt particles from the watershed area rather than by algae.

Summary

The study focused on the quality of water of both the lakes using indexing techniques. The various indexing techniques used for determining the water quality were National Sanitation Foundation Water Quality Indexing (NSFWQI), Bureau of Indian Standards Water Quality Indexing (BISWQI), Modified Water Quality Index (MWQI), Heavy Metal Index (HMI), Modified Heavy Metal Index (MHMI) and Trophic State Index (TSI).

The National Sanitation Foundation Water Quality Indexing (NSFWQI), determined the water quality of both the lakes to be categorized as *'Good'* for the entire monitoring campaign at different sampling locations and depth with NSFWQI values varying between '*71-90'*. The depth wise variation was visible throughout the year but the trend of decrease in water quality with depth was visible only for the months of August 2019 and October 2019, the rest of the months showed no significant trend due to seasonal and lockdown effects. Sampling carried out in June 2020 showed significant improvement in WQI due to onset of early monsoons.

The Bureau of Indian Standards Water Quality Indexing (BISWQI) is based on comparison of water quality with standards prescribed by BIS 2012. The BISWQI determined for both the lakes were categorized as *'Excellent'* for the overall monitoring conditions final values of BISWQI being less than *'50'*. The depth wise variation was not visible throughout the year. The WQI showed seasonal effects but the overall category still was *'Excellent'*.

The Modified Water Quality Index (MWQI) is a proposed WQI which aims at removing the problems of ambiguity, eclipsing and limitation in use of parameters. The MWQI determined the water quality of both the lakes to be in categorized as *'Good'* for overall monitoring conditions with the value ranging between *'71-90'*. The results achieved for indexing was similar to that obtained for NSFWQI

The NSFWQI and MWQI categorized lake 1 and lake 2 in category *'Good'* in comparison to BISWQI which categorized lake1 and lake 2 as *'Excellent'*, also the depth wise variation was significant in NSFWQI and MWQI but was not significant in case of BISWQI. The difference in the categorization was dependent on parameters chosen, scale considered as well as the stringency in application of permissible parameter range, which was lenient in BISWQI as compared to NSFWQI and MWQI.

The overall Heavy Metal Index (HMI), determined for the water quality of Lakes 1 and 2 was categorized to be *'Good'* and *'Poor'* with the value ranging between *'26-50'* and '*51-75'* respectively. The depth wise variation was visible throughout the year but no significant pattern was determined. The main reason attributed to the different categorization was lack of freshwater inflow in June 2020 and increase parametric concentrations in comparison to August 2019. Lake 2 would require certain degree of treatment for heavy metals before being utilized as a water source. The results achieved for MHMI were similar to that obtained for HMI

The Trophic State Index (TSI) was determined for Secchi Disk depth (SD), Chlorophyll -a (Chl-a) concentration and Total phosphorous (TP) concentration using three individual equations for both the lakes. The overall TSI was determined as the average of the three TSI. The overall TSI determined for both the lakes were categorized as *'Eutrophic'* with different categories obtained for the three different TSI considered individually. The three TSI values were not similar to each other therefore algal growth is light limited or nitrogen limited and not phosphorous also the Secchi disk transparency is affected by erosional silt particles and not by algae.

To summarize, the effect of seasonal variation was visible in both the lakes throughout the year for both WQI and DBU. Sampling carried out in August 2019 is representative of Monsoon season marked inflow of freshwater and signified low parametric concentrations resulting in high DO levels and low BOD levels both in case of WQI and DBU, while samples considered for October 2019 (Autumn) and February 2020 (Spring) exhibited slight overturning effects resulting in high DO and EC levels both in case of WQI and DBU. December (Winters) marked stratification effects and June (Summers) marked low water influx and high parametric concentrations resulting in high pH and BOD levels and low DO concentrations for both WQI and DBU determined.

The depth wise variation was observed at all the points throughout the depth in both the Lakes but with spillover effects observed at a few points for each WQI, the trend of variation was not uniform except for August 2019 and October 2019 for NSFWQI and MWQI throughout the sampling duration due to seasonal and lockdown effects.

The following chapter presents the techniques for characterization of water, sediments and soil of watershed area which will be achieved through spectral characterization techniques of XRD, SEM and EDS.

CHAPTER 6

Spectral Characterization of Soil, Sediments and Water of Twin Lakes

6.1 Introduction

Soil is a dynamic system wherein its contamination arises due to weathering of parent rocks [151]. The nature of pollutants that contaminate the soil can be either natural or anthropogenic [151]. The growth of plants and the stability of soil depend on physical characteristics such as soil water retention, porosity, temperature, and resistance to mechanical actions which directly impact its nature. There are few other characteristics that indirectly affect the properties of the soil including soil texture, bulk density, pore size and aggregate stability [152]. The higher bulk density and a low porosity have been observed to lower the diffusion rate of oxygen into soil leading to a reduction in plant growth [153]. The soil properties are greatly affected by mineral concentrations, organic matter, oxides and microorganisms along with physical characteristics such as size of particle and density [154]. The variability in soil characteristics is dependent on topography, climate and surrounding anthropogenic activities [155]. The deterioration in the quality of soil due to its degradation which leads to affect human and surrounding environment [156]. In actuality, since there is no confirmed methodology for quantification of soil degradation and the changes in soil characteristics cannot be evaluated in any pre-defined criteria and therefore it is difficult to form a well – defined strategy for management of soil degradation [157].

Soil erosion is documented as a damaging form of soil degradation as it heavily impacts different soil properties [158]. The increased levels of pollution in water bodies near croplands could be attributed to the outcomes of excessive soil erosion [159]. The soil erosion along with weathering of rocks due to different anthropogenic activities leads to formation of heavy suspended sediment load as inflow to the lakes thereby increasing the sediment loads [160]. The addition of these soil particles contributes to heavy metals along with other chemicals such as nitrogen and phosphorous leading to change in composition of the sediments of the lake which in turn leads to eutrophication and lake ecosystem disturbances due to increased silt inputs [161].

Sediments are composed of common earth minerals and therefore it becomes imperative to understand the mineralogical composition of sediments to discuss the changes in its physico-chemical behavior. The mineralogical examinations comprise of organic and inorganic constituents and fraction size [162]. Lakes often entrap heavy minerals which generally settle at the bottom of the lakes. Therefore, lake sediment cores are often used for identifying the contamination potential and its possible effects on topography and surrounding lake ecosystem [163]. The suspension and trapping of lake sediments are dependent on its ecosystem [164] Therefore monitoring of lake sediment quality is of utmost importance for evaluation of lake ecosystem [165]. Lake sediments are reserves of important information of terrestrial environmental changes in the immediate vicinity of lake [166]. The mineralogical examination of sediments can prove to be sensitive indicator of sediment quality in terms of various pollutant inputs and is essential to determine quality level of sediments [167]. There have been very few studies which focused on relationship between physico-chemical properties and mineralogy, therefore it is imperative to assess the sediment quality and its effects on lake ecosystem appropriately.

In particular, experimental characterization for soil and sediment samples require continuous monitoring which may not be possible on long term basis due to several issues including logistical and costs [154]. Further, increased costs associated with monitoring system also adds to the impracticality [168]. In this context, spectral characterization techniques have been identified as low-cost methods that can overcome such practical difficulties [169]. The main objective of the study was to determine the spectral characteristics of the soil, sediment and water of both the lakes through Scanning Electron Microscope (SEM), Energy Dispersive X-Ray Spectroscopy (EDS) and X-Ray Diffraction (XRD) which could provide a detailed characteristic analysis with only a small volume (few micrograms) of sample collected [170].

Further, application of these microscopic techniques like SEM and EDS are used for quantification of data, whereas XRD analysis focus on qualitative results [87]. Additionally, there is a need for source identification of sediment so as to classify them into natural or anthropogenic and to evaluate the impact of characteristics of soil present in the lake vicinity on plants as well as humans. The sediment quality index has also been determined to identify possible effects on lake ecosystem

6.2 Materials and methods

6.2.1 Sample Collection

6.2.1.1 Collection of Soil Samples

The soil samples were obtained from adjacent fields surrounding both lakes. The sampling locations used for collection of soil have been shown in red color points as shown in Figures 6.1 and 6.2 for lakes 1 and 2 respectively. The samples of soil were collected at a depth of 15-30 cm from the surface to determine various parameters [171]. The soil was then dug with the help of a hand auger with top 1-2 cm layer discarded and the samples collected were filled in a bucket. The external impurities were removed by spreading the sample on clean cloth and removing the foreign items by handpicking [171]. The composite samples were then made by mixing the samples collected from different points thoroughly by separating them into quarters for homogenizing and spreading and mixing in all directions [172]. Alternate sequencing technique was used for filling the soil in appropriately labelled containers by using a shovel as shown in Figure B1 of Appendix -B. The containers were then shifted to laboratory for different testing procedures.

6.2.1.2 Collection of Sediment Samples

The collection of samples for sediment analysis was done at 5 different points in lake bed as shown in Figures 6.1 and 6.2 for both the lakes respectively. These sampling points have been shown in green colored dots. The selection of the sediment sampling points was such that it covered the entire lake bed. For the present study a Van Veen Grab Sampler with (JN Science tech I.D. 20572517688, item code: 134833654) material of stainless steel grade SS 304 with 5 kg was utilized. The dimension of sampler was 24 cm x 22 cm. The sampler can be used for collecting fine grained particles till 30 cm depth [172]. The volume of sediment samples was based on parameters to be determined therefore, 3 Kg of sample was collected [173]. A single composite sample was prepared through technique mentioned in section *6.2.1.1* to reduce the cost of analysis [172]. The samples were then stored in appropriately labelled containers and taken to laboratory for different testing procedures. The field samples for both soil and sediments were collected 2 times a month at 15 days interval and the samples were tested in triplicates and averaged to obtain necessary results.

6.2.1.3 Collection of Water Samples

The sampling methodology used for collecting the water samples have already been explained in *chapter 3 section 3.2.3.*Samplings for both the lakes were carried out at predefined locations and depth. Sampling points for both the lakes have been marked with blue color dot for reference as shown in Figures 6.1 and 6.2 respectively. The samples taken from different points were stored in appropriately labelled bottles, taken to laboratory and analyzed separately.

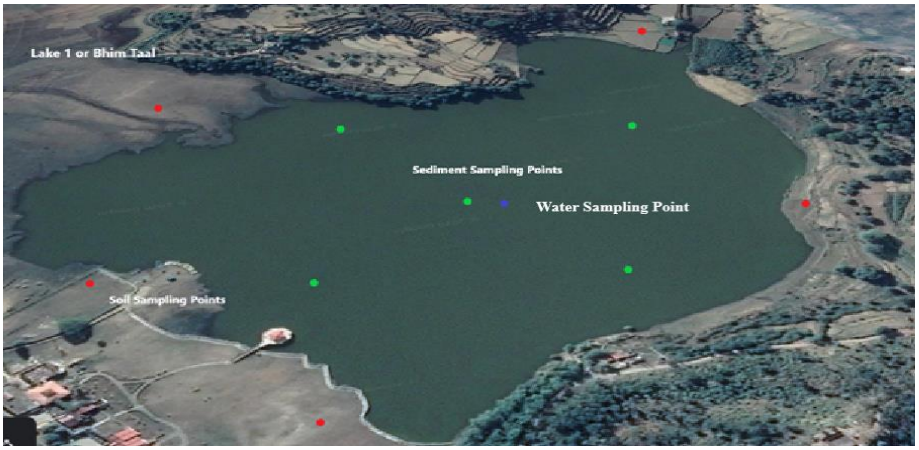

Figure 6.1: Sampling points for Soil, Sediments and Water for Lake 1

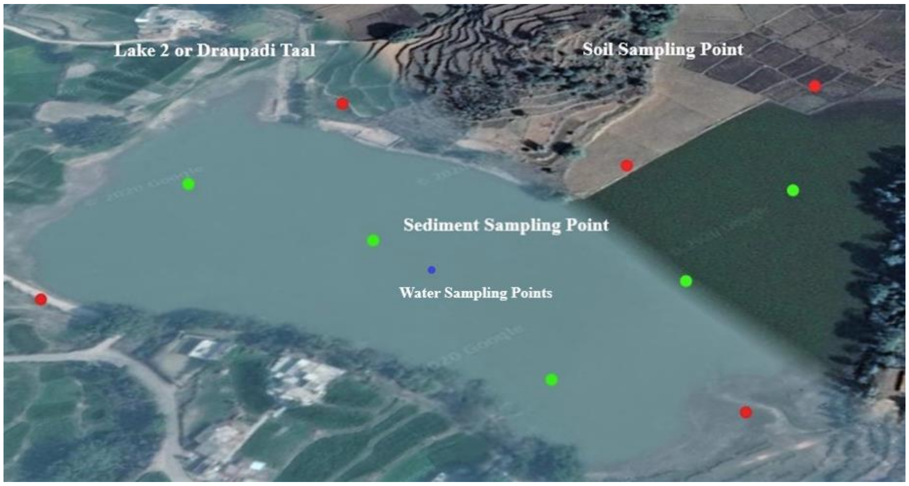

Figure 6.2: Sampling points for Soil, Sediments and Water for Lake 2

6.2.2 Sample Preparation

6.2.2.1 Preparation of Soil and Sediment Samples for Chemical Analysis

The soil and sediment samples for chemical analysis were prepared differently for evaluation of each chemical parameter. The preparation of samples was based on guidelines issued by USEPA 1998, APHA Edition 23rd Edition, 2017, USDA Soil Method Manual, 1996 & 2014, RC 353.08, USEPA 1640 & Oxide Conversion Chart. The methods for sample preparation and analysis have been presented in Appendix A, Table A16. Figure B1 shows the samples of soil and sediments collected from both the lakes.

6.2.2.2 Preparation of Soil and Sediment Samples for Spectral Characterization

Sediment and soil samples used for spectral characterization was prepared by heating 200 mg separately in laboratory hot air memmert type oven (Item code: BTL-27, manufacturer: Bio Techno Lab, Mumbai). The range of temperature for the oven is between 50 to 250˚C with capacity varying between 40 to 325 litres [86]. For sample preparation, the samples were heated to 110°C to 120°C for 2-3 hours to allow for evaporation of excessive moisture [174]. The samples were then cooled to room temperature and then grounded continuously for 15 minutes with help of pestle and mortar for converting the min to powdered form avoiding breakage of the natural molecular structure [86]. The grounded sediment samples were then passed through a sieve less than 0.5 mm diameter mesh. The soil samples were sieved through a 420 µ sieve based on IS: 469/1972 to obtain a powdered form whereas for sediment samples the main purpose of sieving was done to obtain a fine powder. The samples were then stored in appropriately labelled microcentrifuge tube marked with suitable month and location to avoid anomaly in analysis procedures.

6.2.2.3 Preparation of Water Samples

For the purpose of spectral characterization of water; Drop Cast method was employed [174]. The method involves deposition of water samples on glass slides for preparation of the samples for spectral characterization. At first, the glass slides were cleaned by dipping them in acetone and then placing them on hot plate wherein the acetone evaporates leaving a clean slide. The clean slides are then subjected to temperatures between 60 °C to 80 °C and the water samples are then deposited on them with help of syringe and needle. The repeated deposition and evaporation of water samples at center of glass slide forms a uniform layer. The glass slides are then removed from hot plate and then allowed to cool. The slides are then marked appropriately and analyzed.

6.2.3 Sample Testing and Analysis

6.2.3.1 Physical and Chemical Analysis

The samples were prepared and tested for texture, color, organic matter, organic carbon, pH, Cation Exchange Capacity (CEC), Phosphorus, Nitrate, Sulphur, Calcium, Magnesium, Chloride, Aluminum, Silica. They were also tested for traces of pesticide residues such as Alpha BHC, Beta BHC, Gamma BHC, Lindane, OP-DDT, PP-DDT, Alpha Endosulphan, Beta Endosulphan, Malathion, Aldrin, Methyl Parathion, Anilophos, Chlorpyriphos, Chlordane, DDD, DDE, Dieldrin, Endrin, Heptachlor, Nonylphenol, 2-Methyl, Acenaphthene, Acenaphthylene, Anthracene, Benza anthracene, Benza pyrene, Chrysene, Dibenza anthracene, Fluoranthene, Fluorene, Naphthalene, Phenanthrene, PCB1254, tPCB, PCDD/F, Toxaphene.

The samples were also evaluated for heavy metals such as Arsenic, Cadmium, Copper, Lead, Chromium, Zinc, and Mercury through standard procedures as mentioned in APHA, 2012. The obtained results were then compared with prescribed standards by authorities to examine their aptness from agricultural and environmental point of view as well as to check the toxicity of soil and sediments.

The equations for sediment classification and parameter determination [175] were used for calculation of parameters that could not be evaluated '*in-situ*'. The report mentions the appropriateness of the usage of these equations for depth of less than 500 m of the water body [175]. Since the depth of the study lakes were less than 500 m, these equations were considered fit to be utilized. In practical, the parameters should preferably be measured onsite directly [175], but due to lack of certain resources, the following equations were employed as a suitable substitute for the determination of grain size, percentage of Pelite and Total Organic Matter (TOM) [175]. The equations are summarized below.

$$\text{Grain size } (\mu\text{m}) = 229e^{-0.0054(m)} \quad (6.1)$$

$$\text{Pelite } (\%) = 1.19e^{0.012(m)} \quad (6.2)$$

$$\text{Total Organic Matter(TOM)} = 0.51e^{0.0072(m)} \quad (6.3)$$

Where,

m = depth of collection of sediment samples

6.2.3.2 Field Emission Scanning Electron Microscope (FESEM) and Energy Dispersive X-Ray Spectroscopy (EDS)

The basic principle behind the working of FESEM is to focus an electron beam over sample surface to produce an image. The stream of electrons which are focused on the sample surface interacts with it producing necessary data about the morphology of surface and sample composition in form of high-resolution images [86]. The Nova Nano SEM 450 machine manufactured by JEFI S.E.A. PTE. LTD was utilized for the SEM analysis [176].

The Energy Dispersive X-Ray Spectroscopy (EDS) is attached with the FESEM machine and works on the principle of a chemical micro-analysis which is utilized for both quantitative and elemental analysis of the samples [177]. The different energies generated during bombardment process correspond to different elements and these energies are detected by EDS X- ray detector which is a grouping of lithium and silicon in a solid state and usually detects the presence of various elements in the samples [178] along with their morphological details.

The soil and sediment samples were exposed to a voltage of 10 kV after gold (Au) sputter coating for better dispersion of the electron beam. A double-sided carbon tape was used for keeping the samples in position. The image of soil and sediment samples were detected through Everhart – Thornley detector in a field free mode for SEM. The same instrument was used for performing EDS of the samples.

6.2.3.3 X-Ray Diffractometer (XRD)

The crystal's atomic and molecular structure along with other inorganic material can be assessed through X-ray Diffraction (XRD). The basic principle is to detect X- ray beams which get diffracted in different directions and each X-ray diffraction denotes the plane of crystal [179].

The samples were crushed into powdered form and the spectra of the samples were obtained through Rigaku Corporation's Smart lab 9 Kw rotating anode X ray diffractometer with counter detection system [176]. The target material was copper and the fine focus filament material was used as cathode [176]. A small angle X-ray scattering unit was also attached to the system.

6.2.3.4 Sediment Quality Index (SeQI)

The Sediment Quality Index (SeQI) was determined using an excel model of SEQI 1.0 which is user friendly and best for evaluation of quality of sediments in both freshwater and for marine systems [180]. This data tool was used for calculating index which is site specific as well as based for average representation. The results of SeQI conforms to the permissible limits of freshwater standards as prescribed by the Interim Sediment Water Quality Guidelines (ISQG) and Probable Effect Levels (PEL). However, for the developing of the application, the model can be modified according to their needs. The users can enter definite set of guidelines and for their specific cases as well [181].

To summarize, the model application utilizes predefined parameters using Toxic Equivalent Factors (TEQ) explained in [182] and [183], as stated by World Health Organization (WHO). The calculations are performed based on Ontario Severe Effect Level (SEL). The SeQI was determined using above mentioned parameters like heavy metal concentrations and pesticide residue. Further, the non-determined parameters by the user are either set as (-1) or left blank whereas the non-detectable parameters are set to 0 as per the user guidelines [184; 185].

Overall, the SeQI results obtained vary between (0-100) which can be categorized as (95-100) ‘Excellent’, (80-94) ‘Good’. (65-79) ‘Fair’, (45-64) ‘Marginal’ and (0-44) ‘Poor’ [184;185].

6.3 Results and Discussions

6.3.1 Physico- chemical and Pesticide Analysis

The results of the physico- chemical analysis for samples of soil and sediment for both the lakes have been summarized in Table A16 of Appendix A. The results review the various physical and chemical tests performed; the methodology used for conducting these tests along with the suitable classification range of the parameters utilized. It was determined from the study that:

The texture of the soil for both the lakes was clay and for the sediments; it was mixture of sand and clay composing it into fine sand This difference in the texture between the soil and sediments might be due to difference in morphological conditions pertaining to moisture content, pore size along with topographical and seasonal variations [186].

The color of the soil plays an important role and depends on moisture in soil, organic contents and mineral composition. The color of the soil is an important factor for protection of plant against frost since the darker soils have higher organic content and absorb more heat [187]. The Munsell system is used for color determination on the basis of Hue, Value and Chroma for both soil and sediments [188]. The color of the soils surrounding both the lake sites was observed to be lighter as compared to color of sediments thereby confirming the presence of humus in sediments. This may be attributed to soil erosion removing top layer of soil containing humus that usually adds a darker color to the soil [189].

The soil and sediments from both the lakes were determined to be mildly alkaline in nature with pH value of 7.72 and 7.70 for soil of lake 1 and lake 2 respectively and 7.82 and 8.30 for sediments of Lakes 1 and 2 respectively. The pH is an important factor that controls many reactions affecting the environmental conditions for flora and fauna [190].

The humus contains high proportions of organic matter (OM) which increases the lake productivity for fish production. The continuous erosion from the banks leads to higher concentrations of organic matter in sediments than soil. The organic matter was determined to be 0.34% and 0.16% for soils of Lake 1 and 2 respectively. Similarly, organic fraction was determined to be 0.68% and 0.24% for sediments of Lakes 1 and 2 respectively. Both these results have been summarized in Table A16 of the Appendix. It may be mentioned better yield of fish maybe possible from lake 1. Further, it may also be attributed to the fact that the samples were collected in monsoon season which is marked by heavy rains that leads to washing away of top soil rich in organic matter into the lakes.

The proportion of organic carbon (OC) for soils of Lakes 1 and 2 was determined to be 0.19% and 0.09 % respectively. In a similar manner, the proportion of OC in sediments was determined to be 0.39% and 0.14% for sediments of Lakes 1 and 2 respectively. The results showed a slightly higher OC values for soil in lake 1 and for sediments in Lake 2, also the soil of lake 2 showed low value in comparison to soil of lake 2, however as per classification standards the overall productivity for both soil and sediments of both the lakes were classified as low (<0.5%). The organic carbon (OC) is certainly higher in proportions in fine soils such as sediments due to larger particle bonding than coarse soils where smaller pores protect carbon therefore the soils depicted low OC content [175]. Further, the presence of high organic carbon also denotes higher productivity and higher fertility [191].

The Cation Exchange Capacity (CEC) in the soil varies from 5 meq/100g in sandy soils to 15 meq/100g in high organic content soils [189] and they have been summarized in Appendix A Table A16. From our study it was determined that the CEC value of soils from Lakes 1 and 2 were 17.2 meq/100g and 12.3 meq/100 g respectively. Similarly, the CEC values for sediments of Lakes 1 and 2 were determined to be 11.7 meq/100g and 8.6 meq/100g. It is inferred from the above results that both soil and sediments of for the lakes a high CEC values (> 5 meq/100 g) exist which suggest they can retain and supply nutrients specially cations such as Ca, Mg, K, Al and H [189].

The presence of phosphorous is considered to be an essential nutrient for plant growth but excess concentrations can inflow into lakes along with erosion process leading to deterioration of water quality thereby promoting eutrophication and algal bloom [3] whereas a reduced amount may lead to stunted plant growth [189]. The phosphorous concentration was determined to be 15.7 mg/kg and 14.6 mg/kg for soils for Lakes 1 and 2 respectively. Similarly, the phosphorous concentrations were determined to be 8.6 mg/kg and 7.6 mg/kg for sediments for Lakes 1 and 2 respectively. It is observed that the phosphorous concentrations were found to be medium in soils (10 mg/kg - 24.6 mg/kg) as compared to sediments for both the lakes which were in low range (<10 mg/kg). Further, mildly alkaline nature of soil allows easy uptake of phosphorous by plants [189]. In particular, lower concentrations of phosphorous in the sediments is beneficial for lakes but high amount in soil is useful for a good yield for plants.

The concentrations of nitrogen were determined to be 162 mg/kg and 165 mg/kg for soils of Lakes 1 and 2 respectively and were classified as medium (96-192) (as per the prescribed the standards. Similarly, concentrations of nitrogen were determined to be 86 mg/kg and 82 mg/kg for sediments of Lakes 1 and 2 respectively and were classified as low (<96) as per the prescribed the standards.

The concentration of Sulphur in the were determined to be 8.6 mg/kg and 7.2 mg/kg for soils of Lakes 1 and 2 respectively and were classified as medium category (5 mg/kg - 20 mg/kg). Similarly, the concentration of Sulphur in the sediment samples were determined to be 4.5 mg/kg and 4.8 mg/kg for sediments of Lake 1 and 2 respectively and were classified in low category (2 mg/kg – 5 mg/kg) as per standards shown in Appendix A, Table A16 for both the lakes. Sulphur plays an important role in nitrogen fixation and therefore moderate concentrations of Sulphur is estimated to have a good result on plant growth [189] thereby confirming a good status of soils for plant growth.

Cations such as calcium are important for growth of fruits and roots and deficiency of this element can lead to problems in plants [189]. The concentrations of Ca ion can be considered to be low in the context of its correlation with pH levels. The deficiency is related to soils with low pH levels and can easily be removed by lime treatment [192]. The value Ca ion in the soils was determined to be 106 mg/kg and 40 mg/kg for Lakes 1 and 2 respectively. Similarly, the Ca concentrations in sediments were determined to be 250 mg/kg and 216 mg/kg for Lakes 1 and 2 respectively. The high concentrations of Ca in lakes promote alkalinity and hardness in lake waters.

Magnesium (Mg) is an important element for boosting up plant metabolism and is also a part of chlorophyll, and its deficiency in soils can easily be removed by dolomitic lime or Epsom salt treatments [189]. The concentrations of magnesium were determined to be 56 mg/kg and 18 mg/kg for soil of Lake 1 and 2 respectively. It is inferred that the magnesium concentrations were in the lower ranges (< 60 mg/kg) in soil as per the prescribed standards. Similarly, the Mg concentrations for the sediments were determined to be 95 mg/kg and 115 mg/kg for Lakes 1 and 2 respectively and were categorized medium (60 mg/kg - 300 mg/kg) as per the standards. The results confirmed deficiency of magnesium in the soils near the lakes which interfere with plant's photosynthetic activities leading to low plant metabolism [189].

The chloride concentrations for soils of Lakes 1 and 2 were determined to be 15 mg/kg and 10 mg/kg respectively. The chloride concentrations of the sediments of Lakes 1 and 2 were determined to be 10 mg/kg and 40mg/kg. It was inferred from the above values that both soil and sediments were categorized as medium category (10 mg/kg – 20 mg/kg) as per the prescribed standards for both the lakes. The presence of chloride is attributed to irrigation waters or manures applied in the fields [192].

High concentrations of Aluminum can lead to toxicity in plants and interferes with the solubility and uptake of phosphorous. Since, Aluminum is not a plant nutrient, the effects of Aluminum are prevalent on soils with pH less than 5.5 [189]. The concentrations of Aluminum for soil were determined to be 0.04 mg/kg and 0.03 mg/kg for Lakes 1 and 2 respectively. Similarly, concentrations of Al in sediments were determined to be 0.02 mg/kg and 0.03 mg/kg for Lakes 1 and 2 respectively. It is inferred that such low concentrations of Al induces no effect on pH of the soil which is in alkaline range.

The percentages of silica in soils were determined to be 31.5 % and 28% for Lakes 1 and 2 respectively. Similarly, the percentages of silica in sediments were determined to be 63.5 % and 66.9 % for Lakes 1 and 2 respectively. In principle, sediments have a higher silica content which is its characteristic property due to terrestrial inflows and its ability to stay in stable conditions in the sediments leads to its higher values in comparison to soils [193].

Pesticides are used for eradication of unwanted organisms and insects from plants and crops from the agricultural fields [194]. There exists large number of pesticide formulations commercially available which are utilized in agriculture [195]. About 0.1% of pesticide application is enough to kills pests and the remaining concentrations accumulates in the surrounding environment [194]. Since the pesticide degradation is a complex procedure [196] its determination is imperative and essential. In this context, Appendix A (Table A16) summarizes different pesticides determined for both the soil and sediments of both the lakes. It was observed that *pesticides were not detectable for both soils and sediments* due to the use of natural fertilizers such as cow dung and wood ash which are locally available.

Grain Size was determined using eq. 6.1 as mentioned in section *6.2.3.1*. The grain sizes of the sediments were determined to be 221.69 µm and 224.11µm for Lakes 1 and 2 respectively. The value of *phi* (φ) was determined between 2-3, and hence the sediments were classified as fine sand [197;198]. The value of *phi* (φ) used is expressed as negative logarithm of base 2 of the particle size expressed in millimetres and is more convenient to be used for expression of size.

Equation 6.2 was used to determine the percentage of pelite in the sediments and was determined to be 1.28 % and 1.24% for Lakes 1 and 2 respectively. It may be inferred from the results that it conforms in the range of fines as obtained in grain-size analysis above. Further, determination of percentage of pelite or fine-grained sedimentary rock particles are estimated to increase with increase in depth. It signifies that the fineness of particles increases with depth [175].

The Total Organic Matter (TOM) was determined using eq. 6.3. The percentage of TOM for sediments was determined to be 0.52 % and 0.53% for Lakes 1 and 2 respectively indicating the low value of contaminants in form of particulates and more number in dissolved form [175]. Determination of Total Organic Matter (%) indicates solubility of contaminants in water. The larger value indicates greater particulates number in water [175].

6.3.2 Spectral Characterization

Application of Field Emission Scanning Electron Microscope (FESEM), X-Ray Diffraction (XRD) and Energy Dispersive (EDS) techniques were used for spectral characterization of soil sediment and water samples and the results of the same have been discussed below.

6.3.2.1 Field Emission Scanning Electron Microscope (FESEM)

FESEM images of soil near Lakes 1 and 2 have been presented in Figures 6.3 (a) and 6.3 (b) respectively. Similarly, FESEM images of the sediments of Lakes 1 and 2 have been presented in Figures 6.4 (a) and 6.4 (b) respectively.

Soils of Lake 1 and Lake 2

It was observed from Figure 6.3 (a) that the soil of Lake 1 is representative of snowflake with agglomerated structure representing round smooth edges. Figure 6.3 (b) represents soil of Lake 2 [199] from which it is inferred that it is tightly bound together imitating thin sheets rolling over each other. The edges are sharp and the surface is covered with smaller sized broken particles covering the surface of these sheets.

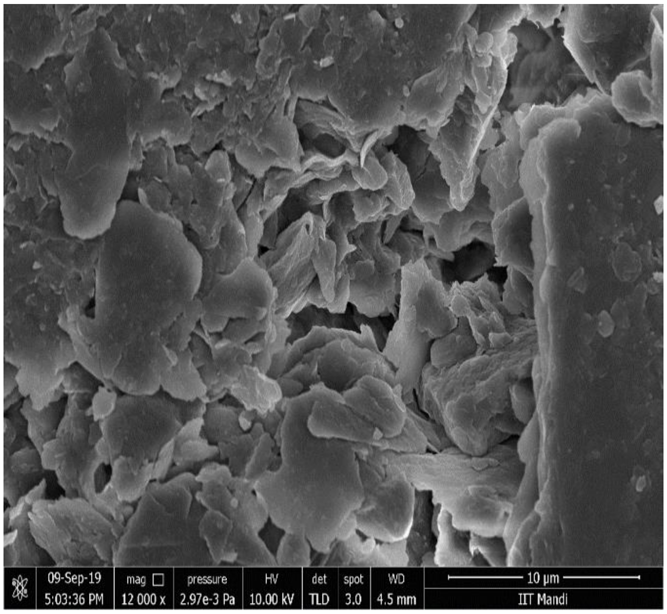

Figure 6.3 (a): SEM micrograph for soil of Lake 1

It may be further be observed from images of 6.3 (a) and 6.3 (b) that they have less dark spaces between particles which are representative of less number of voids and hence low porosity [200]. The agglomerated structure may be attributed to presence of clay particles in the soils confirming low porosity which is characteristic property of clay.

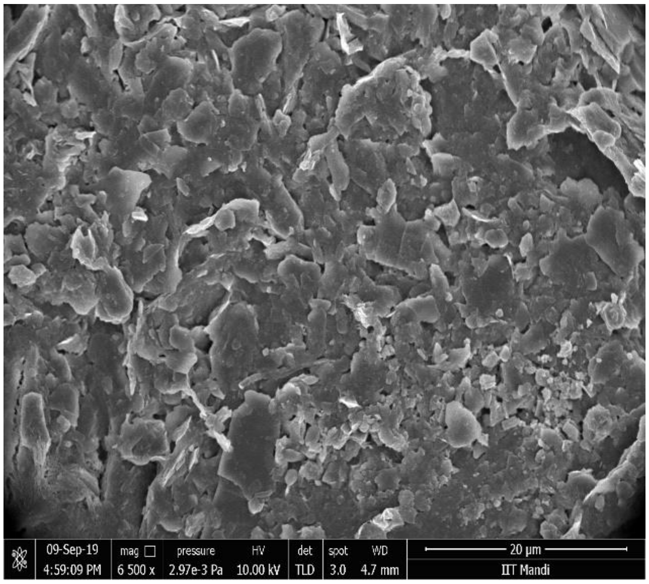

Figure 6.3 (b): SEM micrograph for soil of Lake 2

Sediments of Lake 1 and Lake 2

Figure 6.4 (a) and 6.4 (b) represents SEM images of sediments of Lake 1 and 2 respectively [199].

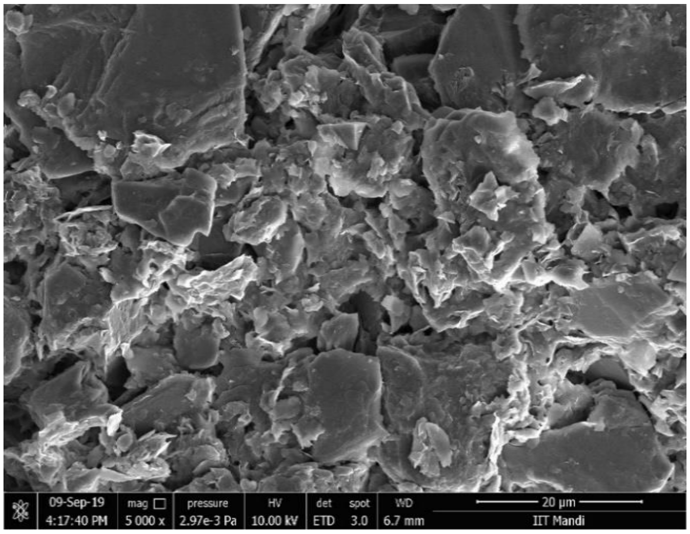

Figure 6.4 (a): SEM micrograph for sediments of Lake 1

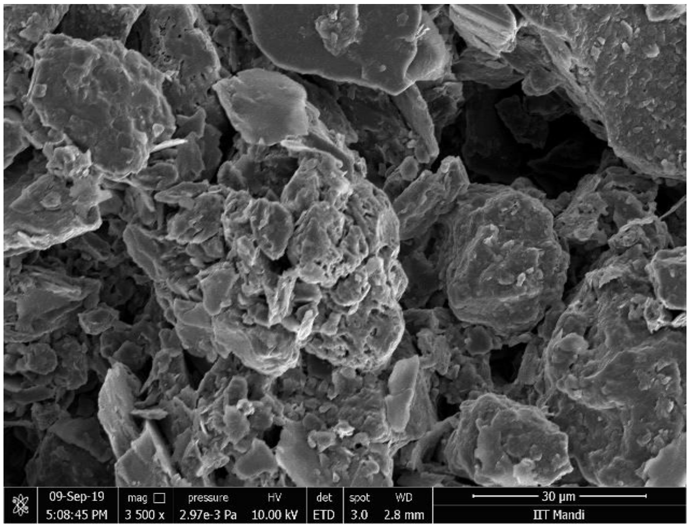

Figure 6.4 (b): SEM micrograph for sediments of Lake 2

It was observed from these SEM images that there existed number of smaller particles representing sharp-edged flakes in sediment samples in comparison to the images observed for soils of Lake 1 and Lake 2 respectively.

The main reason behind the morphological changes in soil and sediment particles may be attributed to the erosion of soil from lake banks forming sediments and since sediments are formed by repeated action of waves over soil surface, they further break the soil into finer particles representing smaller sharp-edged flaky particles fitted into each other like fine graded silt. The presence of a greater number of dark spaces represent loosely held structure and a greater porosity which was similar to observations of study conducted by [200].

Water of Lake 1 and Lake 2

Figures 6.5 (a) – 6.5 (c) represents SEM images of water of Lake 1 at different depths of 2 m - 4 m respectively from the surface.

It was observed from Figure 6.5 (a) that the water of Lake 1 at 2 m depth from surface is representative of snowflake with agglomerated structure representing round smooth edges and lesser amount of dark spaces.

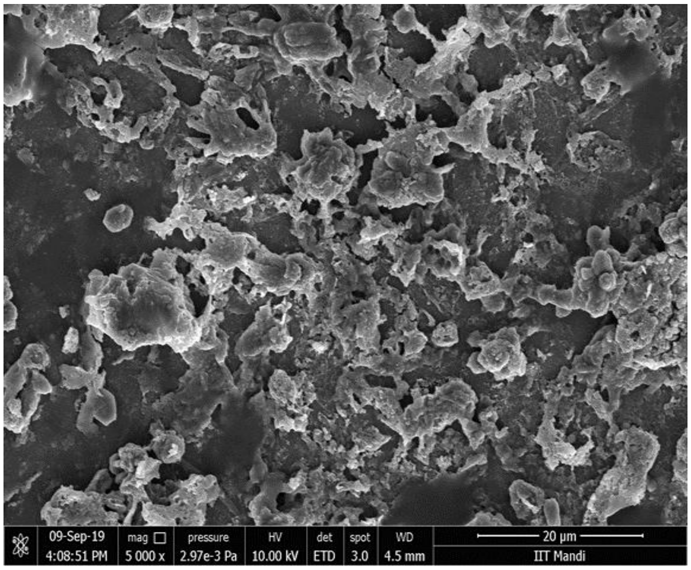

Figure 6.5 (a): SEM micrograph for water of Lake 1 at 2 m depth from surface

Figure 6.5 (b) represents the water of Lake 1 at 3 m depth from surface towards lake bed, which is more concentrated as represented by thin rolling sheets with sharp edges and many smaller sized particles covering the surface of these sheets.

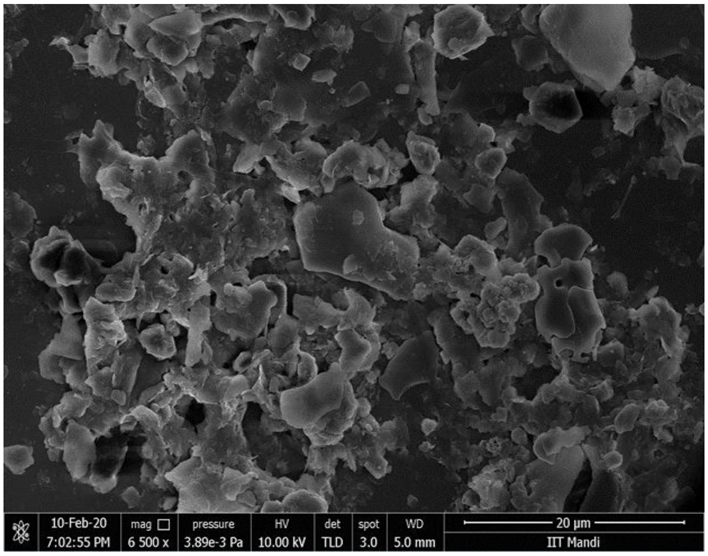

Figure 6.5 (b): SEM micrograph for water of Lake 1 at 3 m depth from surface

Figure 6.5 (c) represents the water of Lake 1 at 4 m depth from surface, which is more concentrated as represented by numerous smaller sized particles with sharp edges covering the surface of these sheets, the image represented lesser amount of darker spaces.

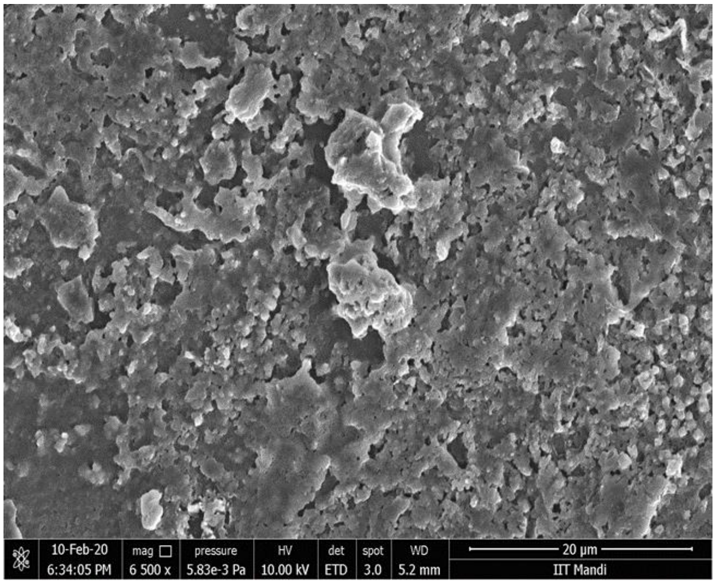

Figure 6.5 (c): SEM micrograph for water of Lake 1 at 4 m depth from surface

Similar, to the above; Figures 6.6 (a) – 6.6 (c) represent SEM images of water of Lake 2 at different depths of 1m – 3 m from surface.

It was observed from Figure 6.6 (a) that the water of Lake 2 at 1 m depth from surface is representative of snow flaky agglomerated structure, round smooth edges and less number of dark spaces.

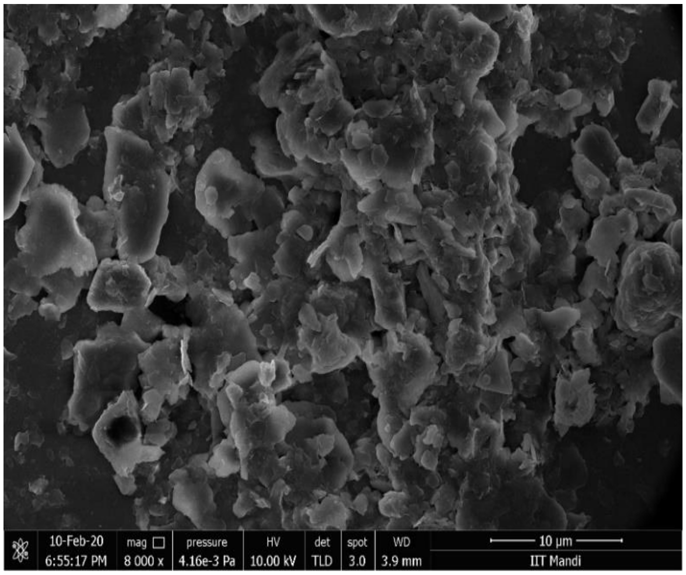

Figure 6.6 (a) : SEM micrograph for water of Lake 2 at 1 m depth from surface

It was observed from Figure 6.6 (b) that the water of Lake 2 at a depth of 2 m from surface was representative of snow flaky agglomerated structure, sharp edges, smaller number of broken particles covering the surface and lesser amount of dark spaces.

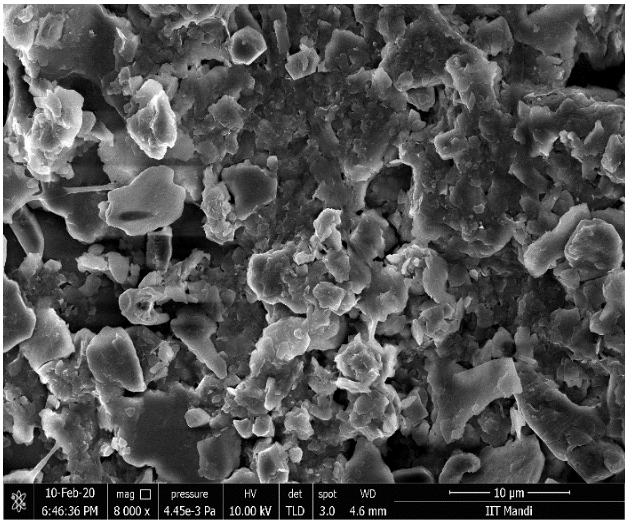

Figure 6.6 (b) : SEM micrograph for water of Lake 2 at 2 m depth from surface

It was observed from Figure 6.6 (c) that the water of Lake 2 at 3 m depth from surface is representative of snow flaky agglomerated structure, sharp edges, more concentrated appearance and least amount of dark spaces.

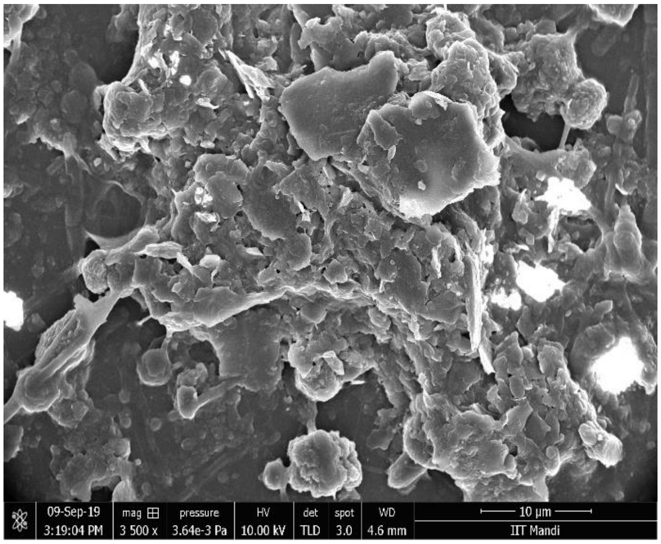

Figure 6.6 (c) : SEM micrograph for water of Lake 2 at 3 m depth from surface

The increased agglomeration is confirmed by decrease in dark spaces with increase in depth for both the lakes. This may be attributed to an increase in density of water with depth which increases concentration and therefore agglomeration in structure is observed.

6.3.2.2 X-Ray Diffraction (XRD)

The XRD images were obtained by plotting difference in angle of incidence and angle of reflection which is known as 2θ on x- axis and the intensity of the X- ray light being focused on the sample known as counts on y-axis.

Soils of Lake 1 and Lake 2

From the XRD analysis carried out sharp peaks were obtained for soil samples representative of both lakes 1 and 2 and as summarized in 6.7 (a) and 6.7 (b) respectively [199]. These peaks indicate presence of crystalline materials in form of elements in samples, which is confirmed by the EDS patterns and discussed separately in the next section.

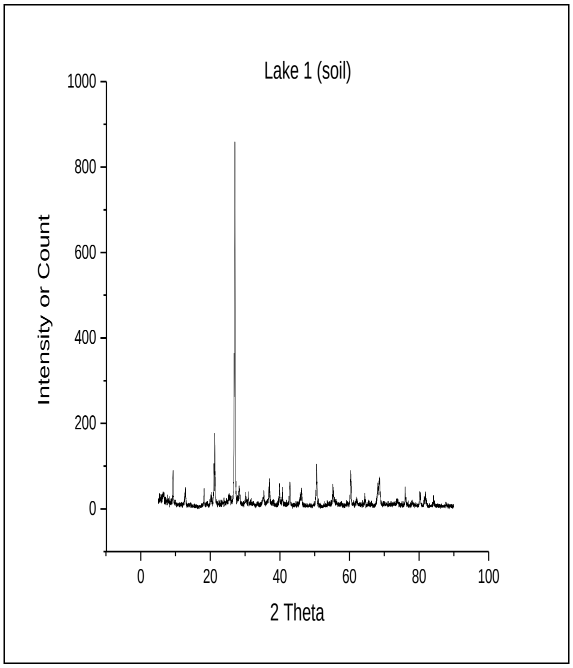

Figure 6.7 (a):XRD graph for soil of Lake1

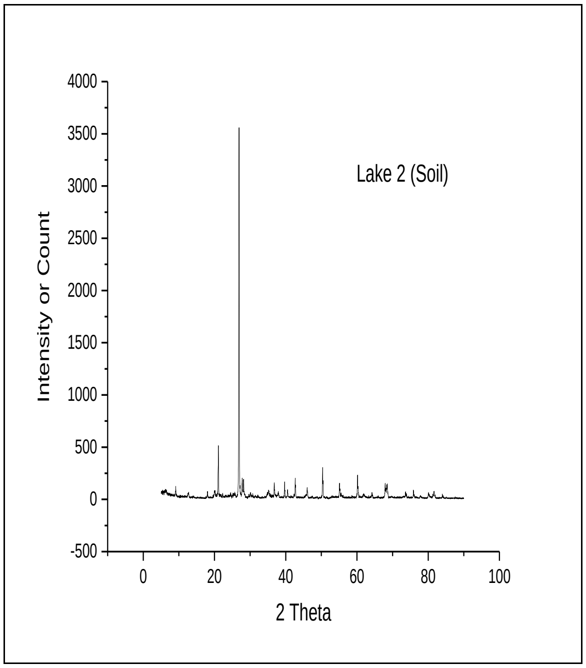

Figure 6.7 (b) : XRD graph for soil of Lake 2

Sediments of Lake 1 and Lake 2

Similar results to soil sample analysis were observed for sediments for both the lakes. Sharp peaks were obtained sediment samples for both the lakes which have been summarized in Figures 6.8 (a) – 6.8 (b) [199]. These peaks indicate presence of crystalline materials in form of elements in the samples, which are also confirmed by the EDS patterns and discussed separately in the next section.

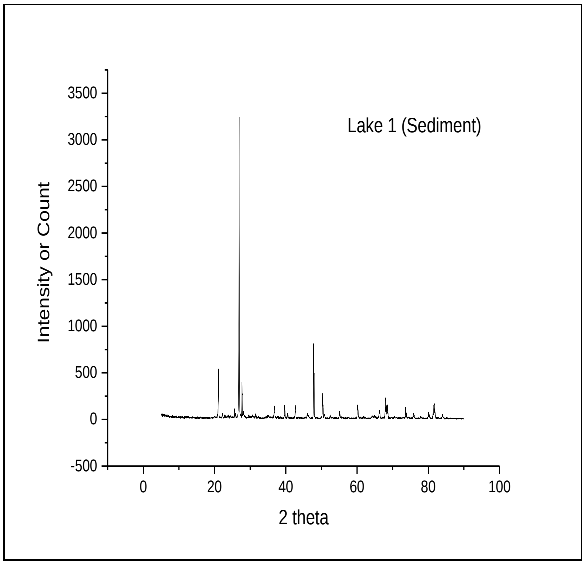

Figure 6.8 (a): XRD graph for sed. of Lake 1

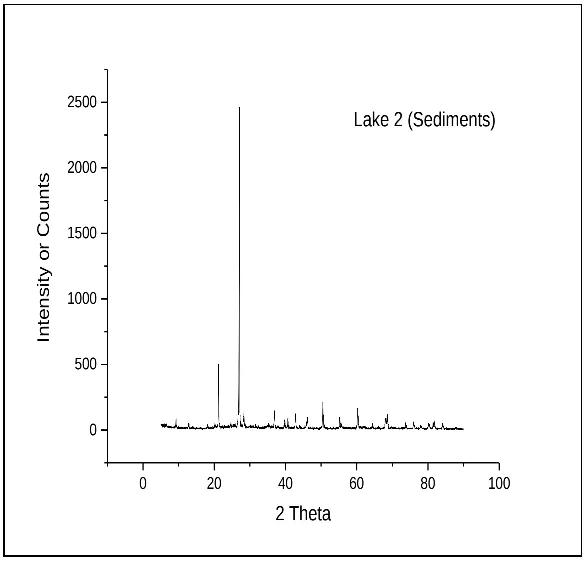

Figure 6.8 (b) :XRD graph for sed. of Lake 2

6.3.2.3 Energy Dispersive X-Ray Spectroscopy (EDS)

The EDS was plotted between Kilo electron volt (Kev) on x-axis and counts per second (Cps) on y-axis and the analysis was carried out for both soil and sediment samples for both the lakes.

Soils of Lake 1 and Lake 2

The elements detected from the EDS analysis of soil samples of Lakes 1 and 2 have been shown in Figure 6.9 (a) – 6.9 (b). The elements determined in Lake 1 were Carbon (C), Oxygen (O), Aluminum (Al), Ytterbium (Yb), Silicon (Si) and Niobium (Nb), while those present in Lake 2 were Carbon (C), Oxygen (O), Magnesium (Mg), Aluminum (Al) and Silicon (Si).

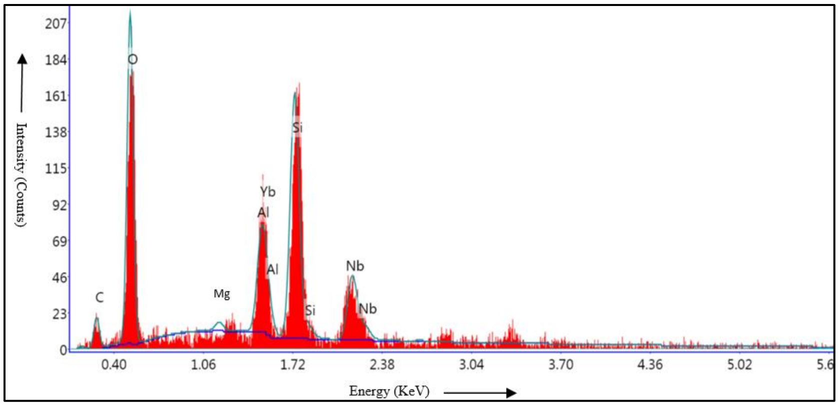

Figure 6.9 (a) : EDS micrograph for soil of Lake 1

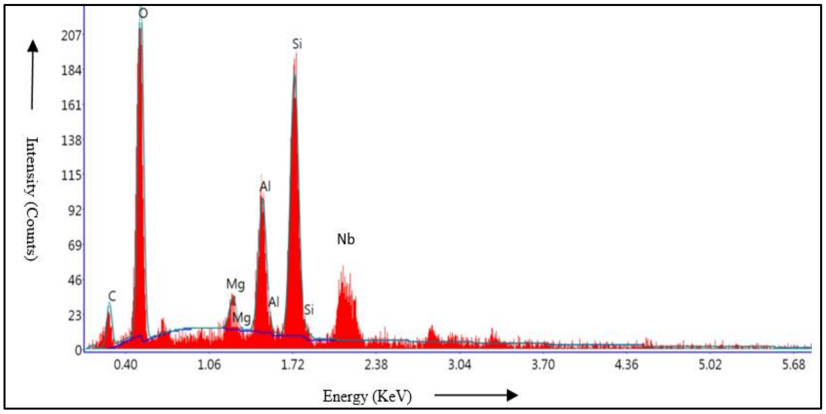

Figure 6.9 (b) : EDS micrograph for soil of Lake 2

The results of the quantitative analysis of soil samples for Lakes 1 and 2 have been presented in Tables 6.1 (a) - 6.1 (b) respectively. The total weight percentage was considered to be 100%, therefore the weight % of each element was considered in comparison to this total weight % of the sample. The weight percentages of Oxygen, Silicon and Niobium were found to be the highest amongst all determined elements for soil sample of Lake 1. Similarly, The weight percentages of Oxygen (O), Carbon (C) and Aluminum (Al) were found to be highest amongst all determined elements for soil sample of Lake 2.

Table 6.1 (a) : EDS (Quantitative) analysis of soil of Lake 1

Element	Atomic number	Weight %	Atomic %	Series	Error %
C	6	9.94	18.75	K	21.46
O	8	38.98	55.17	K	10.70
Al	13	5.52	4.63	K	11.88
Yb	70	9.35	1.22	K	21.31
Si	14	20.27	16.35	K	7.39
Nb	41	15.94	3.89	K	13.85

Table 6.1 (b) : EDS (Quantitative) analysis of soil of Lake 2

Element	Atomic number	Weight %	Atomic %	Series	Error %
C	6	17.65	26.41	K	0.04
O	8	42.06	47.25	K	0.20
Mg	12	2.61	1.93	K	0.02
Al	13	11.48	7.65	K	0.09
Si	14	0.01	16.76	K	0.21

The air comprises of 21 % of oxygen and is available abundantly in environment and hence is also present in the samples. Aeration is an important factor for plant growth [201]. The availability of this element in samples is largely reliant on the water content and its ability to diffuse through the soil [202]. In principle, soils with lesser moisture content have more oxygen content in the soil [203].

The sources of silica in soil are derived from sand, dust and weathering of rocks. The soil comprises of 28% of silica in earth's crust and is 2nd most abundant element after oxygen. It is vital for forming of plant cells for intake of nutrients.

Niobium is a transition metal linked with silicates and exist as alloys with oxygen [204]. The abundance of oxygen in soil could have led to formation of oxides of this metal thereby increasing its concentrations. The element in itself does not pose any biological effects but the dust may cause eye, nose and skin irritation [205].

Carbon is an important component of organic matter of soil [206]. High carbon content is indicative of presence of organic matter which leads to improved water retention, greater productivity, reduction in soil erosion and better quality of ground and surface water [206]. However, the occurrence of cations in acidic ranges in soil can severely affect uptake of organic carbon in soil [207].

The presence of Al was also confirmed in the soil but since pH of the soil lies in basic range, therefore effects of cations on uptake of organic carbon as well as the Al toxicity is greatly reduced.

The difference in the elemental concentration of soils of lake 1 and lake 2 might be attributed to combined effects of variation in topographical factors along with difference in anthropogenic activities around the lakes leading to erosional activities. The area around lake 1 is dominated by high tourist and constructional activities whereas area around lake 2 is dominated by heavy agricultural activities thereby supporting variations in concentrations of elements both in terms of presence and weight percentage.

Sediments of Lake 1 and Lake 2

The elements detected from the EDS analysis of sediments of lakes 1and 2 are shown in Figure 6.10 (a) – 6.10 (b). The elements determined in sediment samples from lake 1 were Carbon (C), Oxygen (O), Aluminum (Al), Magnesium (Mg), Tantalum (Ta), Tellurium (Tm), Silicon (Si) and Niobium (Nb). Similarly, elements from sediments of Lake 2 are Carbon (C), Oxygen (O), Tantalum (Ta), Aluminum (Al) and Niobium (Nb).

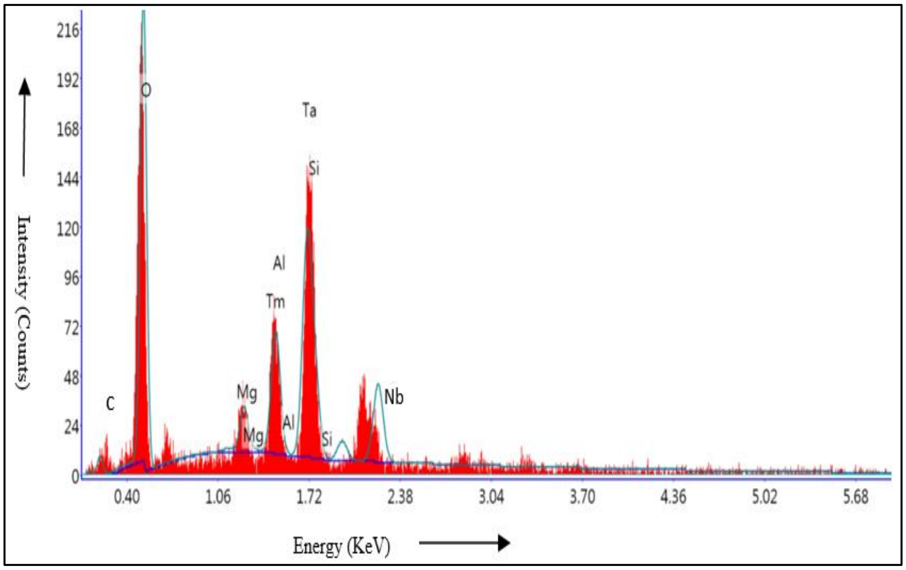

Figure 6.10 (a) : EDS micrograph for sediments of Lake 1

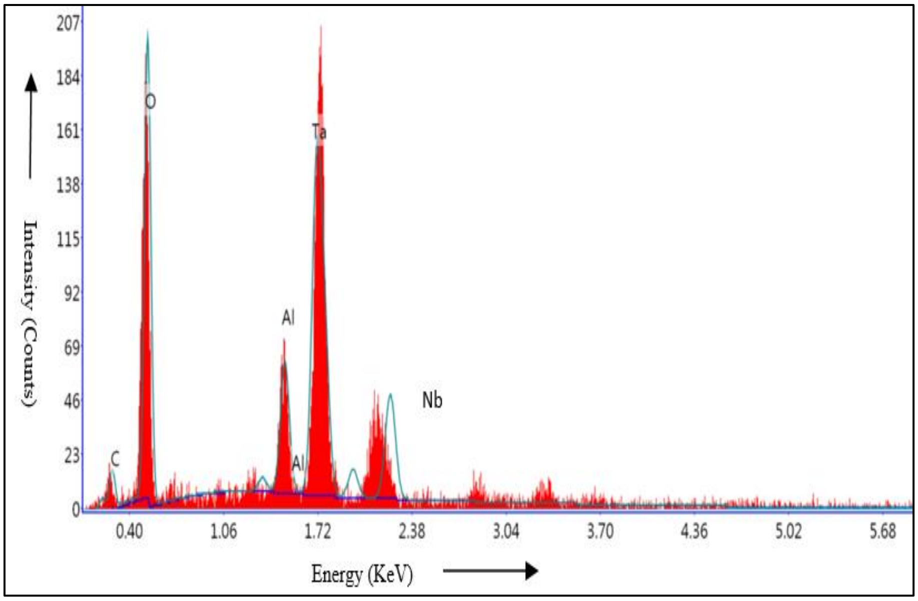

Figure 6.10 (b) : EDS micrograph for sediments of Lake 2

In the above context, Tables 6.2 (a) – 6.2 (b) presents the results of quantitative analysis for sediment samples of Lake 1 and Lake 2 respectively.

Table 6.2 (a) : EDS (Quantitative) analysis of sediments of Lake 1

Element	Atomic number	Weight %	Atomic %	Series	Error %
O	8	42.39	79.89	K	9.29
Mg	12	3.19	3.96	K	22.62
Al	13	7.36	23.56	K	12.43
Tm	69	6.21	6.63	M	31.87
Si	14	0.01	0.03	K	99.99
Ta	73	40.84	55.68	M	8.29

Table 6.2 (b) : EDS (Quantitative) analysis of sediments of Lake 2

Element	Atomic number	Weight %	Atomic %	Series	Error %
C	6	6.69	16.35	K	20.22
O	8	36.77	67.46	K	9.99
Al	13	7.58	8.25	K	10.49
Ta	73	48.96	7.94	M	7.00

It is observed from Table 6.2 (a) that the sediment sample from Lake 1 has the highest weight proportions of Oxygen and Tantalum.

Tantalum is found in the soil, freshwater as well as sea water in the form of particulate matter [208]. The source, transportation and the interaction of this element is still unknown due to inadequate data and incomplete use [208]. Further, no substantial effects of environmental pollution due to Tantalum have been reported [208].

Many soil and sediment properties for both the lakes were found to be similar with slight morphological changes in structure. For example, the ores of tantalum and niobium are identical and both the elements also appear very similar to each other. The tantalum is found to exist in oxides with niobium commonly known as columbite [(Fe, Mn) $(Nb, Ta)_2O_6$] [204]. The presence of Ta in the sediment and Nb in the soil are related to each other since they are derived a common ore and may have inflowed in the lake waters through erosion from banks and watershed area.

The absence of carbon in sediment of lake 1 might be due to low percentage of OC detected. The high presence of silica in the sediment of lake 1 and absence in sediment of lake 2 might be due to heavy soil erosion from the nearby watershed area of lake 1 converting the soil into lateritic clay deprived of silica and a significant amount in sediments . Therefore, the absence or presence of certain elements in the soils and sediments of lake 1 and 2 may be attributed to the anthropogenic, geological, geographical & topographical features of the sites and surrounding vicinity.

Water of Lake 1 and Lake 2

Lake 1

The elements detected from the EDS analysis of water of lake 1 at 2 m – 4 m depth are shown in Figures 6.11 (a) – 6.11 (c). The elements determined at depth of 2 m were Carbon (C), Oxygen (O), Sodium (Na), Zinc (Zn), Tantalum (Ta) and Niobium (Nb). Similarly, elements detected at depth of 3m were Carbon (C), Oxygen (O), Sodium (Na), Bromium (Br), Magnesium (Mg), Silica (Si) and Tungsten (W). Finally at a depth of 4 m, the elements detected in the water samples were Carbon (C), Oxygen (O), Sodium (Na), Bromium (Br), Magnesium (Mg), Silica (Si) and Tungsten (W).

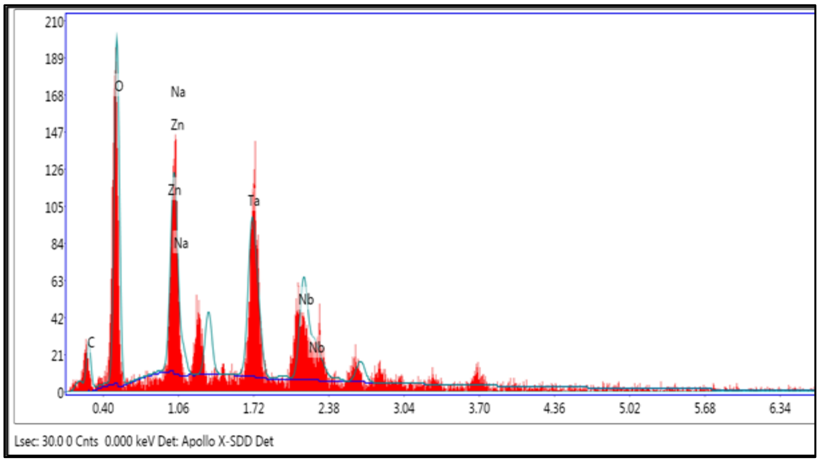

Figure 6.11 (a) : EDS micrograph for water of Lake 1 at 2 m depth

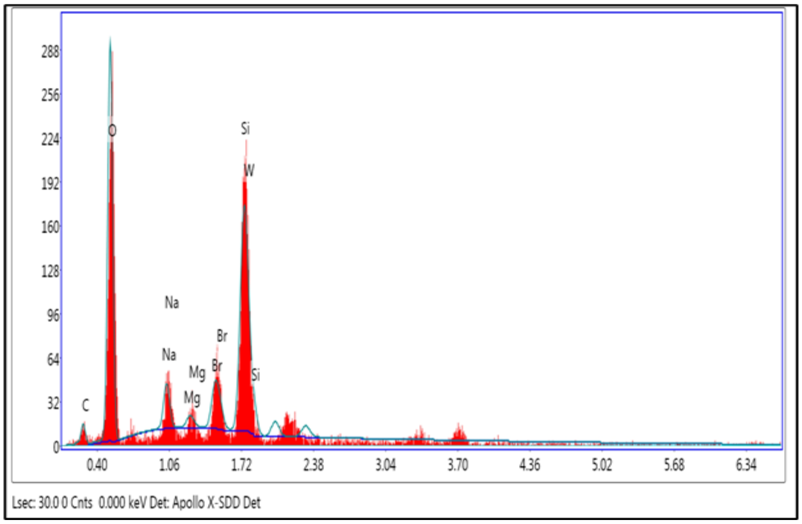

Figure 6.11 (b) : EDS micrograph for water of Lake 1 at 3 m depth

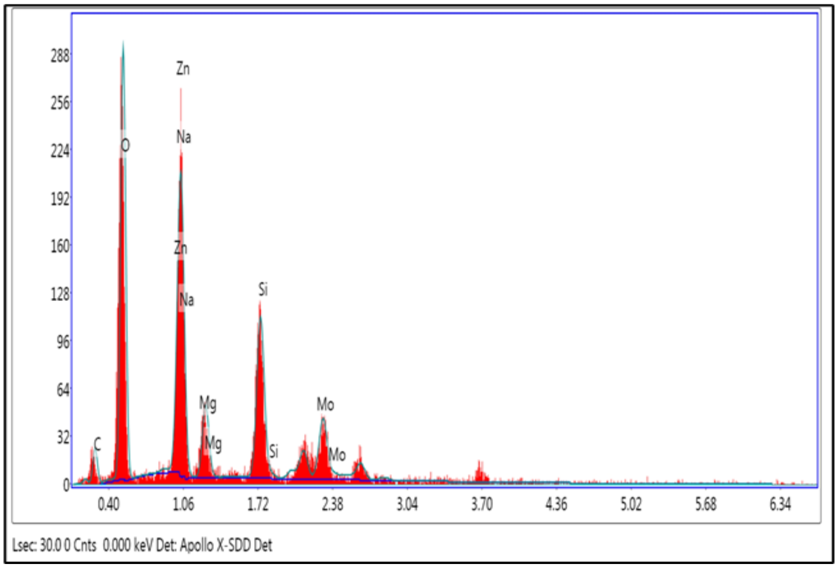

Figure 6.11 (c) : EDS micrograph for water of Lake 1 at 4 m depth

In the above context, Tables 6.3 (a) – 6.3 (c) summarizes the quantitative analysis for water samples of lake 1 at depths of 2 m, 3 m and 4 m respectively.

Table 6.3 (a) : EDS (Quantitative) analysis of Water of Lake 1 at 2 m depth

Element	Atomic number	Weight %	Atomic %	Series	Error %
C	6	9.35	21.77	K	18.87
O	8	31.87	55.71	K	10.99
Zn	30	12.63	5.40	L	9.93
Na	11	6.82	8.30	L	15.61
Ta	73	20.57	3.18	M	7.64
Nb	41	18.77	5.65	L	11.93

Table 6.3 (b) : EDS (Quantitative) analysis of Water of Lake 1 at 3 m depth

Element	Atomic number	Weight %	Atomic %	Series	Error %
C	6	6.04	12.01	K	24.63
O	8	42.84	63.99	K	9.36
Na	11	4.82	5.01	K	18.14
Mg	12	0.97	0.96	K	65.80
Br	35	5.83	1.74	L	13.75
Si	14	15.46	13.16	K	8.13
W	184	24.03	3.12	M	15.43

Table 6.3 (c) : EDS (Quantitative) analysis of Water of Lake 1 at 4 m depth

Element	Atomic number	Weight %	Atomic %	Series	Error %
C	6	7.95	14.72	K	19.34
O	8	35.78	49.76	K	9.53
Zn	30	11.94	4.06	L	10.22
Na	11	15.87	15.36	K	9.69
Mg	12	4.64	4.24	K	13.78

Si	14	11.30	8.95	K	8.38
Mo	42	12.52	2.90	L	15.43

It was observed from the above tables that percentages of Oxygen, Tantalum and Niobium were highest amongst all elements for water sample of Lake 1 at 2 m depth. Similarly, the water samples at 3 m depth from lake 1 reported highest weight percentages of Oxygen and Tungsten. Finally, samples collected from 3 m depth of lake 1 was determined to have the highest weight percentages of Oxygen and Sodium. Further, additional elements having high weight percentage from water samples of lake1 were Niobium and Sodium.

Lake 2

The elements detected from the EDS analysis of water of lake 2 at 1m – 3 m depth are shown in Figures 6.12 (a) – 6.12 (c). The elements determined at depth of 1m were Carbon (C), Oxygen (O), Sodium (Na), Tantalum (Ta)and Niobium (Nb). Similarly, elements detected at depth of 2 m were Oxygen (O), Aluminum (Al) and Silica (Si). Finally at a depth of 3 m, the elements detected in the water samples were Oxygen (O), Sodium (Na), Magnesium (Mg), Aluminum (Na), Ytterbium (Yb), Tungsten (W) and Silica (Si).

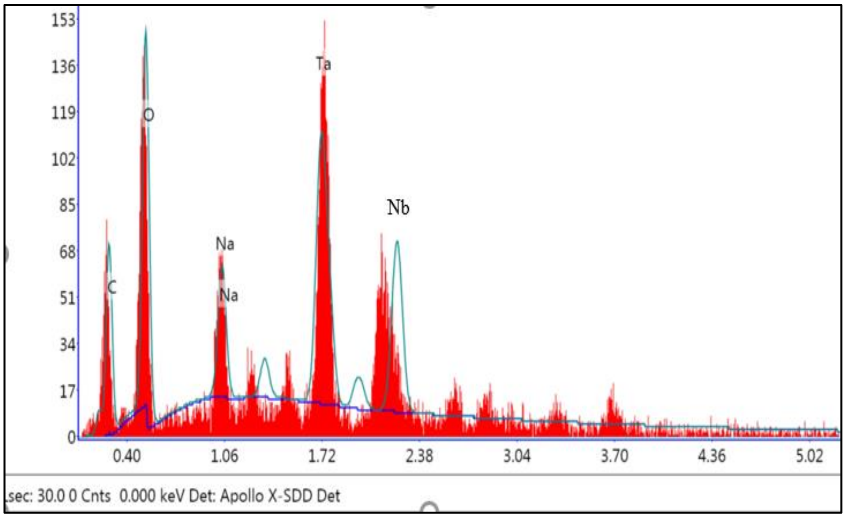

Figure 6.12 (a) : EDS micrograph for water of Lake 2 at 1m depth

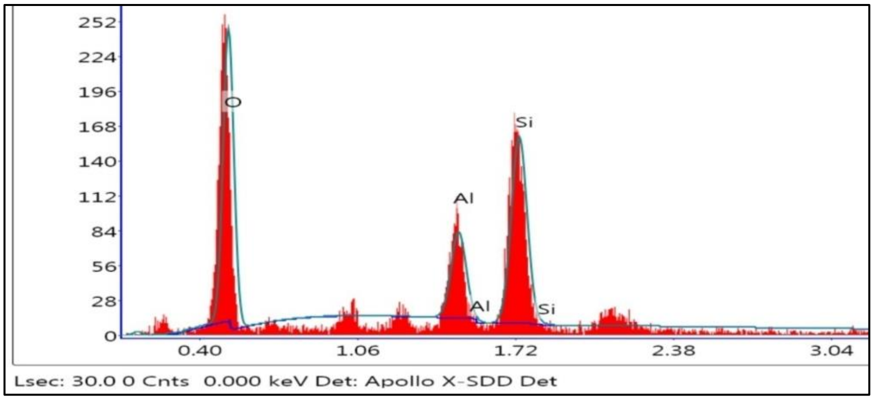

Figure 6.12 (b) : EDS micrograph for water of Lake 2 at 2 m depth

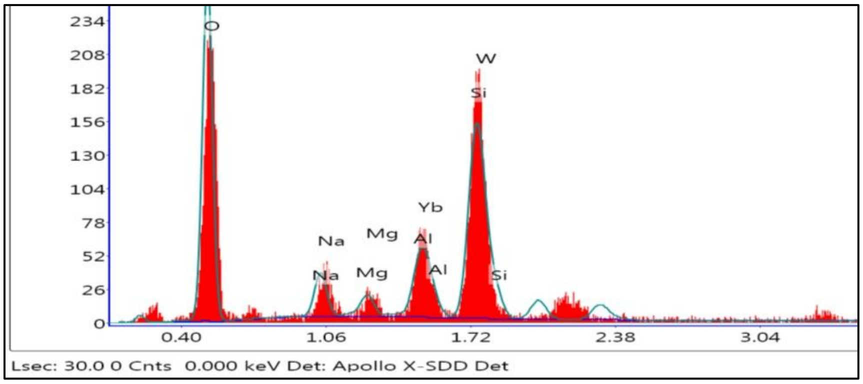

Figure 6.12 (c) : EDS micrograph for water of Lake 2 at 3 m depth

In the above context, Tables 6.4 (a) – 6.4 (c) summarizes the quantitative analysis for water samples of lake 2 at depths of 1m, 2 m and 3 m respectively.

Table 6.4 (a) : EDS (Quantitative) analysis of Water of Lake 2 at 1m depth

Element	Atomic number	Weight %	Atomic %	Series	Error %
C	6	23.54	42.53	K	12.81
O	8	33.03	44.80	K	11.28
Na	11	9.06	8.55	K	15.03
Ta	73	34.37	4.12	M	10.29

Table 6.4 (b) : EDS (Quantitative) analysis of Water of Lake 2 at 2m depth

Element	Atomic number	Weight %	Atomic %	Series	Error %
O	8	52.49	65.72	K	8.56
Al	13	13.48	10.01	K	9.21
Si	14	34.02	24.27	K	6.84

Table 6.4 (c) : EDS (Quantitative) analysis of Water of Lake 2 at 3m depth

Element	Atomic number	Weight %	Atomic %	Series	Error %
O	8	38.86	68.08	K	8.99
Na	11	5.11	6.24	K	14.88
Mg	12	1.95	2.25	K	21.81
Al	13	4.22	4.38	K	13.34
Yb	70	9.33	1.51	M	15.53
Si	14	13.44	13.42	K	8.42
W	184	27.09	4.13	M	9.82

It was observed from the above tables that percentages of Carbon, Oxygen and Tantalum were highest amongst all elements for water sample of Lake 2 at 1m depth. Similarly, the water samples at 2 m depth from lake 2 reported highest weight percentages of Oxygen and Silica. Finally, samples collected from 3 m depth of lake 1 was determined to have the highest weight percentages of Oxygen and Tungsten. Further, additional elements having high weight percentage from water samples of lake 2 were Carbon and Silica.

The high levels of oxygen in water samples at all three depths may be attributed to its chemical structure. The presence of Tungsten in water may be attributed to weathering of rocks and use of fertilizers in the farms [209]. The alkaline environment and presence of Sodium (Na) further leads to solubility and leaching of this element into water. The presence of Tantalum in the sediment and Niobium in the soil are in relation to each other since they are derived from common ore they might have entered the lake waters significantly as a result of excessive erosion of soil from the banks and watershed area. The presence of Sodium in water is due to abundance in natural environment, since the weight of the element did not exceed normal levels, it can be considered to be fine. The carbon is found in form of organic matter or humus in upper layers of soil, the excessive erosion might have led to entry of this element into lake water. The silica is a major soil element and heavy soil erosion might be the reason for its entry into lake waters.

Although common elements such as Oxygen, Tungsten and Tantalum were found at various depths for both the lakes still the variations in the presence as well as weightage of elements at various depths for both lake 1 and lake 2 which might be attributed to various natural and anthropogenic factors such as precipitation, influx of surface runoff, geological processes in lakes, weathering of nearby rocks, intermixing conditions in lakes, depth wise stratification, interdependency among various elements due to difference in chemistry than various physical and chemical parameters [147; 210].

Further, as both the lakes are surrounded by various rocks it adds up to input of various elements into lakes some of which may be common and some variable. Finally, some anthropogenic sources such as constructional activities and agriculture also adds up to variations in elemental concentrations. For example lake 1 is surrounded by heavy tourism activities whereas lake 2 is surrounded by dominance of agriculture therefore variations in concentrations of elements is observed at both sites. [147].

6.3.2.4 Sediment Quality Index (SeQI)

The Sediment Quality Index (SeQI) was evaluated on the base of parameters briefed in Appendix A, Tables A17 (a) & A17 (b) to compare its quality to standards of ISQG and PEL respectively which are associated with freshwaters. The model necessitates 33 parameters for calculation of value of SeQI, the 0 value in the table displays the parameters that were not perceived and thereby represented 26 pesticides measured for the study together with 7 heavy metals. It implies that concentrations of pesticide and heavy metals were significantly below the stated limits where applicable.

Using the prescribed modelling conditions, the quality of sediments for both lake 1 and lake 2 were detected to be *‘98’* i.e. in highest category of *‘Excellent’* (95-100). In general, the extreme sediments present in beds of lakes can be removed by dredging operations at suitable intervals and the sediments dredged can either be discarded at assigned locations or mixed with surrounding soil wherever necessary for enhancing geological properties, also the content can be used as a earth fill, for agricultural or landfill works.

Summary

The study presented in this chapter provides insight on the effects of soil erosion due to constructional and agricultural activities, on lake water bodies. The study also portrays likely consequences if the measurements of the components surpasses the permitted bounds and using appropriate practices including using indexing techniques like SEQI for quantification of the problem. The current study is important for determination of urbanization impacts, excessive land use and deforestation resulting in erosion of soil from the nearby banks and the watershed areas on the water bodies.

The current study described here focused on characterizing of soil sediments and water of both the lakes for determination of effects of pollutants and their interaction with the surroundings in producing necessary changes. The determination of pollutants and change in characteristics was done through analysis of physical and chemical characteristics of soil, sediments and water for both lakes. The changes in morphological characteristics, chemical structure and elemental properties along with their quantification are determined through spectral characterization techniques of SEM, XRD and EDS for soil, sediments and water of both lakes.

The physical and chemical characteristics of sediments and soil for both the lakes were determined through laboratory analysis which comprised of physico-chemical parameters and pesticides. Further, analysis of heavy metals for sediments and soil of both the lakes was also undertaken. The results for the physico- chemical and heavy metal analysis for the soil and sediments of both the lakes revealed that the parameters were well within prescribed limits and no threat to ecosystem of lake and its nearby catchment area was posed. Physical properties of soil for lake 1 and lake 2 such as organic matter, texture and color were also determined and the organic carbon content and organic matter percentage for lake 1 and lake 2 were 0.19 % and 0.09 % were well within the prescribed limit of 0.5 % and thereby confirmed the soils to be low in organic content which was attributed to increased level of erosion of top soil.

The spectral characterization technique of SEM revealed the morphological structure of soil for both the lakes to be representative of clay with flaky, rounded and agglomerated structure. The sediment structure for both the lakes was determined to have sharp edges, porous and flaky structure representative of sand. The water of lake 1 and lake 2 at various depths revealed increased agglomeration of structure due to an increase in density of water with depth.

The micrographs of EDS showed presence of great number of common elements in soil, sediments and water of lake 1 and lake 2 which were additionally reconfirmed by graphs of XRD analysis displaying sharp peaks indicating natural and crystalline materials. Hence, it may be determined that cause of the sedimentation in both the lakes was due to surrounding soil.

The soil, sediments and water of both lake 1 and lake 2 reported high magnitudes of Oxygen (O), Carbon (C), Tantalum (Ta), Silica (Si), Tungsten (W) and Niobium (Nb) along with other elements and transition metals. The presence of natural elements along with rare earth metals like Niobium and Tantalum (metals derived from similar ore) have not been studied and reported sufficiently but they do not cause any lasting environmental effects. Further, it can be determined that since both these elements are derived from the same ore and have been recognized in soils, sediments and water of both the lakes, it reveals that the creation of sediments in lakes is significantly correlated to soil erosion from banks and nearby areas of the lakes.

The values of Sediment Quality Index (SeQI) indicated the sediments of both the lakes to be of Excellent category and were free from any detrimental pollutants thereby not posing any threat to the ecosystem, environment and adjacent areas.

Excessive soil erosion from the banks can lead to loss of fertility from agricultural point of view. The construction and demolition activities can lead to loss of soil's top cover resulting in reduction of Organic Matter (OM), Organic Carbon (OC), Silica and also leads to increase in input of Calcium, Asbestos, Chlorides and Aluminum. The leakage from sewage pipes can further add up to Total Phosphorous and Nitrate content. The excessive agricultural activities like tillage and heavy irrigation can also lead to loss of soil’s top cover. The excessive loss of soil’s top cover can further lead to reduction in Organic Matter (OM), Organic Carbon (OC), Silica Content, change in soil color, reduction in Cation Exchange Capacity (CEC) leading to reduced productivity. The excessive use of lime based fertilizers can increase Calcium content whereas excessive pesticide usage can induce soil toxicity. Therefore, additional measures like adding of fresh manure to the fields, proper tillage of soil, appropriate irrigation can prove to be helpful in elevating the quality of soil.

The following chapter (Chapter 7) presents the use of GIS (Geographic Information System) based interpolation modelling technique of Inverse Distance Weighing (IDW) for determination of complete water quality status of lakes (at inaccessible locations) based on evaluated parametric concentrations at pre-determined points in Lakes.

CHAPTER 7

‘Geographical Information System’ (GIS) Interpolation Modelling for Twin Lakes

7.1 Introduction

Water is an essential natural resource present on earth’s surface available to humans. Water pollution is an acute environmental issue which effects the potability of different water sources. An increase in developmental activities around these sources has led to a greater pollution into lakes. In particular, these pollutants comprise of agricultural runoff, industrial and sewage effluents which play a major role in polluting the existing water quality [168]. The main purpose of monitoring water quality is assessment of existing levels of pollutants, their identification, estimating potential impacts and prediction of future water quality conditions for implementation of appropriate remedial measures. The monitoring of different parameters of surface water bodies are beneficial for policy makers and researchers. In practice, for monitoring, *in-situ* measurements and laboratory determinations of different parameters are used.

Since most of the laboratory techniques for determination of water quality parameters involve point wise collection and evaluation of samples, the results obtained are representative of existing water quality at a particular point and time [211]. Additionally, collection of large number of samples to form representative results from different depths and locations for representing spatio-temporal variations may not be always possible on a continuous basis for practical constraints (example – inaccessibility). Further, these approaches are cumbersome since it involves large number of data sets for evaluation and also financial resources for monitoring [94].

In such scenarios, the use of modelling techniques is great alternative which provides a better insight of different hydrodynamics in a lake ecosystem along with its management [212; 213]. These modelling techniques establish a relationship between the monitored data and predicted model data for evaluation and application of new theories for management of lake water bodies. [214]

In the above context, use of remote sensing and GIS based modelling systems are considered to be an effective tool in the field of environmental engineering particularly water quality studies [93].

Further, application of GIS modelling systems provides a variety of sub-tools to evaluate the water quality, even with a limited data set thereby presenting a complete scenario resolved both spatially and temporally [215].

The main goal of this study was determination of water quality using Bureau of Indian Standards Water Quality Index (BISWQI) annually for both lakes over the entire monitoring campaign, the evaluation being carried out for both surface levels and depth wise assessments. Using the data obtained at these specified points in both the lakes respectively, the water quality throughout the lakes at surface as well as different depths was modelled and represented through GIS Interpolation Modelling Technique of Inverse Distance Weighing (IDW).

Specific water quality parameters were monitored at different sampling locations for both the lakes at surface and different depths to represent any seasonal variations. These values of parameters obtained through laboratory determination at specific points throughout the lakes were then modelled and represented through GIS Interpolation Modelling Technique of Inverse Distance Weighing (IDW), to represent the status of these parameters throughout the lake water body at surface level as well as depth wise. Further, assessment of pollution points for proposing suitable strategies for combatting further deterioration of the water body was also undertaken.

7.2 Materials and Methods

7.2.1 Sampling Points

The detailed sampling methodology including details of sampling locations for both the lakes have been presented in *Chapter 3,* for both lakes.

7.2.2 Sampling Procedure

The sampling procedure for both the lakes have been presented in *Chapter 3, section 3.2.3 for both the lakes*. Further, sampling was conducted in the absence of extreme rainfall or flooding conditions [92].

7.2.3 Selection and Analysis of Selected Parameters

The selected parameters for the study were based on the guidelines provided by Central Pollution Control board [30]. Additionally, the selected parameters were also used for determining the Water quality Index (WQI) which incorporated 10 parameters including NO_3, SO_4, HCO_3, Ca, Mg, Cl, pH, EC, TDS and TA as specified by Bureau of Indian Standards (BIS) [34]. Further, GIS Interpolation Modelling technique was applied to 4 parameters namley Temperature (T), Total Phosphorous (TP), Nitrate (NO_3) and Dissolved Oxygen (DO) according to their importance. The parameters used for GIS interpolation modelling technique have been described in Appendix A, Table A1 - A10 for both the lakes for throughout the sampling duration.

In practise, all the monitored parameters should be utilized in predicting the water quality of the lakes but even modelling approaches have certain limitations specially data generation and interpretation [92; 93]. Considering the above scenario, the parameters used for modelling the water quality in lakes using GIS software were Temperature (T), Total Phosphorous (TP), Nitrate (NO_3) and Dissolved Oxygen (DO). These parameters were selected based on the criterion that they are highly representative of the variations in lake water quality when monitored over a span of 1 year [92]. The importance of these parameters in context of representation of lake water quality has been discussed in the next few paragraphs.

Temperature (T) is one of the most important physical factors in describing the lake ecosystem as it controls various chemical and biological reactions within its environment. It is also a major factor involving the presence of dissolved gases in the water thereby affecting the photosynthetic activities and metabolic rates which affect the biodiversity in lake [3]. The temperature not only affects the aquatic life but also affects the other chemical reactions in water thereby deciding the utility of water [216]. The standard temperature variation for wildlife sustainability in a lake ecosystem lies between 28°C to 30°C with temperature thermocline from surface towards depth. [126].

The Dissolved Oxygen (DO) is indicative of healthy aquatic life therefore making it a necessary water quality parameter in every aspect [38]. DO is a measurement of pollution amount in the water body. Higher levels of DO indicate less pollution in the lake ecosystem. The high levels of DO are seen at upper layers due to abundance of sunlight which reduces with depth leading to lower DO levels at increased depths. DO levels are also affected by parameters like colour, taste and odour which reduces utility of lake water. Further, low levels of DO indicate that nutrients could be released from the sediments present in the lake [106].

Presence of Nitrate (NO_3) in high concentrations indicate presence of *old* pollution in a water body leading to eutrophication. High level of nitrates are generally prevalent in lakes surrounding rural areas due to increased agricultural activities involving high doses of fertilizers and in urban areas due to input of sewage and domestic waste [106]. The depth wise variation of NO_3 is not significantly observed but seasonal variations are prevalent in lakes.

The presence of phosphorous in high concentration leads to algal bloom resulting in low oxygen levels, death of fish and other associated effects. The input of phosphorous can either be from natural sources like soil and rocks or anthropogenic activities such as discharge of agricultural and to an extent human waste [217]. The depth wise variation of Phosphorous is not significantly observed but seasonal variations are prevalent in lake water bodies.

7.2.4 Water Quality Index (WQI)

WQI is a simple technique of categorizing the prevailing water quality of water body and thereby its potential use. The methodology involved in its determination has been described in *Chapter 5 section 5.2.2.2*.

7.2.5 Geographical Information System (GIS)

GIS is a method of obtaining information about the desired area of investigation through an object such as satellite which is not in direct contact with that area [218]. The application of GIS and remote sensing techniques has been recognised as an important tool in field of environmental science specially in water quality monitoring [219]. The monitoring of water quality requires large volume of samples and their detailed analysis which is often cumbersome, also collection of samples from all the points may not be a feasible option due to logistical issues, which makes the application of GIS and remote sensing tools more potent in solving this problem [220].

7.2.5.1 GIS Interpolation Modelling Techniques

GIS interpolation modelling technique is an useful tool for attribute prediction of unsampled locations from values calculated and determined from sampled locations within the same periphery distributed at that particular space and time [221]. Hence, it can be used for creating variogram models or interpolated maps from the sampled data [222].

In this principle, availability and utilization of continuous spatial data is a requirement for activities related to management of natural resources. The spatial interpolation techniques in GIS can play an important role in achieving this objective. The GIS interpolation techniques can interpolate the values of parameters for the unknown areas from the values of known parameters and produce spatial patterns [223]. The most widely used interpolation techniques are Ordinary Kriging (OK) and Inverse Distance Weighing (IDW).

Both the interpolation techniques generate similar pattern maps but with different accuracies [224]. In our study, IDW method has been used because the method serves as a great tool for generating isodynamic contours. Interpolation of values are accurate and lie between maximum and minimum points, thereby omitting any extrapolation beyond the specified range giving out results which have smooth surface changes [92]. The IDW does not require any assumption or data prediction to produce results unlike OK method. Further, the OK method utilizes more than 10 sampling points which is not applicable for the present study area [92].

The Inverse Distance Weighing (IDW) is a commonly used interpolation method which is well automated and easy to use and has been used previously for similar such studies [93; 224]. This method is best suited for use in areas of restricted research neighbourhood [225]. The method is best suitable for interpolation of water quality parameters in rivers, watersheds and lakes [226].

The following eq. (7.1) gives the expression for IDW interpolation technique.

$$\hat{z}(x_0) = \sum_{j=1}^{m} w_j . z(x_j) \qquad (7.1)$$

$\hat{z}(x_0)$= interpolated value (to be determined)
(x_0) = unsampled location
$z(x_j)$= water quality parameter (z) at location j
m = no. of unsampled neighbouring locations
w_j = weights based on distance x_0 (unsampled location) and xj (sampled location) such as $\sum_{j=1}^{m} w_j = 1$

The final formulation of IDW method is done as in eq. (7.2) [225].

$$\hat{z}(x_0) = \frac{\sum_{j=1}^{m} z(x_j).d_{ij}^{-k}}{\sum_{j=1}^{m} d_{ij}^{-k}} \qquad (7.2)$$

Where,

k = distance influence coefficient expressed as either 1 or 2 (value of 1 was used for our study)

d_{ij} = distance between unsampled location $i(x_0)$ and sampled location $j(x_j)$

7.3 Results and Discussions

The results and discussions of the GIS modelling analysis have been summarized in the following sections.

7.3.1 GIS Interpolation modelling of BISWQI

The BISWQI was calculated using standard methodology. In particular, the BISWQI was determined for the entire monitoring campaign for both the study lakes. The mean of the above sampling months was used to report the annual BISWQI at the study locations at different depths. The values for the same have been shown in Appendix A, Table A19 and Table A20 for Lakes 1 and 2 respectively. The GIS modelling was done using *IDW method* for both the lakes at different depths and the results for the same have been discussed below.

For Lake 1, the deterministic interpolation was done at a depth of 2-4 m at points S1 to S4 as in Appendix B, Figure B2(a) -B2(c). The figures represent modelling images for Lake 1 at all of the 4 sampling locations at different depths measured from the surface of the lake. Similarly, for Lake 2, the modelling images have been shown in Appendix B, Figure B3(a) – B3(c) for all the three sampling points at their relevant depths measured from surface of the lake. The water quality was classified as '*Excellent'* as per BISWQI over the entire sampling duration at all of the sampling locations at different depths for both of the lakes. Further, a single colour is shown on the interpolation maps for each point at all the depths in both the lakes, which suggests that for all sampling points and depth locations the classification is *'Excellent'* therefore other colours of legend are not portrayed in the interpolated maps.

Based on the above assessment it may be inferred that water from both the lakes are good source and could be used as a source of drinking water (with some treatment like disinfection) for the nearby population throughout the year.

7.3.2 GIS Interpolation Modelling of Physico-Chemical Parameters

7.3.2.1 Overall seasonal variation

The physico-chemical parameters used for determination of the water quality of the lakes are representative of the trends in the changes for study locations. The results of the physico-chemical analysis of the selected parameters used in the study to represent seasonal changes at different sampling locations at different depths for both the lakes. In particular, Appendix A, Tables A1, A3, A5 and Tables A6, A8 and A10 summarizes the physico-chemical results of the selected parameters for August 2019 (Monsoon), December 2019 (Winter) and June 2020 (Summer) seasons for both the lake1 and lake 2 respectively.

It was detected from the results that the temperature for both the lakes varied between 27.7°C to 30.7°C during the monsoon season. The DO concentrations varied between 1.75 to 8 mg/L for both the lakes during the monsoon season. Nutrient concentration of nitrate and phosphorous varied between 0.18 to 1.2 mg/L and 0 to 0.23 mg/L respectively for the monsoon season. The temperature was observed to vary between 15.9 to 19.4°C for both lakes in the winter season. The concentration of DO vary between 8.1 to 9 mg/L for both the lakes during the winter season. The NO_3 concentrations were determined to range between 0.72 to 0.89 mg/L for both the lakes while the PO_4 varied between 0.05 to 1.3 mg/L for winter seasons. Finally, during the summer season the temperature variation was observed to be between 23°C to 30.7°C for both the lakes. Other monitored parameters like DO concentrations ranged between 5.1 to7.1 mg/L for both the lakes while the nutrient concentrations of NO_3 and PO_4 were determine to be in the ranges of 0.55 to 0.74 mg/L and 0.003 to 0.1 mg/L respectively.

7.3.2.2 Seasonal variation for different depths at different sampling locations

As summarized earlier, sampling was carried out in four locations (S1-S4) and three different depths (2m, 3m and 4m) in Lake 1, and three locations (D1-D3) at three different depths (1m, 2 m and 3 m) in lake 2, the seasonal results are discussed in the following few paragraphs.

Monsoon Season

The temperature variations during the monsoon season are summarized in Figure 7.1 (a) – 7.1 (c) for lake 1 at different depths. The results for the temperature variation have been represented in the units of °C.

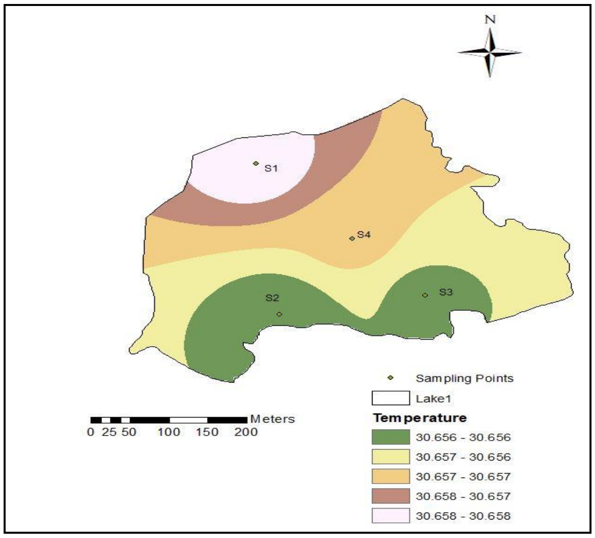

Figure 7.1(a): Temperature variation at 2 m depth in lake 1 for monsoon season

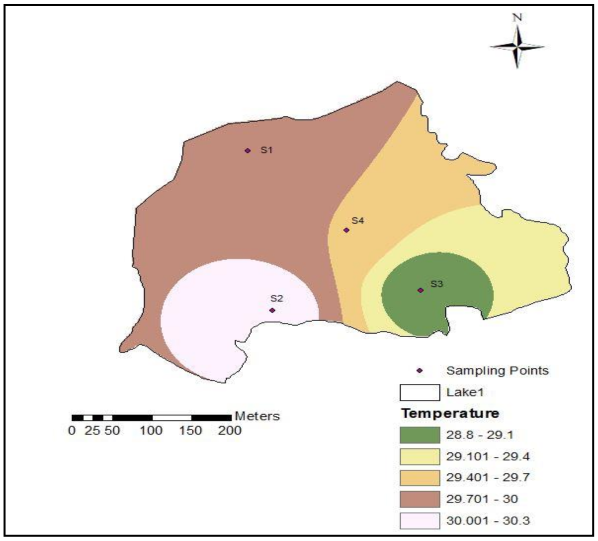

Figure 7.1(b): Temperature variation at 3 m depth in lake 1 for monsoon season

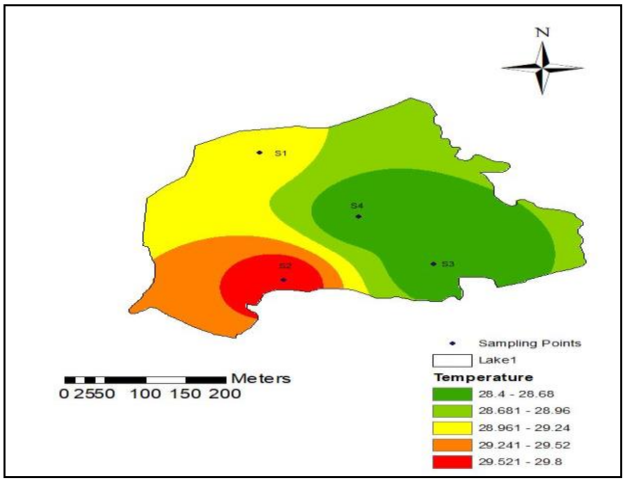

Figure 7.1(c): Temperature variation at 4 m depth in lake 1 for monsoon season

It was observed from the assessment that the temperature of the water decreased with increase in depth (from the surface of the lake) at all of the four sampling locations.

Similar to the observation made in lake 1, The temperature variation in lake 2 was represented in Figure 7.2 (a) - 7.2 (c), for all of the sampling locations and depths. Similar observations were noticed in lake 2 of decrease in temperature with increased depth at the different sampling locations.

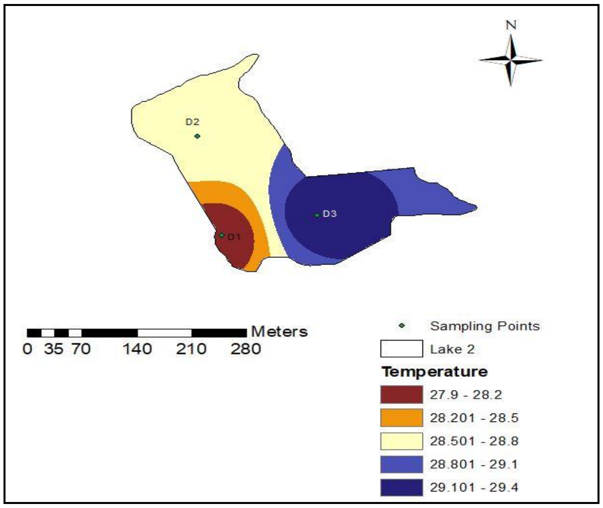

Figure 7.2 (a): Temperature variation at 1m depth in lake 2 for monsoon season

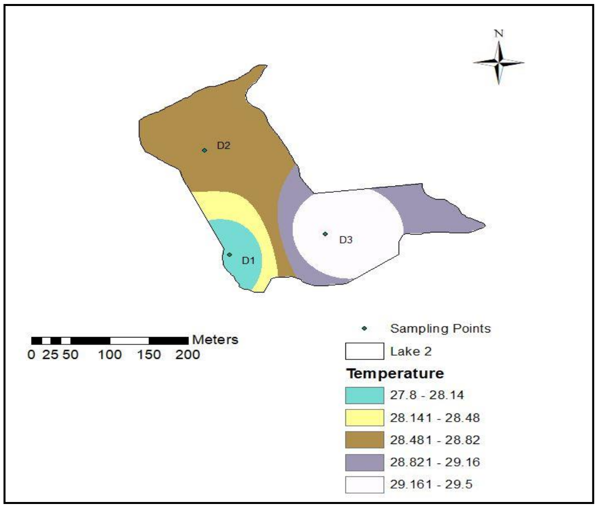

Figure 7.2 (b): Temperature variation at 2 m depth for monsoon season

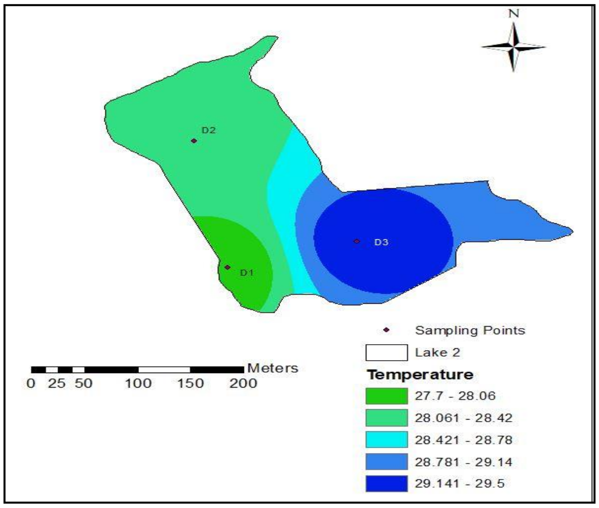

Figure 7.2 (c): Temperature variation at 3 m depth in lake 2 for monsoon season

The lowest temperature was observed at the greatest depth from the surface of both the lakes which may be attributed to low intensity of sunlight reaching at such depths in comparison to the surface levels which showed slightly elevated temperatures. Additionally, the transparency of water also plays an important role in allowing the intensity of sun rays reaching the greater depths which is significantly reduced in monsoon seasons because of increased turbidity due to erosion of soil particles from the nearby watershed area. The addition of water also leads to disturbance of sedimentation bed thereby increase shading and lowering the temperatures [227]. The vegetation cover and grasslands also play an important role in varying the temperatures at different depths [92], this was experienced at points of sampling locations *S1* and *S3* at a depth of 3 m for lake 1 and for all depths of sampling point D1 for lake 2, since these locations were in the vicinity of small nearby forest with shady trees bending over lake in comparison to other sampling locations and depths which are near to agricultural lands.

Similar to the above, the variation in DO concentrations for different sampling locations and depths have been summarized in Figure 7.3 (a) – 7.3 (c) for Lake 1.

It was observed from the assessment that higher concentration of DO was present at depths nearer to top surface and decreased with increase in depth [275]. The DO variation has been represented in units of mg/L.

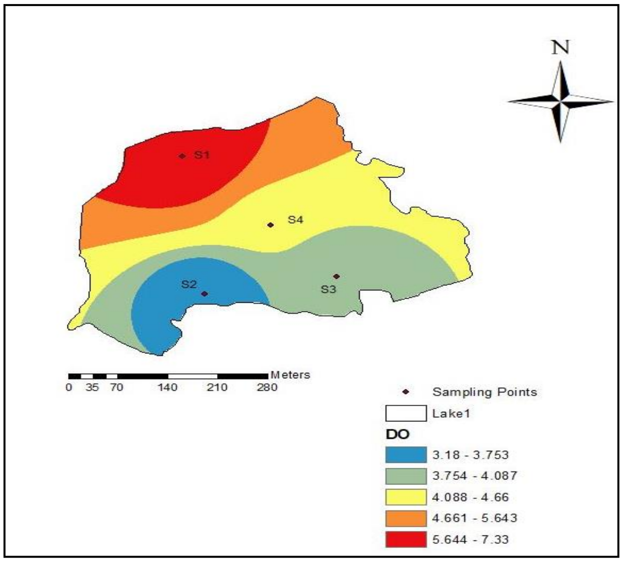

Figure 7.3 (a): DO variation at 2 m depth in lake 1 for monsoon season

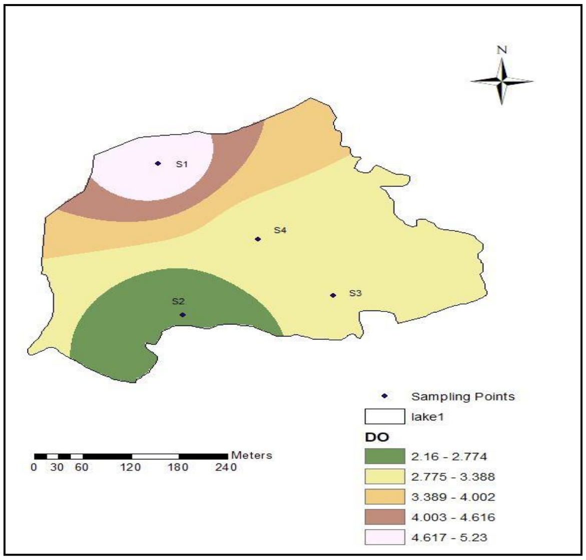

Figure 7.3 (b): DO variation at 3 m depth in lake 1 for monsoon season

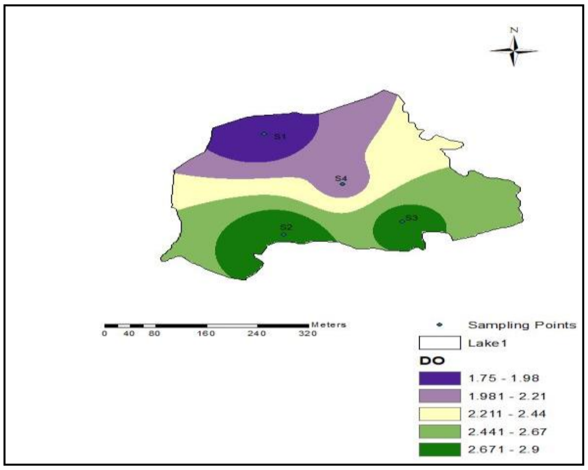

Figure 7.3 (c): DO variation at 4 m depth in lake 1 in monsoon season

Similar observations were noticed for lake 2, with Figure 7.4 (a) -7.4 (c) summarizing the DO concentrations.

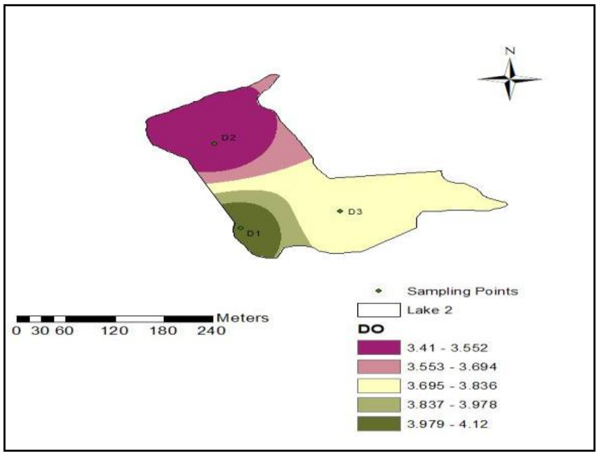

Figure 7.4 (a): DO variation at 1 m depth in lake 2 for monsoon season

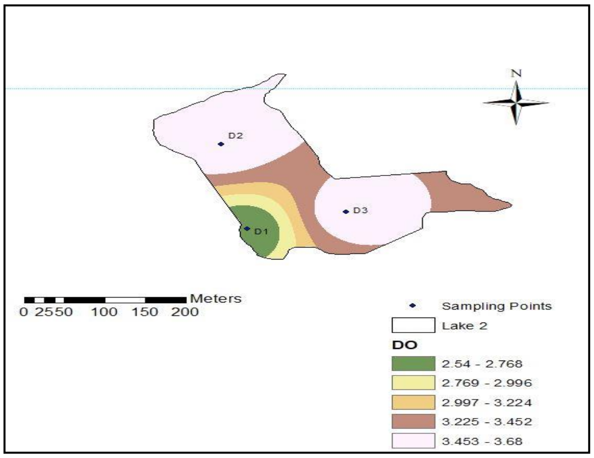

Figure 7.4 (b): DO variation at 2 m depth in lake 2 for monsoon season

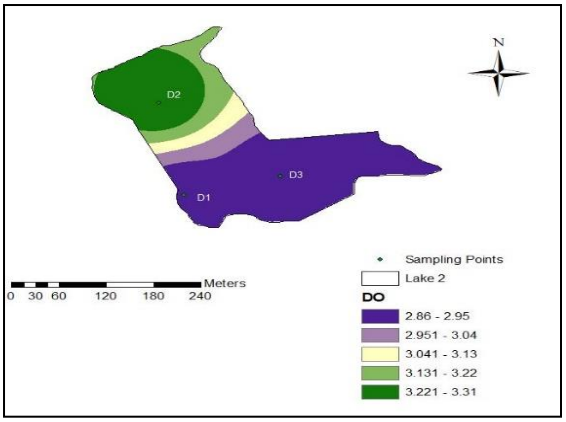

Figure 7.4 (c): DO variation at 3 m depth in lake 2 for monsoon season

This pattern may be possibly attributed to decreased availability of sunlight at greater depths leading to low temperatures and which in turn reduces the photosynthetic activities [147]. Further, at greater depth, anoxic conditions are more prevalent which reduces the DO concentrations [228].

Further, concentrations of DO is also dependent on seasons, temperature and monitoring locations [228; 229]. For example, the highest value of DO concentrations in lake 1 was observed at sampling point *S1* and surrounding areas in comparison to *S2*, the increased concentration being attributed to increased trees at this location which reduce temperature thereby increasing the DO saturation concentrations. The depth wise variation trend at points *S1* and *S2* was significant for 2 and 3 m depths but at the lowest depth of 4 m which is nearest to lake bed, a considerable shift in the DO was observant from high DO levels at these points to lower levels and complete opposite observations were significant. The DO was observed to decrease at point *S1* and considerably increase up till point *S3*. This was due to increased sedimentation rate at point *S1* being near to agricultural fields leading to different hydrodynamic processes undergoing near lake bed due to various depositions in lake bed leading to low oxygen levels near bed [95; 92].

Similarly, in lake 2 at sampling locations *D1* and *D2*, the highest DO concentrations were noted for depths 1m and 2 m as these locations were in the vicinity of growth of trees and different anthropogenic activities such as boating and fishing leading to disturbance in lake water and high DO due to intermixing. However, at depth of 3 m for the sampling locations, the concentrations of DO were higher at *D2* in comparison to *D1* due to effects of different hydrodynamic processes as mentioned above.

The NO_3 variation at different sampling locations and depths for lake 1 and lake 2 have been summarized in Figure 7.5 (a) – 7.5 (c) and Figure 7.6 (a) – 7.6 (c) respectively. The NO_3 variation has been denoted in units of mg/L.

It was determined from the analysis that the concentrations of NO_3 increased with depth at all of the sampling locations for both the lakes. This could possibly be due to the closeness to lake bed and effects of the sediments on hydrodynamic processes leading to atmospheric deposition and benthic flux [95].

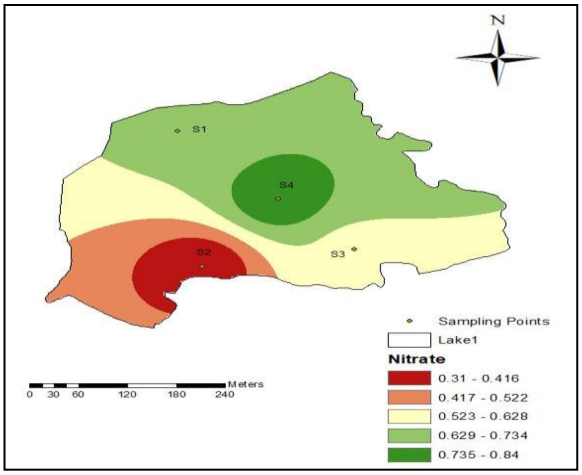

Figure 7.5 (a): NO_3 variation at 2 m depth in lake 1 for monsoon season

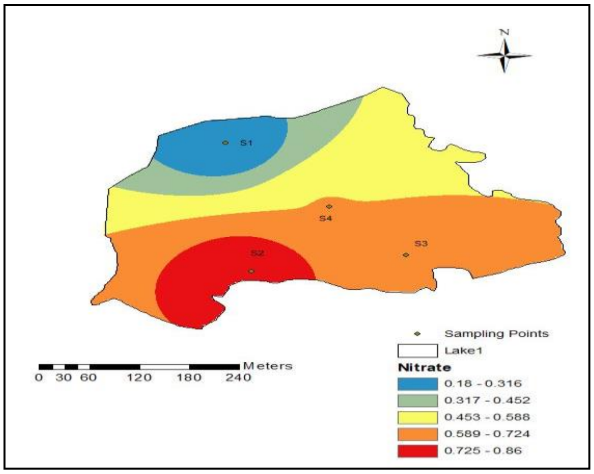

Figure 7.5 (b): NO_3 variation at 3 m depth in lake 1 for monsoon season

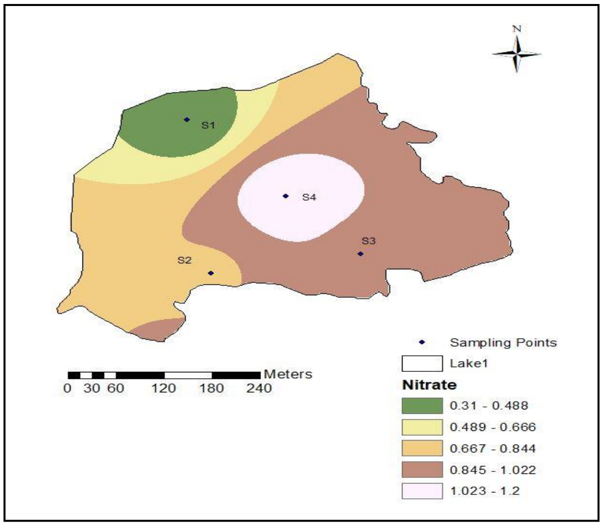

Figure 7.5 (c): NO_3 variation at 4 m depth in lake 1 for monsoon season

For example, in lake 1 the highest NO_3 concentration was observed at sampling location *S4* at 4 m depth. Additionally, high value was determined for sampling location *S1* at 2 m depth as well. The high concentrations of NO_3 at these locations may be attributed to high flux of tourist activities which increases the NO_3 concentrations in lake by dumping of waste material during recreational activities [92]. At 4 m depth from surface the trend was seen to vary with highest value at centre point *S4* followed by *S3* due to heavy anthropogenic activities at these 2 depths. Similarly, for lake 2, the highest value was recorded at *D1* at depth of 3 m.

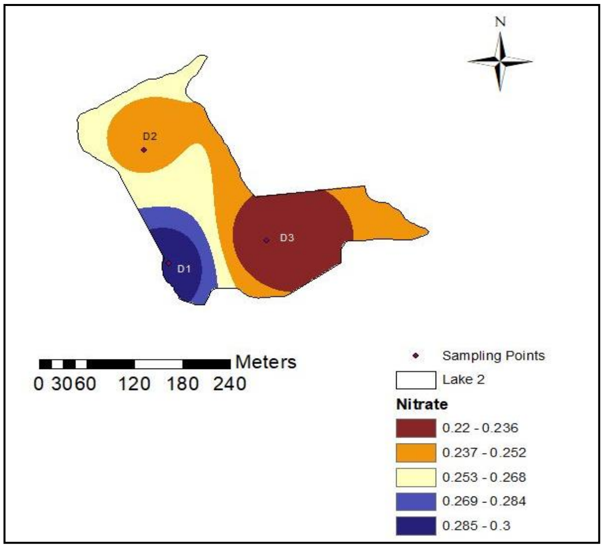

Figure 7.6 (a): NO_3 variation at 1 m depth in lake 2 for monsoon season

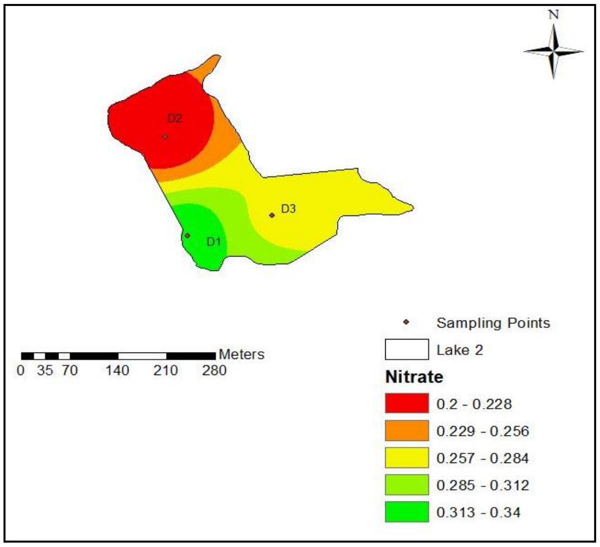

Figure 7.6 (b): NO_3 variation at 2 m depth in lake 2 for monsoon season

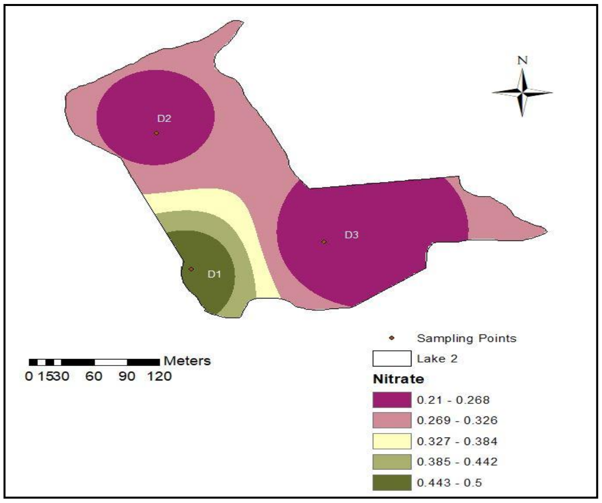

Figure 7.6 (c): NO_3 variation at 3 m depth in lake 2 for monsoon season

For lake 2, the presence of a temple is the major anthropogenic pollution source. Further, sampling point *S1* in lake 1 and *D3* in lake 2 are representative of effects due to agricultural activities. Since the runoff from these fields during monsoon and end of harvesting season leads to influx of fertilizers and pesticides thereby increasing NO_3 concentration levels [230]. The variation in Total Phosphorous (TP) concentrations for lake 1 and lake 2 have been summarized in Figures 7.7 (a) – 7.7 (c) and Figures 7.8 (a) – 7.8 (c) respectively. The TP variation has been presented in units of mg/L.

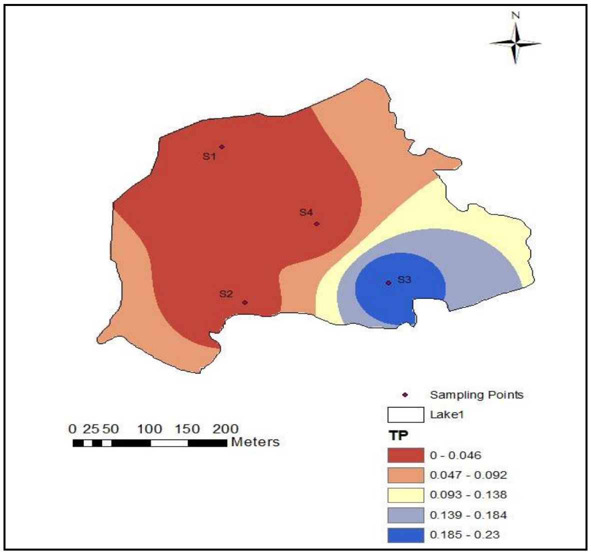

Figure 7.7 (a): TP variation at 2 m depth in lake 1 for monsoon season

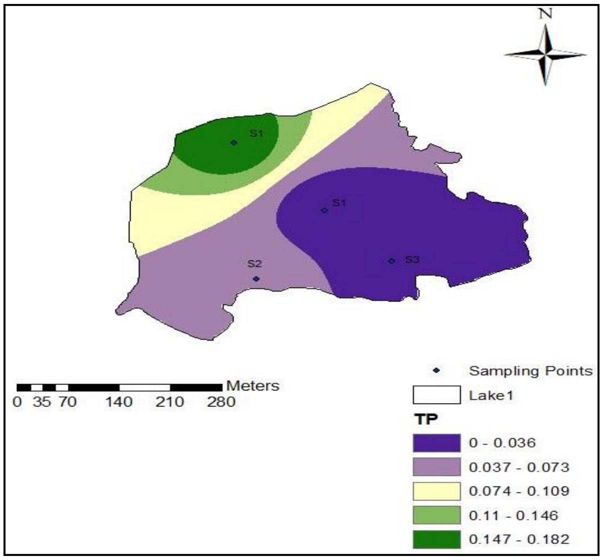

Figure 7.7 (b): TP variation at 3 m depth in lake 1 for monsoon season

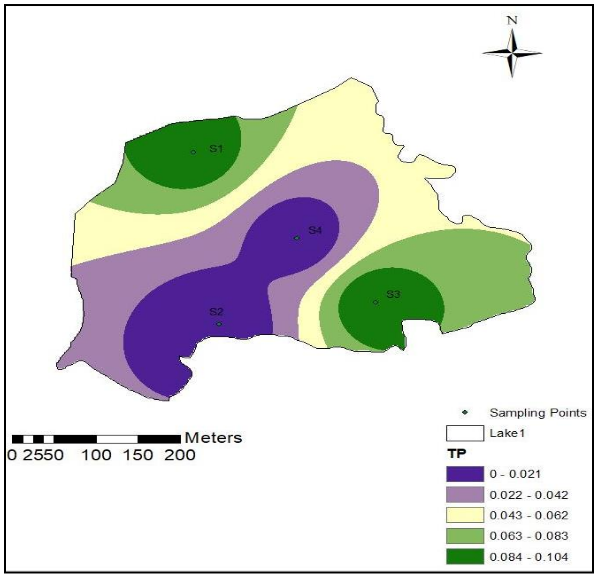

Figure 7.7 (c): TP variation at 4 m depth in lake 1 for monsoon season

It was observed for lake 1 that the highest concentration of TP occurred at sampling location S3 at depths of 2-3 m due to their close vicinity to agricultural fields which during monsoon leads to deposition of fertilizers and pesticides leading to increased concentrations [231]. Further, it was observed that TP concentrations increased with depth particularly for sampling locations S1 and S3 due to proximity of agricultural fields and use of phosphorous based detergents [95; 92] near these sampling locations for lake 1.

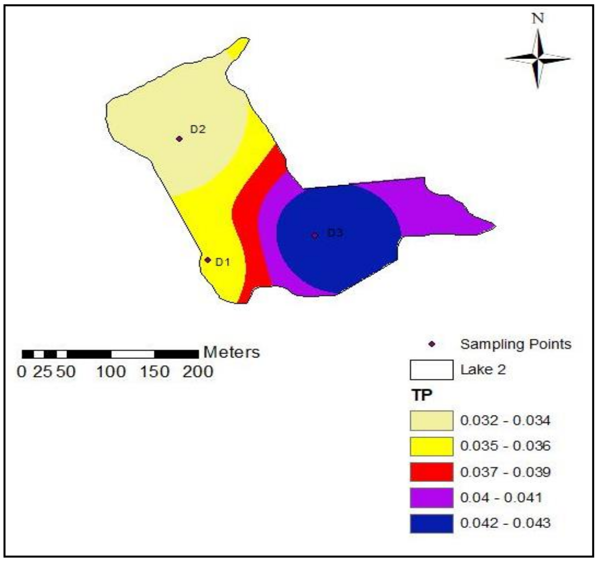

Figure 7.8 (a): TP variation at 1 m depth in lake 2 for monsoon season

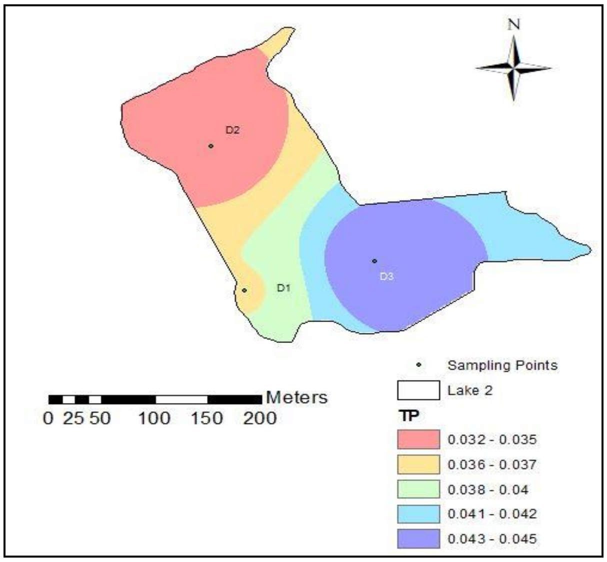

Figure 7.8 (b): TP variation at 2 m depth in lake 2 for monsoon season

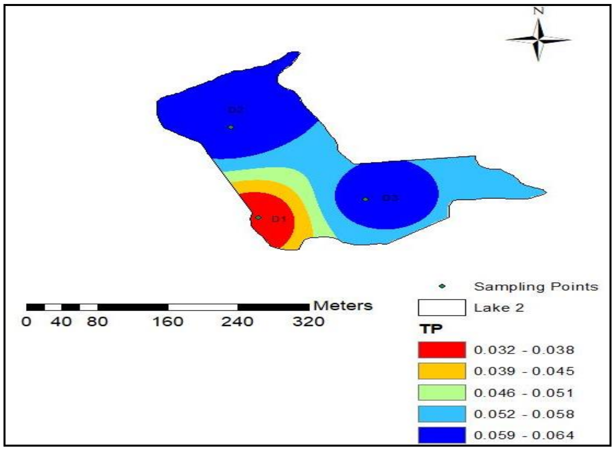

Figure 7.8 (c): TP variation at 3 m depth in lake 2 for monsoon season

Similarly, for lake 2, the highest concentrations of TP were associated with sample location *D3* which was in the immediate vicinity of agricultural field followed by *D1* wherein due to location of temple anthropogenic activities involved using phosphorous based detergents and soaps. Additionally, TP increased with depth at both of these sampling locations for lake 2, which follows the same trend as observed in lake 1.

Winter Season

The variation in temperature for the winter season is summarized for different depths in Figures 7.9 (a) – 7.9 (c), for Lake 1 and Figures 7.10 (a) – 7.10 (c) for Lake 2.

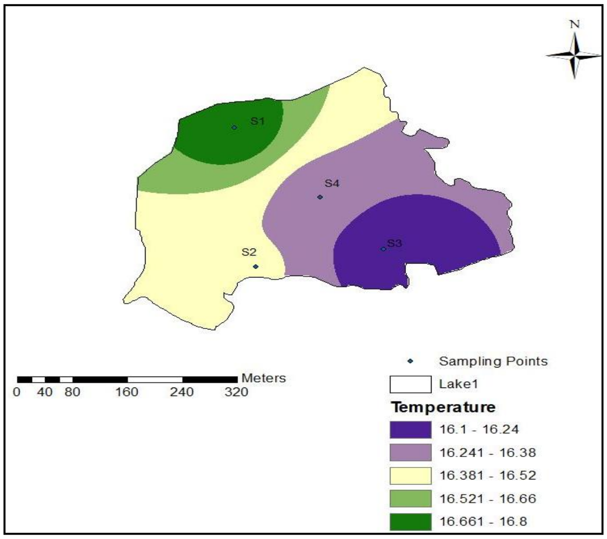

Figure 7.9 (a): Tempertaure variation at 2m depth in lake 1 for winter season.

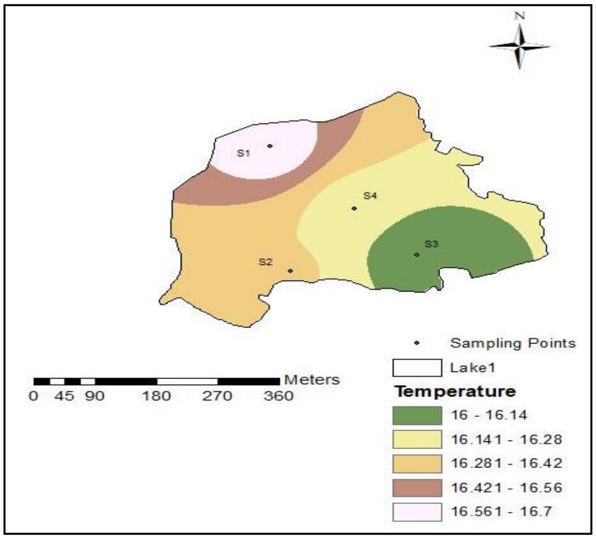

Figure 7.9 (b): Temperature variation at 3 m depth in lake 1 for winter season

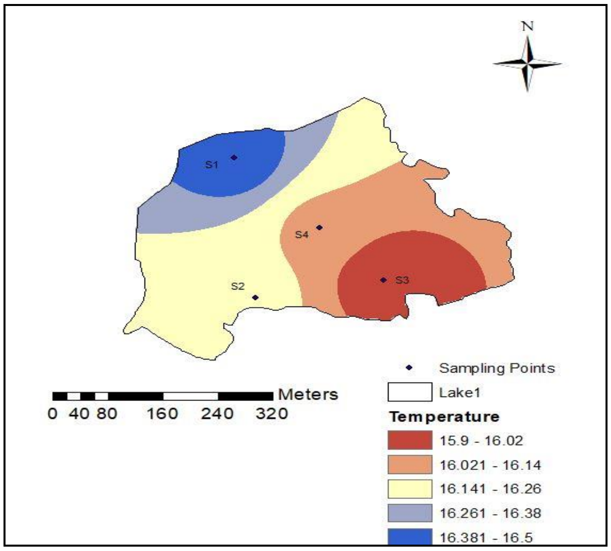

Figure 7.9 (c): Temperature variation at 4 m depth in lake 1 for winter season

Similar to the observation made in the monsoon season, the temperature decreased with increase in depths for all the sampling points and depths for both the lakes. This is primarily because of decrease in sunlight intensity reaching the lower regions of the lakes along with increased sedimentation (thereby increased turbidity) which reduces the transparency of the lake.

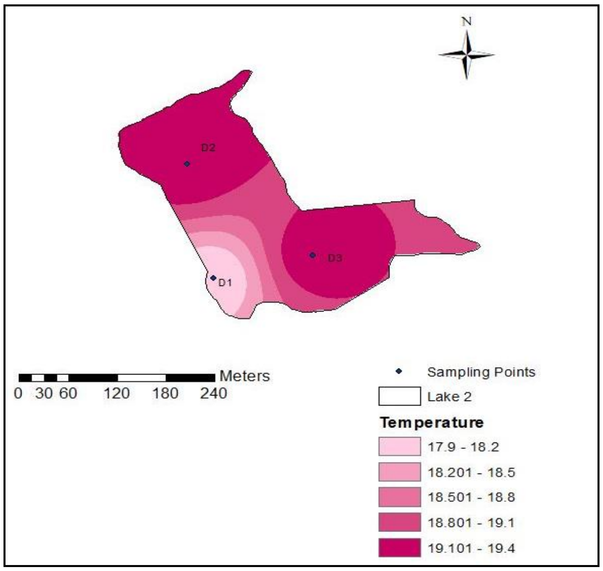

Figure 7.10 (a): Tempertaure variation at 1 m depth in lake 2 for winter season.

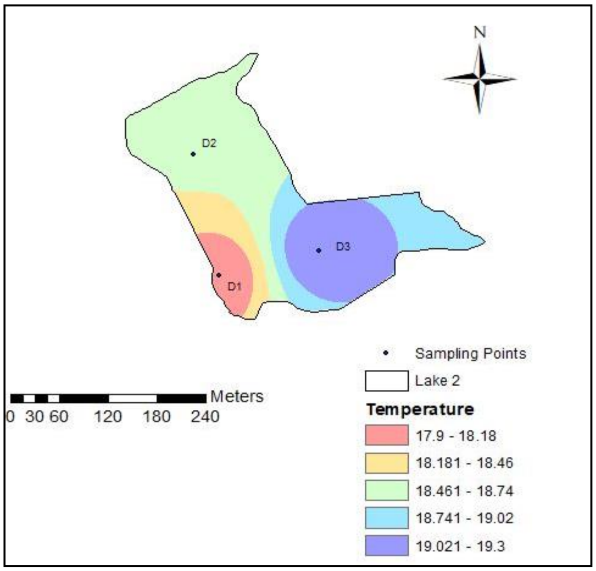

Figure 7.10 (b): Temperature variation at 2 m depth in lake 2 for winter season

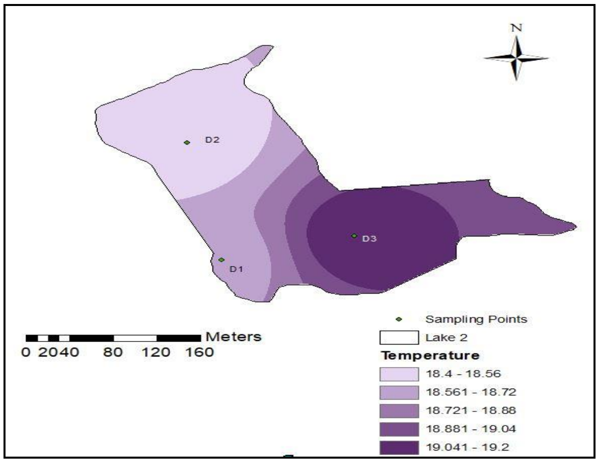

Figure 7.10 (c): Temperature variation at 3 m depth in lake 2 for winter season

The highest temperature was observed near sampling location *S1* in *Lake 1* and *D3* in *lake 2* at all of the considered depth being in immediate vicinity open agricultural fields which leads to washout of soil from the watershed areas into the lake and settlement around the point and thereby leading to high sedimentation rates [231; 92] whereas lowest temperatures were observed near *S3* in *lake 1* and *D1* in *Lake 2* due to proximity to shady vegetation area the vegetation cover and grasslands also play an important role which leads to reduced sunlight reaching the lake waters and thereby reducing the overall temperature at the place [92].

The variation in DO concentrations have been summarized in Appendix B, Figures B4 (a) – B4 (c) for Lake1 and Figures 7.11 (a) – 7.11 (c) for Lake 2, for all study depths.

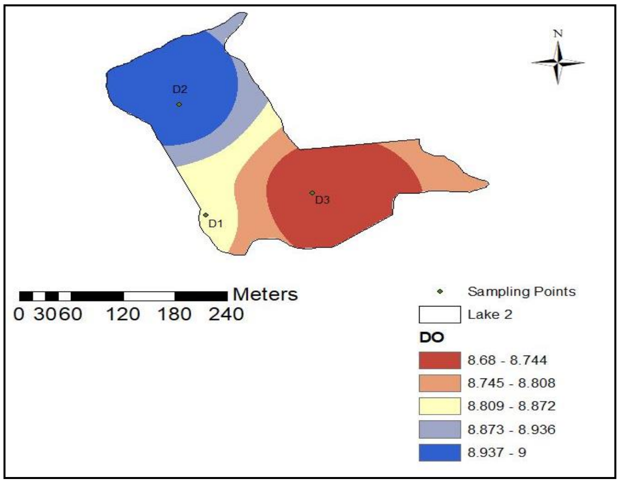

Figure 7.11 (a): DO variation at 1m depth in lake 2 for winter season

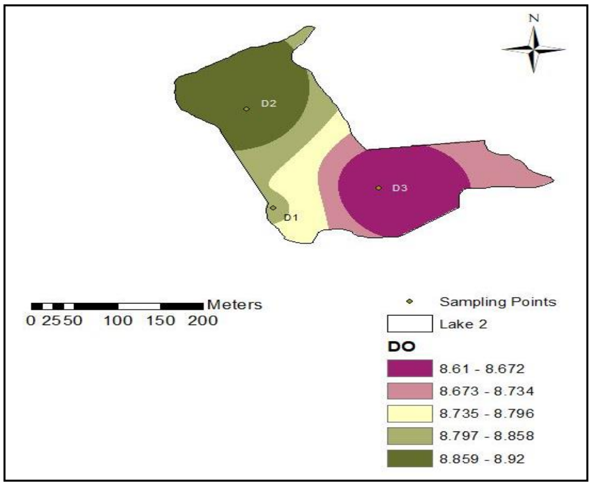

Figure 7.11 (b): DO variation at 2 m depth in lake 2 for winter season

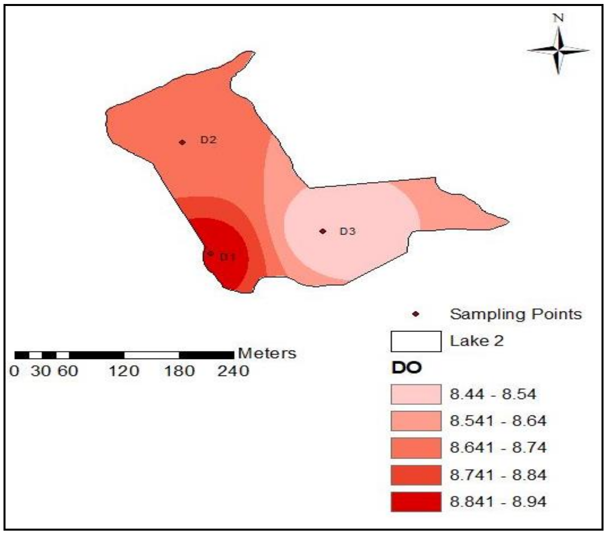

Figure 7.11 (c): DO variation at 3 m depth in lake 2 for winter season

In essence, the DO concentrations showed no overall visible trends depth wise for all sampling locations but trends were visible for points *S1 and S3* which is a normal pattern observed in lakes with seasons and depths due to changes in temperatures, levels of sunlight and photosynthetic activities [147; 92]. The significant correlation leads to interdependency amongst parameters which implies that the variation in one leads to change in other which results in modification of overall water characteristics and a possible reason for the non variability in the depth wise trend of DO [147;92].

The lack of depth wise trend as in *S2* and *S4* might be due to effects of variation in temperatures in winter and locations for points *S2* and *S4* for lake waters often leading to stratification at points [228; 229]. The point *S4* in *Lake 1* which is in centre of lake is prone to direct sunlight for upper layers leading to heated conditions but winters promote stratification effects at deeper depths and therefore are susceptible to low temperatures, as a result the DO concentrations in the at this point are higher due to low temperatures and decreased photosynthetic activities both promoting higher DO levels [228; 229]. The point *S2* in *Lake 1* is in close proximity to forest area and surrounded by shady vegetations which leads to lower temperatures at the surface and comparatively further lower temperatures in the bottom of the lakes. The main reason is to shading effects of trees and seasonal effects of winters but near lake beds temperature are higher leading to various hydrodynamic processes which promote lower concentration in DO near beds and a haphazard behavioural pattern is visible in DO concentrations overall. Therefore, the upper layers have high DO levels at 1m, highest at 2 m and lowest near lake bed level at 3 m [228; 92].

The DO is also dependent on seasons, temperature and monitoring locations which affect the variations in concentrations with depths and points in both the lakes [228; 229]. Interestingly, even though sampling location *S2* for *lake 1* showed no depth wise variation of DO concentrations, the highest values were observed at point *S2* for all the depths due to its close proximity to shady regions which leads to lower temperatures in lake along with seasonal winter effects and thereby increases concentration of DO due to inverse relationship between DO and temperature which leads to higher gaseous concentrations at lower temperatures [147]. In contrast, the DO concentrations decreased with depth at all of the sampling locations of lake 2. Similarly, it was observed in lake 2, that highest concentration of DO was recorded at sampling point *D2 at m depth followed by 2 m depth* which may be credited to increased anthropogenic activities such as boating and fishing leading to turbulence and hence increased levels of concentrations. The lowest concentrations of DO were observed near sampling point *S3* in *Lake 1* and *D3* in *lake 2* for all depths specially at 3 and 4 m respectively due to its proximity to agricultural fields causing sedimentation and leading to lake bed effects due to various hydrodynamic processes undergoing near lake bed due to various depositions in lake bed [95; 92]

The variation in concentration of NO_3 have been presented in Appendix B, Figures B5 (a) - B5 (b) and Figure 7.12 for Lake1 and Appendix B, Figures B6 (a) – B6 (b) and Figures 7.13 for Lake 2 for the relevant depths respectively.

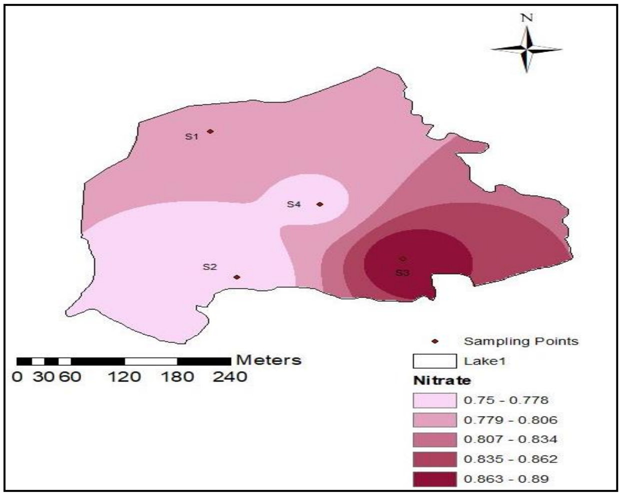

Figure 7.12 : NO_3 variation at 4 m depth in lake 1 for winter season

Increased levels of NO_3 concentrations were observed at greater depths of 4 m in lake 1 and 3 m in lake 2 due to bed effects as a result of various hydrodynamic processes resulting due to depositions in the lake [95; 92] but no depth wise trend was visible. The maximum concentration was observed for sampling point *S3* at *4 m* due to high sedimentation rates and at *S4* at *3 m* due to recreational activities in lake 1. Similar such observations were made in a study conducted by [92].

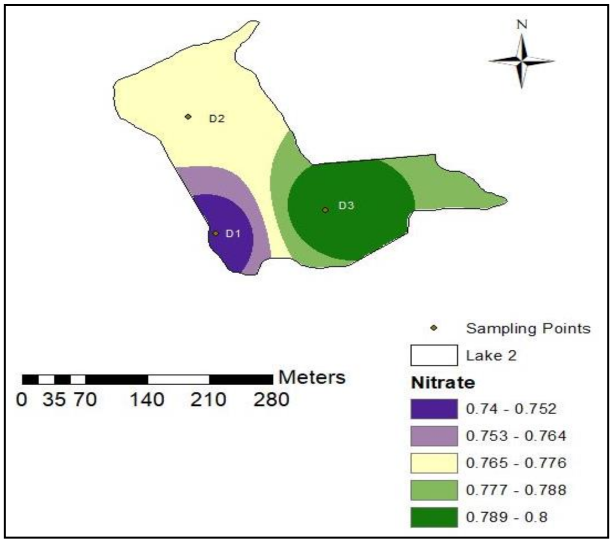

Figure 7.13 : NO_3 variation at 3 m depth in lake 2 for winter season

For Lake 2, sampling points *D1* at *2 m*, *D2* and *D3* at *3m* depths showed high nitrate levels due its close proximity to temple and agricultural fields respectively which contributed to higher concentrations. The main inflow of nitrates is due to use of detergents and fertilizers along with lake bed effects at higher depth of *3 m* at points *D2* and *D3*. Further, high concentrations in intermediate region in case of *D1* may be attributed to non-inflow of freshwater due to finish of monsoon season and starting of winters due to absence of mixing conditions in the lake which resulted in absence of mixing conditions [61; 92].

The TP variation have been summarized in Appendix B, Figures B7 (b) – B7 (c) and Figure 7.14 for lake 1 and Appendix B, Figures B8 (b) – B8 (c) and Figure 7.15 for lake 2 respectively.

The highest concentration of TP was observed at point *S3* at *4 m* depth in Lake 1 and *D3* at *3 m* depth in Lake 2 due to low bed depth and DO concentrations which leads to release of TP due to hydrobiological changes which increases the TP concentrations at greater depths of lake bed [92].

Higher concentrations were also observed at *S3* and *S4* at *2 m depths* followed by *S3* at *3 m* depth in case of Lake 1.

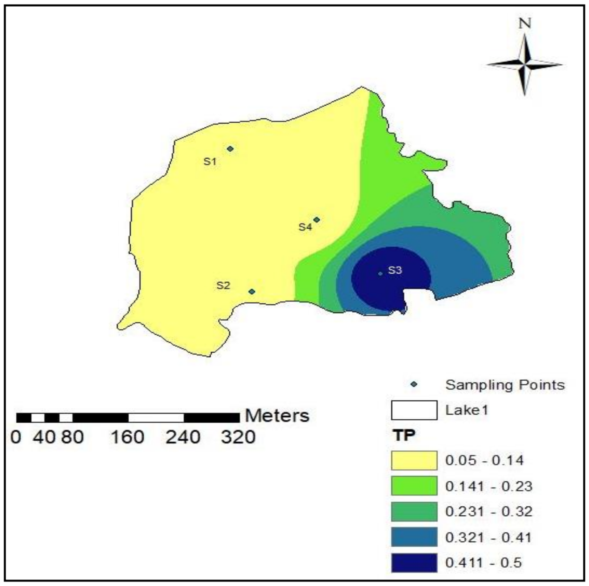

Figure 7.14 : TP variation at 4 m depth in lake 1 for winter season

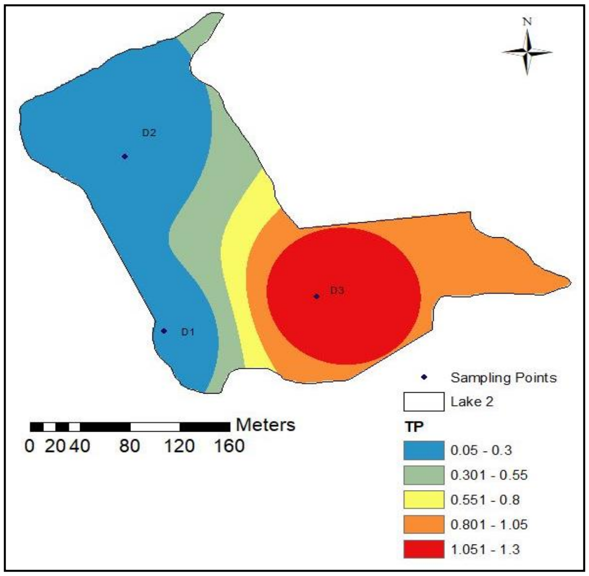

Figure 7.15 : TP variation at 3 m depth in lake 1 for winter season

The high concentrations at these locations may be attributed to increased residential activities promoting anthropogenic activities causing release of phosphorous based detergents into lakes as well as close proximity to agricultural fields.

Summer Season

The temperature variation during the summer season can be observed from Appendix B, Figures B9(a) – B9(c) for Lake 1 and Figures B10(a) – B10 (c) for Lake 2 respectively. As observed previously, the temperature decreased with lake depth at all of the sampling points for both the lakes. This is primarily due to decreased intensity of sunlight reaching the greater depths of the lake. The highest temperatures were observed at point *S1* in *lake 1* and *D1* in *lake 2 for all the depths* due to close proximity to agricultural fields.

The variation in DO concentration is summarized in Appendix B, Figures B11(a) - B11(c) and Figures B12(a) – B12(c) for Lake 1 and Lake 2 respectively. It was observed that there was a progressive decrease in DO concentrations with depths for both the lakes at different sampling locations due to decrease in temperatures leading to low photosynthetic activities. The highest DO concentrations in Lake 1 were observed at *S1* and *S3* for 2m depth. Interestingly, during the summer season no point wise variation in DO concentrations at different sampling locations were observed which may be attributed to reduction in levels of water in the lake. It may be mentioned that during remaining study seasons additional source inputs like waterfall (particularly in months of August to December) leads to increased volume of lake waters, due to changes in concentrations of these parameters and their interactions with each other promoting correlation and interdependencies in the parameters [61; 147]. The overall result is changes in behavioural patterns of different lake parameters which affecting other hydrodynamic processes in the lakes as well. The highest DO concentrations in Lake 2 were observable at *D1* and *D2* for 1 m followed by *D1* and *D3* at 2 m depths with these points being adjacent to heavy anthropogenic activities leading to heavy turbulence inducing higher concentrations.

The variation in NO_3 concentrations is presented in Appendix B, Figures B13(a) - B13(c) and Figures B14(a) – B14(c) for Lake 1 and Lake 2 respectively. It was observed that for Lake 1, highest values of NO_3 concentrations were observed at *S3* at *2 m* depth; along with *S1* at *2 m* depth due to nearness to agricultural fields which is source of nitrate-based fertilizer washing out into lake. Similarly for Lake 2 highest levels were observed at point *D2* for *2 m* depth due to anthropogenic activities involving use of nitrate-based detergents for washing of clothes and *D3* at *1 m* depth due to nearness to agricultural fields which is source of nitrate-based fertilizer washing out into lake. The reason for variability in concentration at intermediate depths might be due to reduction in levels of water leading to increase in concentrations of other parameters in lake since the source inputs water from August to December leads to haphazardness in behavioural patterns of lake. The correlation and interdependencies in these parameters [61;147] leads to various effects on hydrodynamic processes and overall a variability in behaviours of these parameters in lake [61;147].

The variation in TP concentrations is summarized in Figures B15(a) - B15(c) and Figures B16(a) – B16(c) for Lake 1 and Lake 2 respectively. There was no significant trend for depth wise variations observed for TP for both the lakes at all of the sampling points. The value of TP was observed to be highest near point *S3* at *3 m* depth due to close association with agricultural fields causing influx of phosphorous based fertilizers and effects of recreational activities around the point. Further, high values were observed at point *D2* in lake 2 at depth of *2 m* being in vicinity to different anthropogenic activities being carried out and washing out of phosphorous based detergents into lake. The haphazard patterns in case of TP were contributed by no influx of fresh water leading to increased concentrations of parameters along with their corelation and interdependencies among each other as explained in sections above.

Summary

The study revealed that the lake waters are affected by seasonal variations in parametric concentrations due to both anthropogenic and natural causes.

The BIS WQI interpolated through IDW method for the entire year at different depths for both the lakes categorized them to be *'Excellent'* and therefore a potable source of water for nearby areas. However, some preliminary treatment like disinfection should be done to avoid the effect of any pathogens.

The temperature was observed to *decrease with increase in depth* for all seasons at all of the sampling points at different depths for both the lakes due to reduced amount of sunlight intensity reaching the greater depths of the lake and also due to presence of vegetation surrounding the lakes. The seasonal variations in temperature revealed *higher temperatures in monsoon* in comparison *to summer* due to low water levels causing high turbidity in summers which induces scattering of the sunlight rays by turbid particles reducing overall temperatures. The turbidity is reduced in monsoon season due to fresh water influx which increases the transparency of the lake water allowing greater intensity of sunlight reaching the depths leading to increased temperatures in monsoons.

The concentration of DO were observed to have a *decreasing trend with increase in depth* for all seasons at all sampling points and depths for both lakes due to reduced amount of sunlight reaching the depths leading to low photosynthetic activities causing low oxygen saturation in depths. The seasonal variations in DO show *high concentrations in winters* as *compared to summer and monsoon seasons.* In particular, the parameters of temperature and DO are inversely related and therefore higher concentration of DO is observed in winters due to lower temperatures than any other season specially monsoons.

The NO_3 concentrations showed *no depth wise variation* for all seasons at all of the sampling points and depths for both lakes. The seasonal variations in NO_3 concentrations revealed *high levels in winters with reductions till summer for both the lakes*. This is possible since *high levels of DO* favours nitrification in lakes rather than ammonification and therefore higher concentrations were observed in winter. The high values even in intermediate region for both the lakes at depth of *3 m in lake 1* and *2 m in Lake 2* which showed haphazard patterns in summer was primarily due to absence of freshwater at end of monsoon season and starting of winters leading to a low or no dilution in the lake along with no mixing conditions or certain levels of stratification. The various chemical reactions amongst them at different stages and their interdependency among each other does not follow any significant behavioural patterns.

The TP concentrations variations showed *no depth wise variation* for all seasons at all sampling points and depths in both lakes. The seasonal variations in TP revealed *higher concentration levels in winters than monsoons and summer. The loss of TP* from water column in monsoon season due to overflowing *in monsoons* and *settlements into sediment beds* in summer season due to low level of water in lakes might be the possible causes. The haphazard patterns in case of TP were contributed by no influx of fresh water leading to increased concentrations of parameters for winter and summer seasons along with their corelation and interdependencies among each other in comparison to monsoons.

Further, the lakes are a large fresh water source and therefore the banks of the rivers should be properly maintained to avoid influx of soil into the lakes from watershed areas. The use of degradable fertilizers and biological agriculture methods are few tools to promote green agriculture. The tourist influx increases recreational activities causing deterioration of lake and its water due to anthropogenic activities therefore strict laws should be enforced to keep the situation in check. The reforestation of water shed area, growing carpeting grass along banks and creating bunds around lake banks can be few measures to avoid sediment flux into lakes. Government bodies should start monitoring water quality of the lakes and maintain data records to facilitate suitable data to policy makers for creating designing policies and remedial measures

In the above context, it may be mentioned that suitable remedial measures need to be suggested for application to lake waters to restore and preserve its quality for further use. The following chapter (Chapter 8) discusses in details the suitable remedial measures that can be applied for lake restoration and quality preservation.

CHAPTER 8

Remediation Techniques and Design of small-scale Water Treatment Unit for Twin Lakes

8.1 Introduction

Lakes, rivers and Ponds are such water bodies form an significant part of our community and their indiscriminate use can lead to severe deterioration of its quality. The developing nations portray a threat to these water bodies as they are limited resources, increased urbanization and population [96]. The contaminated water sources might lead to spread of life-threatening diseases. The main sources of pollution in these water bodies include dumping of grey water, storm water, municipal waste, industrial wastes and agricultural wastes and other associated similar disposals [97, 98]. The above mentioned pollution sources also lead to heavy inflow of sediments, organic components and nutrients into water bodies causing issues like eutrophication.

The remediation measures and regulatory policies need to be applied to these water bodies for an overall reduction of pollution and also possibly for their restoration in quality [99]. The remediation techniques involve either *in-situ* or *ex-situ* treatments for lake pollution control. Additionally, these treatments are further separated into physico- chemical and biological approaches [100, 101]. The consolidation of these approaches can be used for treating severely contaminated waters.

Physical approaches comprise of manual methods such as aeration, algae eradication, weed removal, water dilution, hydro-raking and dredging of sediments amongst the methods for improving of characteristics of these water sources. Chemical treatments comprise of input of chemicals such as Poly Aluminum chloride for flocculation, using copper sulphate and use of lime for eutrophication and nutrient control, and application of ferrous salts in optimal doses for overall improvement [102]. The biological or ecological methods comprise of wetland construction, formation of floating bed, use of biofilm and bioreactors, ecological ponds, including other minor techniques of filtration [96]. The biological treatment also includes use of micro-organisms and use of plants for absorption of damaging components which lead to overall reduction in concentrations of BOD, COD, phosphate and nitrate [100]. These methods can lead to production of bacteria, and fungi leading to *on site* bioremediation [232]. The combination of *on site* and bacterial techniques can prove to be highly fruitful remediation methods for treating severely polluted waters. The techniques being sustainable and cost-effective with no secondary pollution can lead to total eradication of pollutants form source [233].

The present chapter aims to determine the best and economic remediation technologies for shallow lakes in sub urban areas. The study focusses on review of global scientific literature to crucially examine the best available techniques including their advantages and disadvantages for applying to the study sites to be determined on the previously evaluated parameters for lakes.

8.2 Site Description

The description of the study sites has already been mentioned in Chapter 3, *section 3.2* under *subsection 3.2.1.*

8.3 Methods and Their Applications

The different methods for remediation involves traditional as well as novel applications. The remediation techniques are generally categorized into physico - chemical and biological methods [102]. These approaches involve either removal or fixing of pollutants or restricting concentrations of pollutant.

The physical remediation techniques include Rip Raps, Sediment Dredging, Aeration, Vegetative Buffers and Riparian zone stabilization and Hydro Raking.

The chemical remediation techniques include use of substances such as Alum, Phoslock $^{\mathrm{Tm},}$ Modified Zeolites, Ferrous Iron Salts, Copper Sulphates and Calcium based compounds in optimum doses.

The biological or ecological techniques include use of microorganisms in form of microbial dosing and Biofilm Reactors, use of Aquatic Animals, Aqua Mats, Aquatic Plants, Constructed Wetlands and Floating Beds.

The various remediation techniques have been summarized in Figure 8.1 below [234].

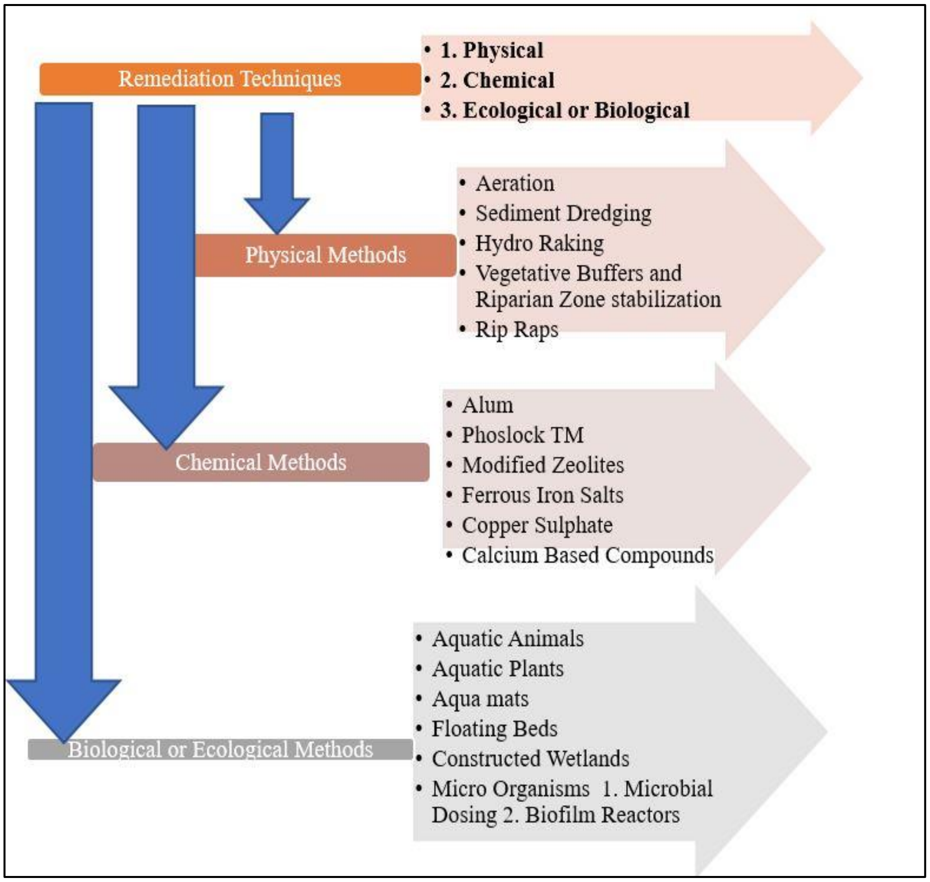

Figure 8.1: Remediation Techniques for Lakes

8.3.1 Physical Methods

Aeration

Aeration is used for increasing the oxygen saturation concentrations in water body thereby reducing the effects of organic pollutants in the lake [104]. Aeration is carried out using compressors which release air at the bottom of lake or its surface [235]. The technique promotes favourable conditions for microorganisms to degrade organic matter and thereby leads to reduction in organic and nutrient concentrations [96]. It also helps in reduction of phosphorous and nitrogen concentrations in the water body [236]. Aeration can be done using either a fixed-point aeration system or a mobile aeration system [237]. The efficacy of the aeration process increases when applied in association with other remediation techniques [238]. This method has been efficiently used for various deep lakes and also rivers like River Thames in U.K., Canal Homewood in United States [239].

Sediment Dredging

Sediment dredging is effective and direct remediation technique which is applied to various shallow lakes. The method includes use of engineering structures and heavy machines such as dredgers for removal of sediments from lake bottom at fixed depth. An example of this application was in Lake Taihu wherein sediment loads were removed resulting insignificant improvement of aquatic ecosystem [240]. This technique is used for removal of nutrients from enriched sediments [103]. This technique can also help in removal of organic matters, heavy metals and pesticides from sediments [241] leading to overall reduction in cyanobacterial blooms [240]. Lake Trummen in Sweden observed a considerable decline in cyanobacterial concentrations when remediated with dredging operations carried out in the lake [237]. The method is beneficial when collaborated with other techniques that help in reduction of outside loading as it focuses on decreasing of interior load [241; 242].

Hydro Raking

Hydro Raking is used for removal of undesirable aquatic flora from water bodies. The method aids in regulation of benthal population through broad elimination of biomass [243]. It uproots unwanted aquatic plants along with their dormant seeds [244]. The technique is extremely efficient in removal of undesirable vegetation along with nutrients. A case study of application of this technique was carried out in Lake Chemung, Ontario where 35000 kg of unwanted plants were removed leading to 560 kg of Phosphorous removal [245]. The method is best for lake remediation with negligible damage to aquatic animals. The technique is also economical in comparison to dredging.

Vegetative Buffers and Riparian Zone stabilization

Native flora is generally planted along the banks for prevention of sediment influxes from nearby areas into lakes [246]. The native plants aid in nutrient uptake preventing high inflow of nutrients in freshwater [247]. The riparian vegetation aids infiltration of water into subsoils, therefore increasing the levels of water table. However, the type of vegetation selected, if appropriate, reduces the overflow rate [246]. Grass covers are efficient than woody covers in regulation of temperatures but requires higher maintenance [248]. However, [249] demonstrated that native vegetation to be better in prevention of sediment inflows and infiltration.

Fencing of riparian zone with bamboos is an extensive measure which can act as both cover and also aid stabilization of soil against runoff and erosion. The crib walls can be constructed using bamboo samples. It is used for soil stabilization by reducing pore water pressure, incrementing strength of surface [250]..

This method is best used in association with other physical or biological methods in increasing efficacy of other methods such as dredging and hydro raking.

Rip Raps

Rip Raps is a method of placing pointed or round rocks along the banks to prevent soil loss arising from soil erosion due to constant water collision along shore lines. These are defensive covers having no vegetative growth over surface. It protects only the area in contact and hence fails in providing shield to exposed shoreline which erodes due to continuous water flow. Further, it provides greater visibility and ease of accessibility to predators and proves to be harmful to aquatic life. Also, minute vegetation and noticeable stone surfaces cause excessive reflection and heating of lakes resulting in high temperatures.

8.3.2 Chemical Methods

Alum

Alum is a frequently used material for capping of sediments and also as flocculant [251]. The chemical reduces turbidity and improves aesthetics of water by binding the phosphorous thus disabling the algae to feed on it. The chemical is often applied in powdered form or in form of solution for algae reduction. The chemical fixes the free phosphorous to the sediments by settling down over them and forming flocks with phosphorous through process of ‘flocking’. The lack of nutrients makes algae to wither off [100]. The highest use of chemical is prevalent in United States and Europe [103]. The chemical is best suitable for pH ranges of 6 to 8 [100]. The depth and morphology are the factors affecting effectiveness of this chemical technique which may last up to 20 years in some lakes [46].

Phoslock ™

It is a commonly known as Lanthanum and is in form of modified natural mineral or bentonite clay having high affinity for phosphorous. The material forms a compound with phosphorous called as Lanthanum phosphate which is insoluble thereby working as a sink for phosphorous [252]. The chemical is applied into the lake in slurry or granular form thoroughly mixed with bentonite clay, which is highly reactive and quickly disperses and thereby helps in phosphorous removal by confining the efflux from sediments [253].The chemical is suitable for use in near neutral to alkaline pH i.e. 6.5-10 with maximum adsorption at pH of 4.5 and 8 [238]. This chemical has been utilized heavily in the lakes of United Kingdom and the studies suggested it to be an efficient technique for remediation of lakes if applied in optimal doses [252].

Modified Zeolites

It is a recent method which emphases on encapsulation of both nitrogen and phosphorous [242]. It is readily available highly porous material which is obtained from sedimentary rocks and is commonly known as Aluminosilicates [100]. The material can be used for removal of cationic pollutants since it has a high affinity for cations [254]. The structure of this material can be easily altered which upsurges its attraction to adsorb cations and other organic contaminants [254]. The use of modified zeolites in optimum doses can be an effective management practice for remediation as well as avoid any detrimental effects.

Ferrous Iron Salts

The salts of aluminium work better at pH less than 5.5. However, enlarged solubility of aluminium is poisonous to aquatic life. Hence, it becomes imperative to monitor optimum doses of salts on constant basis specially in case of drinking water sources [255]. In this context, ferrous salts are 250 times less soluble than alum at a pH of 7 and leads to phosphorous precipitation [256]. An example of its application for bloom control was Bautzen reservoir in Germany but the pH was kept in attention [255]. Aerators were used in amalgamation with ferrous salts [60]. Fe^{2+} salts help in phosphorous eradication from lakes, due to delayed formation of floc and can operate in wide pH range [255].

Copper Sulphate

Copper sulphate is used as an algicide for monitoring algae in various water bodies [257]. About 9 million kg copper sulphate is used in United States for lakes and more is estimated to be used in future also [258]. The copper sulphate was first used by Moore and Kellerman in year 1905 and observed formation of scum of dead algae along banks after its application. Copper Sulphate is a narrow range treatment used for control of algae growth and might portray unfavourable effects on parameters such as Dissolved Oxygen (DO) and also, its constant usage leads to resistance in lakes, one such example is Shallow Fairmont Lakes of Canada [258].

Calcium Based Compounds

Compounds such as Calcium Oxides, Calcium Hydroxide, Calcium Chloride and Gypsum, are acknowledged for controlling nitrogen and phosphorous in regions of low oxygen, specially Hypolimnion. Free hydrogen ion is released by Gypsum through decay of organic matter under anaerobic conditions [259]. The aeration is used in combination with doses of calcite doses thereby inducing phosphorous precipitation [260]. This treatment is best for hard waters and waters with phosphorous loading [261]. The calcium based compounds are selected on various environmental factors including its pH [262]. The increment of pH is frequently observed in lake [262], therefore these compounds should be used in lakes with high phosphorous or nitrogen and low pH with oxygen deficiency in Hypolimnion region.

8.3.3 Biological or Ecological Methods

Aquatic Animals

Aquatic animals are used for bio-remediation specially in eutrophic lakes. Gastropods act as biological indicators against presence of heavy metals in fresh water bodies [263]. Silver Carp, has a long life span and effectively controls eutrophication through removal of excess phytoplankton [264]. The silver carp decreases its competence in existence of large herbivorous, inorganic and organic toxins. They are also affected by release of biotoxins by other species [264].

Aquatic Plants

Aquatic plants such as Hyacinth, algae and water lettuce can efficiently remove toxins from effluents, wastewater and other toxicants through various physico- chemical processes [97]. Duckweed, cattail, Common weed, pondweed, and canna are few species used for onsite wastewater remediation through systems such as constructed wetlands, floating beds and submerged systems [265] These schemes work by either direct adsorption of pollutants or through various reactions aiding purification [265]. The techniques stated below utilize aquatic plants and can prove as a great approach for remediation.

Aqua mats

Aqua mats are artificial seaweed that have large surface areas which promotes growth of other aquatic microorganisms, aerobic and anaerobic bacteria and algae [104]. The increase in efficiency is best achieved by restraining bacteria, selecting correct species of plants and increased plant growth [266].

Floating Beds

The floating bed technique is suited for removal of nutrients, BOD, COD, and heavy metals, particularly for eutrophic lakes [104]. This technique employs use of floating beds carriers for plants, it can also be used as habitat by birds and animals. A study on Hong Feng Lake successfully utilized this ecological technique of remediation [267]. The flexibility in use of variety of plants has made it popular in USA, China, and in European nations. Remediation using Integrated floating beds (RPIFB) [265] is an advanced floating bed technique.

Constructed Wetlands

The main purpose of its construction is an improvement of water quality along with preservation of biodiversity. The sediment rooted wetlands which can easily remove the nutrients [268]. There are three types constructed wetlands (CW), Vertical divided into Surface and Subsurface. The surface and subsurface structures remove COD and chlorophyll -a [268]. The CW's are based on promoting reoxygenation through various reactions.

Micro Organisms

The microorganisms are used for remediation as well as treatment of polluted waters and are extremely effective in decomposing, absorption and transformation of pollutants. It involves use of suitable microbial groups such as microalgae bacteria for removal of BOD, COD, TP, NH_3, nutrients and photosynthetic bacteria for increasing DO concentrations [269]. The methods are divided into in - situ such as microbial dosing and surface water technique such as Biofilms.

Microbial Dosing

The microbes are directly applied for pollutant removal by use of product like FLO-1200 in conjunction with bio energizers for promoting aeration [233]. Black and odorous river in Fangcun region of China was remediated using Photosynthetic bacteria and Bacillus Subtilis [269].

Biofilm Reactors

This technology employs use of Bio membrane attached to micro carrier for degradation under conditions of aeration. The biofilm reactors are highly efficient in removing organics and nutrients from water [270]. The most commonly used techniques are Suspended Carrier Biofilm and Thin Layer Flow Reactors. Bio-ceramics are used for removal of Nitrogen, colour, COD, Phosphorous, organic matter and turbidity [271]. Bamboo has been used as a biofilm for polluted river remediation [271]. It leads to a higher bio remediation than other techniques.

8.3.4 Design of Small-Scale Water Treatment Unit

The sites endure a constant problem of siltation in the lake bed, due to high levels of erosion from the banks and watershed areas. The inflow of heavy sediments due to expansion of agriculture, large tourist influx, landslides from nearby mountains also add up to various kinds of pollutant loads into the lakes along with soil and sediment loads. These conditions make it necessary for the water of the lakes to be treated before being utilised as a source of drinking water, since the DBU classification as in *Chapter 3* clearly showed that the water is fit to be utilized as drinking water source with treatment. Therefore, a small-scale water treatment unit is necessary at the study locations. The water treatment unit must include intake structures for input of water, conduits for transportation of water, pumping units for commute of water to main tanks, screens for removal of fine and coarse impurities, sedimentation and coagulation tanks for removal and control of sediments, filtration unit for removal of finer materials and a disinfection unit for removal of pathogens. The complete design of treatment Plant with various units have been added in APPENDIX -A.

8.4 Results and Discussions

8.4.1 Technology Consideration

The suitability of the different technologies for our study sites have been summarized in Table 8.1 below.

Table 8.1: Advantages, Disadvantages and suitability of technologies [234]

Technology	Advantages	Disadvantages	References	Suitability for our study sites
Aeration	1. Easy to apply 2. Improves water quality 3. Effective against removal of nutrients and increment of DO.	1. Can be applied to small and shallow lakes. 2. High maintenance cost.	[97]	Yes pH - 6 – 6.5 DO- 5- 5.5mg/L
Sediment Dredging	1. Improves quality of Water. 2. Direct Application. 3. Reduction of sediment loading and release.	1.Can be applied to Small and shallow lakes. 2. High maintenance cost. 3. Destabilization of shore.	[103]	Yes NO_3 0.5mg/L- 1.2mg/L TP 0.2mg/L - 0.5mg/L
Hydro Raking	1. Aquatic wildlife is not disturbed. 2. Removal of unwanted weeds.	1. Can be applied to Small and shallow lakes. 2. High maintenance cost.3. Dispersion of Sediments and increase of turbidity.	[243]	NA
Vegetative Buffers and Riparian Zone stabilization	1. Prevention of inflow of sediments.	Constant maintenance of stabilization techniques.	[247]	Yes

	2. Promotes native vegetation growth. 3. Provides shielding to aquatic animals from high temperatures and predators.			
Rip Raps	1. Bank Stabilization. 2. Prevention of soil erosion. 3. Prevention of damage to shoreline.	1. Increment of temperature of by reflection of sunlight into waters. 2. Makes aquatic wildlife prone to preying. 3. Constant maintenance is required.	[100]	NA
Alum	1. Provides long term benefits. 2. Reduction in concentrations of nutrient.	Not suitable for large cyanobacterial blooms.	[103]	Yes BOD 1 mg/L-1.5mg/L COD 40mg/L- 50mg/L
Phoslock ™	1. Control of Eutrophication. 2. Can be used singly or in combination for achieving suitable results.	1. Sediment restricting in benthic. 2. Toxicity	[253]	NA

Modified Zeolites	1. Safe for aquatic animals. 2. Wide area of application.	Costly	[253]	NA
Ferrous Iron Salts	1. Inhibition of nutrient release. 2 Removal of large algal blooms. 3. Improvement in quality of water.	1. Approach is limited. 2. Toxicity	[256]	NA
Copper Sulphate	1. Removal of concentrations of large algae. 2. Low cost.	1. Toxicity in Zooplankton and Fish. 2. DO Depletion. 3. Accumulation of Copper in sediments. 4. Killing of non-target organisms.	[258]	NA
Calcium Based Compounds	1. Suitable for application to hard waters. 2. Direct Application	1. Decrease in transparency. 2. Increase in pH of water.	[260]	NA HCO_3 120 mg/L-170 mg/L
Aquatic Animals	1. Inhibition of excessive phytoplankton. 2. Improvement of water quality	1. Obstructive to toxic environments and organic contents from algae.	[97]	Yes
Aqua mats	1. High surface area, solar based,	Susceptible to natural disasters	[270]	NA

	low cost, eco-friendly. 2. Bacterial removal is high 3. Better in removal of organics and nutrients.	and needs constant maintenance.		
Floating Beds	1. Cost effective, better removal efficiency, Better accommodation for plants. 2. Removal of nutrients and also provides home to plants and animals.	Often affected by natural disasters and waves, pollutant loads, seasonal changes.	[270]	NA
Constructed Wetlands	1. Low cost, easy maintenance, no secondary pollution, economic and environmental friendly.	1. Intolerance to heavy pollution loads 2. Necessitates large area 3. Seasonal Death and Plant diseases.	[97]	NA
Microorganisms (Direct Application)	1. Enhanced control of pollution. 2. Ease of Application with no extra construction.	1. Limitation in achievement of remediation. 2. Inefficient for many parameters.	[97]	NA

Biofilm Reactors	1. Reduction of cost of sewage collection. 2. Less landscape required. 3. Low cost	1. Prone to breakage from strong water flows. 2. Construction of extensive works required.	[270]	NA

Both the lakes are urban shallow in nature and endures natural and anthropogenic effects of different activities. The lakes experience tremendous sedimentation resultant of continuous erosion from lake shores and their watershed areas due to deforestation along with agricultural activities [147,149]. The lakes are therefore threatened by increased rates of sedimentation and therefore control and remediation of high rates of sedimentation are of immediate concern. The continuous erosion of soil from banks due to agricultural expansion has led to minor increase of nutrient concentrations [147,149], which may surge further if measures for control are not implemented.

For remediating of sites through technologies mentioned above, namely dredging, vegetative buffers, aeration and application of chemicals like alum and other biological methods like aquatic animals can be applied suitably alone or in combination to attain long term remediation benefits. The physical techniques like hydro raking and dredging of sediments can be effective in removal of already deposited sediments. Further application of methods like vegetation buffers and riparian zone stabilization can prove to be other effective tools for combatting further lake sedimentation and help in eradication of future issues like build-up of nutrients in sediments. Further, the chemical treatment such as alum can be helpful for building up flocks and thereby reducing haziness.

Summary

The study revealed that the lake waters are affected by various pollutants due to both anthropogenic and natural causes.

The problems at study sites such as heavy sedimentation resultant of constant soil erosion from banks and lake’s watershed areas due to deforestation along with expansion of agriculture can be remediated by use of physical techniques like dredging, vegetative buffers and riparian zone stabilization. These methods are highly proven for removal as well as prevention of heavy sedimentation in lakes. The dredging activities can be used once a month for removal of already existing sediments from bed of the lakes whereas growing of native vegetation along the banks can prove to be successful technique in binding of soil particles together to avoid further sediment inputs into the lakes along with promotion of infiltration into water tables. The chemical methods such as use of alum in optimum dosage can be used successfully for removal of turbidity and nutrients, at a near neutral pH range (6-8) of lake waters by *flocking* of sediments. The above mentioned physico-chemical techniques can be combined together for achieving improved and more stable results of remediation. The biological remediation practices namely use of Aquatic Plants and Aquatic Animals can also be beneficial for eutrophication control and restriction of nutrient concentrations in lake waters.

The lakes are a fresh water source and the water can be utilized for drinking purpose but with suitable treatment therefore a water treatment unit can be considered to be a necessity at the place. Therefore, the design of a small-scale water treatment unit was proposed and has been added in APPENDIX-A, which if implemented could be beneficial for the population of the nearby villages during water scarcity and also supply water to the villages.

In the nutshell, it can be concluded that the remediation techniques and water treatment unit design for twin shallow lakes of Haryana will help in controlling, remediating and utilizing the freshwaters of these natural lakes, thereby reducing environmental impacts, promoting restoration of lakes and ensuring regular and safe water supply to public.

CHAPTER 9

Conclusions

9.1 General

This section summarizes the major conclusions resultant from all of the investigations carried out throughout the study.

9.2 Conclusions

- It was concluded that the lake waters were affected by seasonal variations in DBU determination for both the lakes due to both anthropogenic and natural causes. The seasonal variations exhibited high variability in the pH, DO and BOD throughout seasons. The pH was seen to vary from neutral to alkaline for both the lakes with seasonal variations especially during summers due to fluctuations in water levels therefore affecting parametric concentrations. The highest and lowest DO concentrations were observed in spring and monsoons due to change of temperature resulting in overturning effects and high input organic and inorganic content from watershed area respectively. The DO and BOD concentrations were inversely proportional to each other and were observed throughout the sampling period.
- The overall DBU status confirms that the water of both the lakes can be used directly for any category between B to E, i.e., outdoor bathing, drinking water source with treatment, propagation of wildlife and fisheries and irrigation; but not for category A i.e., drinking water source with mere chlorination, which suggests the requirement of small-scale treatment unit before using the sources for potable water.
- The Pearson's correlation matrix established a strong correlation between the various parameters considered for study for both the lakes. High turbidity was found to be positively correlated to EC and COD which indicated a heavy amount of soil erosion from watershed areas and along lake banks which led to input of heavy sediments into lakes. Further, a strong correlation was observed between pH, Ca, Mg, HCO_3, SO_4, TA and TH which indicated an increase in alkaline nature of water due to high TA increasing the pH values. Concentrations of Ca, Mg, HCO_3 and SO_4 indicated leaching of minerals from

nearby sedimentary rocks leading to formation of $CaSO_4$, $CaHCO_3$, $MgSO_4$ and $CaSO_4$ thereby increasing the hardness of water. The strong correlation between TP, NO_3 and BOD revealed that the organic content in the lakes was contributed by increased agricultural and irrigational activities in the vicinity which led to increased TP and NO_3 concentrations in lake waters promoting slight eutrophication.

- The PCA analysis revealed different principal components of pollution sources in both the lakes. Six major components were determined in both the lakes respectively. The total cumulative variance for components of Lake 1 and 2 were determined to be 89.32 % and 95.14% respectively. The principal components determined for lake 1 showed maximum variance for parameters TA, HCO_3, pH, DO, Temperature EC, Turbidity, COD, TP SO_4, Ca, TH and Cl. Lake 2 exhibited principal components for parameters such as BOD, EC, HCO_3, NO_3, TA, Temperature, SO_4, COD, TP, TDS, TSS, TH, Na, Cl, Ca, TH; representing maximum variances. These components were seen to have a deteriorating effect on the existing water quality in lakes.
- The HCA analysis was used for determining the parameters or sites related to source contamination by grouping them together into clusters depicting similar characteristics and effects. Lake 1 exhibited 15 sites with parameters such as DO, pH, Turbidity, NO_3, K, Temperature, Cl, Mg, COD, SO_4, TP, BOD, Na, Ca, TSS contributing to low pollution and 5 sites with parameters such as TDS, TH, TA, HCO_3, EC contributing to moderate pollution levels. Lake 2 exhibited 15 sites with parameters such as NO_3, TP, BOD, K, DO, pH, Mg, Temperature, Turbidity, Na, Cl, COD, SO4, Ca, TSS contributing to low pollution and 5 sites with parameters such as TDS, TH, TA, HCO_3, EC contributing to moderate pollution levels in lake 2 respectively.
- The National Sanitation Foundation Water Quality Indexing (NSFWQI), determined the water quality of both the lakes to be categorized as *'Good'* for the entire monitoring campaign with NSFWQI values varying between '71-90'. The depth wise variation was visible throughout the year but the trend of decrease in water quality with depth was visible only for the months of August 2019 and October 2019, the rest of the months showed no variations due to seasonal and lockdown effects. Sampling carried out in June 2020 showed significant improvement in WQI due to onset of early monsoons.

- The Bureau of Indian Standards Water Quality Indexing (BISWQI) is based on comparison of water quality with standards prescribed by BIS 2012. The BISWQI determined for both the lakes were categorized as *‘Excellent’* for the overall monitoring conditions, the final values of BISWQI being less than ‘50’. The depth wise variation was not visible throughout the year. The WQI showed seasonal effects but the overall category remained *‘Excellent’*.
- The Modified Water Quality Index (MWQI) is a proposed WQI which aims at removing the problems of ambiguity, eclipsing and limitation in use of parameters. The MWQI determined the water quality of both the lakes to be in categorized as *‘Good’* for overall monitoring conditions with the value ranging between ‘71-90’. The results achieved for indexing was similar to that obtained for NSFWQI.
- The NSFWQI and MWQI categorized lake 1 and lake 2 in category *‘Good’* in comparison to BISWQI which categorized lake1 and lake 2 as *‘Excellent’*, also the depth wise variation was significant in NSFWQI and MWQI but was not significant in case of BISWQI. The difference in the categorization was dependent on parameters chosen, scale considered as well as the stringency in application of permissible parameter range, which was lower in BISWQI as compared to NSFWQI and MWQI.
- The overall Heavy Metal Index (HMI), determined for the water quality of Lakes 1 and 2 was categorized to be *‘Good’* and *‘Poor’* with the value ranging between ‘26-50’ and ’51-75’ respectively. The depth wise variations were observed throughout the year but no significant pattern was determined. The main reason attributed to the different categorization was lack of freshwater inflow in June 2020 leading to increase parametric concentrations in comparison to August 2019 which was marked by influx of freshwater during monsoons. Lake 2 would require certain degree of treatment for heavy metals before being utilized as a water source. The results achieved for MHMI were similar to that obtained for HMI.
- The overall TSI determined for both the lakes were categorized as *‘Eutrophic’* with different categories obtained for the three different TSI considered individually. The three TSI values were not similar to each other therefore algal growth is light or nitrogen limited and not phosphorous. Further, the Secchi disk transparency was affected by erosional silt particles and not by algae.

- The effect of seasonal variation was observed for both the lakes throughout the year. Sampling carried out in August 2019 and representative of Monsoon season marked inflow of freshwater and signified low parametric concentrations, while samples considered for October 2019 (Autumn) and February 2020 (Spring) exhibited slight overturning effects. December (Winters) marked stratification effects and June (Summer) marked low water influx and high parametric concentrations.
- The depth wise variation was observed at all the points throughout the depth in both the Lakes but with spill over effects observed at a few points for each WQI, the trend of variation was not uniform except for August 2019 and October 2019 for NSFWQI and MWQI throughout the sampling duration due to seasonal and lockdown effects.
- The results for the physico- chemical and heavy metal analysis for soil and sediments for both the lakes revealed that the parameters were well within prescribed limits and posed no threat to lake ecosystem and its surrounding catchment area. Physical properties of soil for lake 1 and lake 2 such as organic matter, texture and color were also determined and the organic carbon content and organic matter percentage for lake 1 and lake 2 were 0.19 % and 0.09 % were well within the prescribed limit of 0.5 % and thereby confirmed the soils to be low in organic content which was attributed to increased level of erosion of top soil.
- The spectral characterization technique of SEM revealed the morphological structure of soil for both lakes to be representative of clay with flaky, rounded and agglomerated structure. The sediment structure for both the lakes were determined to have sharp edges, porous and flaky structure representative of sand. The water of both lakes at various depths revealed increased agglomeration of structure due to an increase in density of water with depth.
- The micrographs of EDS showed presence of large number of common elements in the soil, sediments and water of both the lakes which were further reconfirmed by the XRD graphs displaying sharp peaks indicative of natural crystalline materials. Hence, it may be concluded that the source of the sediment in the lakes was due to the surrounding soil of the lakes.

- The soil, sediments and water of both the lakes reported high proportions of Oxygen (O), Carbon (C), Tantalum (Ta), Silica (Si), Tungsten (W) and Niobium (Nb) along with other elements and transition metals. The presence of natural elements along with rare earth metals like Tantalum and Niobium (metals derived from same ore) have not been studied and reported sufficiently but they do not cause any lasting environmental effects. Further, it may be concluded that since both these elements are derived from same the ore and have been recognized in soils, sediments and water of both the lakes, it reveals that the formation of sediments in the lake is highly correlated with the erosion of the soil in the banks and surrounding areas of the lakes.
- The values of Sediment Quality Index (SeQI) indicated the sediments of both the lakes were of *Excellent* category and free from any harmful contaminants thereby not posing any threat to environmental, lake ecosystem and surrounding areas nearby.
- The BIS WQI interpolated through IDW method for the entire year at different depths for both the lakes categorized them to be '*Excellent*' and therefore could be used as potable source of water for nearby areas. However, some preliminary treatment like disinfection should be done to avoid the effect of any pathogens.
- The temperature was observed to decrease with increase in depth for all seasons at all of the sampling points at different depths for both the lakes due to reduced amount of sunlight intensity reaching the greater depths of the lake and also due to presence of vegetation surrounding the lakes. The seasonal variations in temperature revealed higher temperatures in monsoon in than summer due to low water levels causing high turbidity in summers which induces scattering of the sunlight rays by turbid particles reducing overall temperatures.
- The concentration of DO were observed to have a decreasing trend with depth for all seasons at all sampling points and depths for both lakes due to reduced amount of sunlight reaching the depths leading to low photosynthetic activities causing low oxygen saturation in depths. The seasonal variations in DO show high concentrations in Winters as compared to Summer and Monsoon seasons. In particular, the parameters of temperature and DO are inversely related and therefore higher concentration of DO is observed in Winters due to lower temperatures than any other season, especially Monsoon.

- The NO_3 concentrations showed no depth wise variation for all seasons at all of the sampling points and depths for both lakes. The seasonal variations in NO_3 concentrations revealed high levels in Winters with reductions till Summer for both the lakes. This is attributed to high levels of DO concentrations which favours nitrification in lakes rather than ammonification leading to increased concentrations in Winters. The high values even in intermediate region for both the lakes were mainly due to lack of input of freshwater due to end of Monsoon and starting of Winters leading to a low or no dilution in the lake along with no mixing conditions and stratification levels. The various chemical reactions amongst them at different stages and their interdependency among each other does not follow any significant behavioural patterns.
- The TP concentrations showed no depth wise variation for all seasons at all sampling points and depths in both lakes. The seasonal variations in TP revealed higher concentration levels in Winters than Monsoons and Summer. The loss of TP from water column in Monsoon season due to overflowing and settlements into sediment beds in Summer season due to low level of water in lakes might be the possible causes. The haphazard patterns in case of TP were due to no influx of fresh water leading to increased concentrations of parameters for Winter and Summer seasons along with their corelation and interdependencies among each other in comparison to monsoon.
- The problems at study sites such as heavy sedimentation due to constant erosion from banks and watershed areas due to deforestation along with expansion of agriculture can be remediated by use of physical techniques like dredging, vegetative buffers and riparian zone stabilization. These methods are highly proven for removal as well as prevention of heavy sedimentation in lakes. The dredging activities can be used once a month for removal of already existing sediments from bed of the lakes whereas growing of native vegetation along the banks can prove to be successful technique in binding of soil particles together to avoid further sediment inputs into the lakes along with promotion of infiltration into water tables.
- The chemical methods such as use of alum in optimum dosage can be used successfully for removal of turbidity and nutrients, at a near neutral pH range (6-8) of lake waters by flocking of sediments. The above mentioned physico-chemical techniques can be

combined together for achieving improved and more stable results of remediation. The biological remediation techniques such as use of aquatic plants and animals could be beneficial for eutrophication control and restriction of nutrient concentrations in lake waters.

- The lakes can be considered as a fresh water source and the water can be utilized for drinking purpose but with suitable treatment therefore a water treatment unit can be considered to be a necessity at the place. Therefore, the design of a small-scale water treatment unit was proposed and has been added in APPENDIX -A, which if implemented could be beneficial for the population of the nearby villages during water scarcity and also supply water to the villages.

9.3 Future scope of the work

1. The sampling and testing can be carried out for entire 12 months duration to give a more elaborative insight by determination of water quality for the entire year.
2. The results for SEM, EDS and XRD of water, soil and sediment samples can be evaluated and compared to represent any seasonal variations.
3. Improved computational techniques such as Fuzzy logic approach, application of AI and ML, use of sensors and IOT based systems could also be used for prediction and interpretation of water quality parameters if continuous sampling is not possible.
4. The proposed remediation techniques could be implemented at the sites to analyze the best possible technique of remediation and for further improvement of water quality status.
5. The prototype design for small scale water treatment plant can also be implemented at the site to utilize the lake water for drinking for nearby population.

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PUBLICATIONS

Journal Publications

1. Vasistha, P., & Ganguly, R., *"Assessment of spatio-temporal variations in lake water body using indexing method",* Environmental Science and Pollution Research, 27(33), 41856-41875, 2020. **(Springer Publications, Scopus/SCI Indexed).**

2. Vasistha, P., & Ganguly, R., *"Spectral characterization of sediment of two lake water bodies and its surrounding soil in Haryana, India",* Arabian Journal of Geosciences, 14(1), 1-18, 2021. **(Springer Publications, Scopus/SCI Indexed).**

3. Vasistha, P., & Ganguly, R., *"Water Quality Assessment in Two Lakes of Panchkula, Haryana using GIS: Case study on Seasonal and Depth wise variations",* Environmental Science and Pollution Research, available online, https://doi.org/10.1007/s11356-022-18635-y, 2022. **(Springer Publications, Scopus/SCI Indexed, Accepted).**

Book Chapters

1. Vasistha, P., & Ganguly, R., *"Water Quality and Designated Best Use (DBU) Determination of Bhim Taal Lake of Panchkula, Haryana",* In Water Security and Sustainability: Proceedings of Down To Earth 2019, Springer Singapore, pp. 43-50, 2021.

2. Vasistha, P., & Ganguly, R., *"Effective Remediation Techniques for Twin Shallow Lakes in Panchkula, Haryana",* In Advances in Construction Materials and Sustainable Environment, Springer, Singapore, pp 953-971, 2022.

Conference Proceedings

1. Vasistha, P., & Ganguly, R., *"Water quality assessment of natural lakes and its importance: an overview"*, Materials Today: Proceedings, 32, 544-552, 2020.

2. Vasistha, P., & Ganguly, R., *“Water Quality and Designated Best Use (DBU) Determination of Draupadi Taal Lake of Panchkula, Haryana”,* In Roorkee Water conclave: Theme Concepts and Abstracts Roorkee Water Conclave 2020, Springer Singapore, pp. 182, 2020.

APPENDIX-A

LIST OF SUPPLEMENTARY TABLES

Table A1 : Determined value of different parameters for the month of August 2019 for Lake 1 at different depths

Parameters	S1(a) (a=2m)	S1(b) (b=3m)	S1(c) (c=4m)	S2(a) (a=2m)	S2(b) (b=3m)	S2(c) (c=4m)	S3(a) (a=2m)	S3(b) (b=3m)	S3(c) (c=4m)	S4(a) (a=2m)	S4(b) (b=3m)	S4(c) (c=4m)
DO	7.33	5.23	1.75	3.18	2.16	2.90	3.80	2.79	2.76	4.14	3.06	2.12
pH	8.1	7.6	6.7	7.2	6.8	6.9	7.5	7.2	7.1	7.3	7.2	6.7
Temperature (°C)	30.7	30	29.1	30.4	30.3	29.8	29.1	28.8	28.5	29.7	29.7	28.4
EC(µmhos/cm)	262	260	264	255	256	256	260	258	262	248	245	252
TDS	112	136	144	127	126	128	130	128	130	126	124	132
Turbidity (NTU)	2	3	14	15	15	22	12	12	12	10	14	19
TA	162	160	190	164	170	174	162	180	166	166	174	176
Ca	40.03	37.63	38.43	28.82	28.82	32.83	32.33	35.23	32.83	29.62	44.03	49
Mg	8.26	6.80	10.20	13.60	11.66	11.66	15.55	13.60	13.12	13.12	8.26	15.04
Cl	15.99	11.99	18.99	11.99	9.99	18.99	12.0	13.99	12	9.99	12	16.99
NO_3	0.65	0.18	0.31	0.31	0.86	0.82	0.60	0.61	0.99	0.84	0.59	1.2

TSS	112	136	144	127	126	128	130	128	130	126	124	132
SO_4	53.77	51.37	50.79	51.79	51.12	49.8	48.49	49.28	51.99	48.24	34.20	26.86
HCO_3	162	160	190	164	170	174	162	180	166	166	174	176
BOD	0.2	0.2	0.1	0.3	0.2	0.6	1	0.4	0.1	0.1	0.2	0.3
COD	8.0	8.0	4.0	8.0	18.0	12.0	24	12	4	4	8	12
TP	0.035	0.182	0.099	0.032	0.064	0	0.23	0.014	0.104	0	0	0
TH	134	122	138	128	120	130	144	145	136	128	144	184
FC (coliforms per 100 ml)	0	0	0	0	0	0	0	0	0	0	0	0
Zinc	67	21	29	21	19	32	73	0	0	33	0	0
Iron	18.1	98	73	131	42.1	43	33.4	11	29	17	131	23
Arsenic	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Cadmium	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Mercury	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Chromium	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Lead	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Nickel	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Copper	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Pesticides-Alpha BHC	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Beta BHC	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Gama BHC	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Lindane	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
OP-DDT	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
PP-DDT	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Alpha Endosulphan	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Beta Endosulphan	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Aldrin	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Malathian	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Methyl Parathian	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Anilophos	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Chlorpyriphos	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

[Note: Concentrations of Physico-Chemical parameters are in (mg/L), Heavy Metals and Pesticides are in (µg/L)**]**

Table A2 : Determined value of different parameters for the month of October 2019 for Lake 1 at different depths

Parameters	S1(a) (a=2m)	S1(b) (b=3m)	S1(c) (c=4m)	S2(a) (a=2m)	S2(b) (b=3m)	S2(c) (c=4m)	S3(a) (a=2m)	S3(b) (b=3m)	S3(c) (c=4m)	S4(a) (a=2m)	S4(b) (b=3m)	S4(c) (c=4m)
DO	7.61	6.33	6.3	5.73	4.96	4.66	7.72	6.74	5.16	6.57	5.51	5.39
pH	7.5	6.9	7.1	6.7	6.3	6.5	7.4	7.0	7.0	6.9	6.8	6.5
Temperature (°C)	25.1	25	24.9	25.3	25.2	25.3	25.3	25.3	25.5	25.2	25.3	25.1
EC(µmhos/cm)	291	274	271	264	265	267	262	240	294	275	276	280
TDS	200	170	164	145	144	125	111	85	195	111	85	195
Turbidity (NTU)	2	9	10	5	3	4	3	15	9	1	2	3
TA	164	163	191	164	170	174	168	182	163	167	175	178

Ca	39.32	41.43	40.3	28.82	28.82	32.83	34.82	36.5	33.12	29.62	45.01	51.2
Mg	7.54	9.24	12.82	13.6	11.66	11.66	13.12	14.14	15.55	15.16	10.55	16.54
Cl	11.99	15.99	18.99	11.99	9.99	18.99	12.97	11.97	20.95	12.97	12.97	15.96
Nitrates	0.671	0.180	0.304	0.303	0.885	0.840	0.611	0.626	2.30	3.375	0.566	1.477
TSS	200	170	164	145	144	125	85	95	195	171	189	175
SO_4	55.1	53.33	52.75	51.79	51.12	49.8	53.79	51.29	50.16	56.92	36.7	29.82
HCO_3	164	163	191	164	170	174	168	182	163	167	175	178
BOD	3.0	2.8	2.4	2	2	3.6	0.8	0.1	3.8	0.8	0.1	3.8
COD	44.0	32.0	36.0	20.0	20.0	40.0	16	4	48	12	28	24
TP	0.072	0.066	0.061	0.084	0.086	0.840	0.045	0.500	1.994	0.148	0.122	0.103
TH	141	129	153	138	127	140	141	149	150	137	156	196
FC (coliforms per 100 ml)	0	0	0	0	0	0	0	0	0	0	0	0

[Note : Units are in mg/L**]**

Table A3 : Determined value of different parameters for the month of December 2019 for Lake 1 at different depths

Parameters	S1(a) (a=2m)	S1(b) (b=3m)	S1(c) (c=4m)	S2(a) (a=2m)	S2(b) (b=3m)	S2(c) (c=4m)	S3(a) (a=2m)	S3(b) (b=3m)	S3(c) (c=4m)	S4(a) (a=2m)	S4(b) (b=3m)	S4(c) (c=4m)
DO	8.67	8.52	8.4	8.63	8.8	8.74	8.29	8.28	8.1	8.52	8.46	8.5
pH	8.06	8.47	8.07	8.16	7.83	8.15	7.83	8.16	7.34	8.13	8.25	8.17
Temperature (°C)	16.8	16.7	16.5	16.4	16.3	16.2	16.1	16	15.9	16.3	16.2	16.1
EC(µmhos/cm)	272	266	276	254	264	267	274	264	304	8.52	8.46	8.5
TDS	170	164	172	156	163	166	170	162	180	158	168	163
Turbidity (NTU)	3.5	5.4	43.6	18.2	17.6	19.1	23.15	32.9	53.46	7.1	5.7	9.2
TA	110	120	70	110	80	80	90	80	80	80	80	80
Ca	49.64	51.24	44.83	53.64	54.44	56.84	44.03	44.83	68.05	44.83	55.24	54.44
Mg	22.35	16.03	15.06	12.63	15.55	9.72	17.98	17.98	7.77	18.46	12.63	22.84
Cl	1	5	6	6	5	5	5	1	5	7	7	5
Nitrates	0.78	0.77	0.78	0.74	0.74	0.75	0.78	0.77	0.89	0.78	0.81	0.77
TSS	20	15.5	25.3	14	20	25	10	20	28	10	15	25

SO_4	14.84	14.98	13.72	12.32	12.56	12.72	15.85	15.98	16.84	12.14	12.72	12.28
HCO_3	110	120	70	110	80	80	90	80	80	80	80	80
BOD	0.4	0.6	0.4	0.4	0.3	0.4	0.8	0.5	22	0.6	0.4	0.3
COD	56	52	52	36	40	44	84	44	308	56	56	48
TP	0.09	0.06	0.06	0.08	0.07	0.08	0.49	0.42	0.5	0.45	0.38	0.05
TH	216	194	174	186	200	182	184	186	202	188	190	230
FC (coliforms per 100 ml)	0	0	0	0	0	0	0	0	0	0	0	0
Sodium (Na)	56.29	54.51	55.57	54.73	53.98	54.01	56	56.11	56.59	57.21	57.61	57.82
Potassium (K)	1.28	1.33	1.32	1.30	1.29	1.39	1.42	1.44	1.32	1.42	1.40	1.33

[Note : Units are in (mg/L)**]**

Table A4 : Determined value of different parameters for the month of February 2020 for Lake 1 at different depths

Parameters	S1(a) (a=2m)	S1(b) (b=3m)	S1(c) (c=4m)	S2(a) (a=2m)	S2(b) (b=3m)	S2(c) (c=4m)	S3(a) (a=2m)	S3(b) (b=3m)	S3(c) (c=4m)	S4(a) (a=2m)	S4(b) (b=3m)	S4(c) (c=4m)
DO	9.91	8.93	8.23	9.38	8.09	6.87	9.74	8.03	5.68	9.64	7.83	6.97
pH	8.47	8.42	8.26	8.48	7.76	7.8	8.25	8.19	8.29	8.52	8.37	8.43

Temperature (°C)	16.8	17.3	17.4	18.9	16.9	17.5	17.5	18.4	18.1	20	18.7	18.5
EC(µmhos/cm)	347.6	374.7	381.6	383.6	408.1	417.8	383.5	390.64	408	383.1	387.8	389
TDS	180	184	196	198	195	198	192	192	197	197	195	192
Turbidity (NTU)	12.3	13.9	15.9	6.2	10.3	6.6	6.6	6.6	8.1	12.5	1	6.1
TA	240	240	260	260	240	200	260	200	200	200	200	200
Ca	56.04	24.02	24.02	16.01	16.01	20.02	38.42	43.23	64.05	26.42	36.03	22.42
Mg	7.29	13.61	27.7	36.44	34.01	35.47	27.7	13.61	12.15	26.42	36.03	22.42
Cl	70	30	30	40	40	20	20	60	40	20	40	30
TP	0.1	0.05	0.05	0.07	0.05	0.06	0.18	0.45	0.45	0.49	0.48	0
Nitrates	4.66	2.12	1.72	1.99	1.71	2.18	3.77	4.41	2.72	2.16	2.18	2.05
TSS	14	524	256	40	24	8	4	12	29.64	2	2	1.2
SO_4	34.73	49.6	41.76	48.24	42.57	43.79	38.65	45.68	55.95	34.73	28.24	34.06
HCO_3	240	240	260	260	240	200	260	200	200	200	200	200

BOD	12.3	13.9	15.9	1.43	1.24	1.35	1.5	1.12	2.45	1.8	1.5	2.01
COD	14	524	256	50.05	43.4	47.25	52.5	39.2	85.75	63	52.5	70.35
TH	170	216	174	190	180	196	180	164	210	174	196	204
FC (coliforms per 100 ml)	0	0	0	0	0	0	0	0	0	0	0	0

[Note : Units are in (mg/L)**]**

Table A5 : Determined value of different parameters for the month of June 2020 for Lake 1 at different depths

Parameters	S1(a) (a=2m)	S1(b) (b=3m)	S1(c) (c=4m)	S2(a) (a=2m)	S2(b) (b=3m)	S2(c) (c=4m)	S3(a) (a=2m)	S3(b) (b=3m)	S3(c) (c=4m)	S4(a) (a=2m)	S4(b) (b=3m)	S4(c) (c=4m)
DO	7.1	6.2	6	6.5	6	5.7	6.8	6.6	6	6.7	6.4	6.3
pH	8.3	7.5	7.3	8.1	7.7	7.4	8.2	7.9	7.3	8.2	7.9	7.2
Temperature (°C)	26.5	26	25.5	24.8	24.6	24.3	24.3	24.1	23.9	23.7	23.5	23
EC (µmhos/cm)	305	349	369	320	332	355	326	334	349	331	339	366
TDS	162	169	181	163	165	177	164	164	180	164	160	180
Turbidity (NTU)	10.1	8.2	6.7	7.7	7.1	11.2	7.6	8.5	11.2	8.7	8.8	11.6
TA	500	200	190	160	180	200	180	200	200	200	180	70

Ca	20.01	20.82	28.82	24.02	27.22	28.02	20.82	22.42	30.42	26.42	23.22	28.82
Mg	20.89	20.43	18.95	16.52	14.09	16.03	19.44	30.13	21.38	13.12	17.98	21.87
Cl	10	70	50	90	50	60	50	80	60	80	80	60
Nitrates	0.64	0.56	0.57	0.6	0.6	0.55	0.58	0.65	0.63	0.56	0.55	0.57
TSS	15	18	24	10	15	17	5	8	14	9	15	25
SO_4	33.78	34.19	27.03	32.03	28.92	26.89	28.24	35.68	31.35	35.68	32.16	30
HCO_3	500	200	190	150	180	200	160	200	200	180	180	70
BOD	1.3	1.5	1	1.1	0.4	8	0.7	3	1.9	1.1	0.8	2
COD	20	12	20	16	20	72	20	40	80	20	20	8
TP	0.05	0.05	0.03	0.03	0.02	0.02	0.01	0.07	0.03	0.02	0.02	0.02
TH	136	62	150	128	126	136	132	180	164	120	132	162
FC (coliforms per 100 ml)	0	0	0	0	0	0	0	0	0	0	0	0
Sodium(Na)	31.62	30.48	30.02	31.13	30.28	28.89	28.87	29.01	31.44	31.49	29.65	28.99

Potassium(K)	3.26	3.41	3.55	3.19	3.26	3.29	3.11	3.20	3.48	3.09	3.15	3.39
Zinc	40	44	74	49	205	3	61	72	373	18	7	4
Iron	912	861	698	518	904	200	252	992	2331	46	0	0
Arsenic	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Cadmium	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Mercury	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Chromium	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Lead	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Nickel	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Copper	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

[Note: Concentrations of Physico-Chemical parameters are in (mg/L), Heavy Metals are in (µg/L)**]**

Table A6 : Determined value of different parameters for the month of August 2019 for Lake 2 at different depths

Parameters	D1(a) (a=1m)	D1(b) (b=2m)	D1(c) (c=3m)	D2(a) (a=1m)	D2(b) (b=2m)	D2(c) (c=3m)	D3(a) (a=1m)	D3(b) (b=2m)	D3(c) (c=3m)
pH	7.41	7.3	7.2	7.1	7.3	7.5	7.3	7.4	7.3
DO	4.12	2.54	2.87	3.41	3.68	3.31	3.71	3.61	2.86
Temperature(°C)	27.9	27.8	27.7	28.7	28.6	28.2	29.4	29.5	29.5
EC(µmhos/cm)	201	134	137	132	129	131	145	145	151
Turbidity (NTU)	16	19	9.9	18.98	13.99	20	20	16.98	36.96
TDS	99	67	68	65	28	64	74	75	77
Nitrates	0.3	0.34	0.5	0.25	0.2	0.25	0.22	0.28	0.21
BOD	0.8	0.6	0.8	0.7	0.8	0.5	0.7	0.8	0.8
COD	25.6	24	28	28	32	32	32	80	48
Ca	37.63	37.63	26.42	24.82	26.42	25.62	33.63	40.03	24.82
Mg	8.26	5.83	5.34	3.88	4.86	4.86	7.29	5.34	4.86
Cl	17.99	16.98	9.99	18.98	13.99	20	16.98	36.96	15.98
HCO_3	100	98	108	94	96	96	124	142	84
SO_4	2.19	2.44	2.11	2.44	3.51	3.01	4	2.23	6.22
TA	100	98	108	94	96	96	124	142	84
TH	128	118	168	78	86	84	114	122	82
TP	0.035	0.037	0.032	0.032	0.032	0.064	0.043	0.045	0.061
TSS	99	67	68	127	65	28	74	74	37
FC (coliforms per 100 ml)	0	0	0	0	0	0	0	0	0

Zinc	45	75	32	51	39	61	55	31	23
Iron	43.5	48.7	55	29.2	27.1	30.6	38.4	37.63	30.4
Arsenic	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Cadmium	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Mercury	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Chromium	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Lead	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Nickel	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Copper	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Pesticides-Alpha BHC	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Beta BHC	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Gama BHC	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Lindane	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
OP-DDT	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
PP-DDT	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Alpha Endosulphan	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Beta Endosulphan	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Aldrin	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Malathian	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Methyl Parthian	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Anilophos	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Chlorpyriphos	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Table A7 : Determined value of different parameters for the month of October 2019 for Lake 2 at different depths

Parameters	D1(a) (a=1m)	D1(b) (b=2m)	D1(c) (c=3m)	D2(a) (a=1m)	D2(b) (b=2m)	D2(c) (c=3m)	D3(a) (a=1m)	D3(b) (b=2m)	D3(c) (c=3m)
pH	7.5	7.1	7.2	7.2	7.3	7.3	6.9	6.7	6.7
DO	6.16	6.66	6.01	6.28	6.55	6.64	6.31	5.8	5.18
Temperature(°C)	25.2	24.9	25.2	25.3	25.5	25.1	24.9	24.9	25.2
EC(µmhos/cm)	229.5	233.8	275.7	234.7	230.4	227	227.5	228.1	231.5
Turbidity (NTU)	7.3	12	18.02	5.4	10	14.4	2.4	11.3	14
TDS	110	120	102	115	117	110	112	113	118
Nitrates	0.29	0.33	0.48	0.22	0.26	0.22	0.2	0.26	0.2
BOD	0.6	0.4	0.2	0.6	0.4	0.4	0.6	0.4	0.3
COD	32	20	40	40	36	36	48	32	28
Ca	28.43	39.23	39.35	27.22	28.44	28.22	36.33	42.66	26.65
Mg	6.34	6.33	9.43	5	7.21	6.23	8.36	7.33	7.41
Cl	6.5	7	6	6	6	5.5	5.5	7	5.5
HCO_3	112	103	110	100	100	115	130	142	152
SO_4	3.12	3.18	3.89	2.9	3.45	3.86	5	5.05	6.88
TA	112	103	110	100	100	115	130	142	152
TH	97.1	124	137	101	96.1	125	125	137	97
TP	0.023	0.028	0.022	0.045	0.04	0.043	0.042	0.045	0.04
TSS	110	120	102	115	117	110	112	113	118

FC (coliforms per 100 ml)	0	0	0	0	0	0	0	0	0

[Note: Units are in mg/L)**]**

Table A8 : Determined value of different parameters for the month of December 2019 for Lake 2 at different depths

Parameters	D1(a) (a=1m)	D1(b) (b=2m)	D1(c) (c=3m)	D2(a) (a=1m)	D2(b) (b=2m)	D2(c) (c=3m)	D3(a) (a=1m)	D3(b) (b=2m)	D3(c) (c=3m)
pH	7.92	8.12	8.26	8.02	8.1	8.05	8.34	8.08	8.32
DO	8.82	8.8	8.94	9	8.92	8.64	8.68	8.61	8.44
Temperature(°C)	17.9	17.9	18.6	19.4	18.5	18.4	19.3	19.3	19.2
EC(µmhos/cm)	216	206	214	214	215	216	216	217	221
Turbidity (NTU)	12.4	5	45	6.7	11.4	6.1	2.2	29	11.7
TDS	133	126	130	126	136	134	130	132	138
Nitrates	0.72	0.77	0.74	0.74	0.72	0.77	0.76	0.72	0.8
BOD	0.1	0.8	0.1	0.3	0.2	0.6	0.4	0.1	1.3
COD	12	80	16	32	28	60	48	8	88
Ca	48.04	60.05	53.64	48.84	48.84	53.64	49.64	58.45	58.45
Mg	12.15	2.91	4.36	11.17	9.23	5.34	4.37	7.29	2.43
Cl	5	6	4	12	5	4	11	3	4
HCO_3	200	190	180	200	190	170	120	80	70
SO_4	1.98	2.14	2.22	2.14	2.56	2.87	2.87	2.65	2.56
TA	200	190	180	200	190	170	120	80	70
TH	170	162	152	168	160	156	142	176	156
TP	0.21	0.2	0.05	0.18	0.2	0.15	0.4	0.1	1.3
TSS	23.8	40.5	32.43	10	7	15	20	15	5
FC (coliforms per 100 ml)	0	0	0	0	0	0	0	0	0
Sodium(Na)	28.1	27.26	27.55	29.54	27.43	29.76	26.73	28.87	27.55

Potassium(K)	1.52	1.44	1.46	1.61	1.54	1.50	1.39	1.42	1.44

[Note: Units are in mg/L)**]**

Table A9 : Determined value of different parameters for the month of February 2020 for Lake 2 at different depths

Parameters	D1(a) (a=1m)	D1(b) (b=2m)	D1(c) (c=3m)	D2(a) (a=1m)	D2(b) (b=2m)	D2(c) (c=3m)	D3(a) (a=1m)	D3(b) (b=2m)	D3(c) (c=3m)
pH	8.27	7.93	8.09	8.1	7.28	8.1	8.15	8.37	8.27
DO	8.57	7.63	7.19	9.52	8.42	8.62	9.17	8.2	7.55
Temperature (°C)	14.7	14.3	14.2	14.3	14.3	13.8	13.9	13.9	13.6
EC(µmhos/cm)	302.6	331.6	307.2	293.5	303.5	295.5	293.2	291	296.5
Turbidity (NTU)	5.87	7	8.3	5.2	7.2	8.1	3.2	3.7	5.3
TDS	157	152	157	152	157	157	157	152	157
Nitrates	2.31	2.35	2.18	1.62	2.22	1.98	1.61	2.03	2.22
BOD	2.79	2.16	2.3	2.9	2	2.2	2.6	2.2	2.5
COD	65	56	58	80	60	58	75	64	78
Ca	45.64	58.24	52.04	44.04	48.04	64.85	40.03	42.43	50.44
Mg	11.18	32.56	21.87	26.72	15.06	6.32	14.58	17.98	17.98
Cl	50	30	30	60	90	50	30	40	40
HCO_3	200	200	200	200	200	200	230	200	180
SO_4	12.83	15	14.46	13.92	18.11	13.51	14.05	16.89	21.35
TA	200	200	200	200	200	200	230	200	180
TH	160	266	220	220	220	182	160	180	200
TP	0.12	0	0.01	0.13	0.14	0.11	0.04	0.14	0.18

TSS	20.4	37.28	29.84	6	4	6	14	12	2
FC (coliforms per 100 ml)	0	0	0	0	0	0	0	0	0

[Note: Units are in mg/L)**]**

Table A10 : Determined value of different parameters for the month of June 2020 for Lake 2 at different depths

Parameters	D1(a) (a=1m)	D1(b) (b=2m)	D1(c) (c=3m)	D2(a) (a=1m)	D2(b) (b=2m)	D2(c) (c=3m)	D3(a) (a=1m)	D3(b) (b=2m)	D3(c) (c=3m)
pH	7.9	7.2	7	7.9	7.2	6.9	7.7	7.2	
DO	6.8	6.5	5.1	6.8	5.2	5.2	6.2	5.2	5.1
Temperature(°C)	30.7	29.5	28.4	28	27.5	27	27.7	27.4	27.2
EC(µmhos/cm)	213	232	267	230	246	274	234	241	272
Turbidity (NTU)	14.1	15.6	15.5	48.3	25.6	2.3	24.2	30.9	18.3
TDS	123	129	141	122	127	149	123	129	145
Nitrates	0.64	0.55	0.6	0.68	0.74	0.65	0.73	0.56	0.7
BOD	12	5	12	2.4	2.6	7	8	2.6	5
COD	84	64	40	28	24	72	72	24	44
Ca	28.02	28.02	28.82	25.62	29.62	38.43	29.62	28.02	34.43
Mg	9.72	13.12	1.94	10.69	8.75	9.72	9.23	28.67	20.89
Cl	40	50	50	50	50	70	40	80	70
HCO_3	150	120	200	11.89	13.78	9.32	150	150	200
SO_4	10.95	14.19	5.41	80	250	250	2.43	1.22	4.05
TA	150	120	200	80	250	250	150	150	200
TH	110	124	80	108	110	136	112	188	134

TP	0.02	0.008	0.003	0.03	0.1	0.07	0.02	0.02	0.03
TSS	5	11	20	8	8	15	10	19	22
FC (coliforms per 100 ml)	0	0	0	0	0	0	0	0	0
Sodium(Na)	13.85	13.27	15.71	14.14	14.03	15.60	14.25	13.42	13.90
Potassium(K)	4.46	4.42	4.38	4.46	4.33	4.10	4.45	4.41	4.28
Zinc	151	75	93	58	44	144	60	98	63
Iron	638	509	1110	676	767	999	1127	380	1547
Arsenic	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Cadmium	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Mercury	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Chromium	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Lead	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Nickel	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Copper	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

[Note: Concentrations of Physico-Chemical parameters are in mg/L, Heavy Metals are in (µg/L)**]**

Table A11 : Rotated Component matrix for Lake 1

Rotated Component Matrix						
	Components					
	1	2	3	4	5	6
TA	0.94				-0.16	0.22
HCO_3	0.93	0.16		0.13		
pH	0.80	-0.40		-0.11		
DO	0.80	-0.42		-0.21		0.19
Temp.	0.71	-0.27	0.30	-0.40		
Mg	-0.65	-0.38	-0.50	-0.13	-0.27	
EC	0.14	0.85	0.17	-0.11	-0.40	0.21
Turb.	-0.36	0.81		0.12	-0.12	

COD		0.79		0.30	0.42	
TP			0.96		-0.16	
SO_4	0.15		0.93	-0.12	-0.22	
K	-0.33	0.50	0.54	0.48	-0.11	
Ca	0.13	0.25		0.86	0.26	-0.13
TH	-0.39		-0.33	0.83		
TSS			0.50	0.66	0.38	
TDS		0.39	0.40	0.59		0.47
NO_3	-0.23		-0.29		0.90	
Na	0.31	-0.23		0.40	0.73	
Cl	-0.13					-0.93
BOD	0.30	0.21	0.24	-0.20	-0.48	0.52
Eigenvalues	4.68	3.17	3.11	3.03	2.33	1.55
% of Variance	23.39	15.84	15.54	15.15	11.64	7.76
Cumulative %	23.39	39.23	54.77	69.92	81.56	89.32

Table A12 : Rotated Component matrix for Lake 2

Rotated Component Matrix						
	Component					
	1	2	3	4	5	6
BOD	0.95			-0.18	-0.25	
EC	0.87	-0.14	-0.13	0.14	0.39	0.11
HCO_3	0.79	0.38	0.12	0.15		-0.27
NO_3	0.76			0.45	0.25	
Cl	-0.70		-0.14		0.22	0.59
TA	0.18	-0.87	0.26		-0.18	
Temp.		0.81	0.13	-0.49	-0.12	-0.15
SO_4	-0.49	-0.79		-0.16	-0.11	0.19
Mg	-0.50	0.63	0.19	0.16	0.35	-0.31
K		0.62	0.58	-0.48		-0.11
COD			-0.90	0.13	-0.33	-0.15
TP			-0.90	-0.24	0.31	-0.10
TDS	0.54	0.21	-0.69	0.19		0.37
TSS	0.21	0.64	0.65		-0.16	-0.17
Ca	0.19		-0.11	0.97		
TH		0.23	0.41	0.82	0.30	
Turb.		0.29	0.17		0.91	0.16
DO	-0.34	0.11	0.39	-0.49	-0.69	
pH	0.19	0.27	0.23	-0.61	-0.64	0.13
Na		-0.40	0.13			0.87
Eigenvalues	4.40	3.85	3.45	3.16	2.55	1.62
% of Variance	22.01	19.27	17.27	15.78	12.74	8.08
Cumulative %	22.01	41.28	58.55	74.32	87.06	95.14

Table A13: Average Weight and Relative Weight for MWQI derived based on Scientific Literature

Parameters	Assigned Weight (AW)	Relative weight (RW)
pH	1	0.05
Electrical Conductivity (EC)	1.78	0.09
Dissolved Oxygen (D.O.)	2.85	0.14
Turbidity	1.09	0.05
Total Dissolved Solids (TDS)	1.79	0.09
Nitrate (NO_3)	2.32	0.12
Biological Oxygen Demand (BOD)	1.72	0.09
Chemical Oxygen Demand (COD)	1.16	0.06
Calcium(Ca)	0.80	0.04
Magnesium (Mg)	0.72	0.04
Chloride (Cl)	1.28	0.06
Bicarbonate (HCO_3)	0.36	0.02
Sulphate (SO_4)	1.60	0.08
Total Alkalinity (TA)	0.56	0.03
Total Hardness	1.11	0.05
	$\sum_{i=1}^{n} AW = 20.14$	$\sum_{i=1}^{n} RW = 1.00$

Table A14 : Parameters for calculation of TSI for Lake 1

Months	TP(µg/L)	SD (m)	CHl-a (µg/L)
August 2019	73	0.52	0.948
October 2019	87	0.625	0.849
December 2019	278	0.40	0.529
February 2020	210	0.45	0.772
June 2020	28	0.57	1.025
Average Yearly	**135.2**	**0.513**	**0.825**

Table A15 : Parameters for calculation of TSI for Lake 2

Months	TP(µg/L)	SD (m)	CHl-a (µg/L)
August 2019	37	0.235	3.792
October 2019	37	0.41	2.783
December 2019	94	0.275	1.039
February 2020	97	0.39	1.211

June 2020	8	0.28	2.015
Average Yearly	**54.6**	**0.318**	**2.168**

Table A16: Physico-chemical parameters and pesticide determination for soil and sediment samples of Lake 1 and Lake 2

		Lake 1		Lake 2			
S.No.	Parameter	Soil	Sediments	Soil	Sediment	Method Used	Suitable Range
1.	Texture	Clay	Fine sand	Clay	Fine sand	Hydrometer	None
2.	Colour	5YR63 (Dull Orange)	7.5YR51 (Brownish Grey)	7.5YR64 (Dull Orange)	5YR51 (Brownish Grey)	Munsell System	None
3.	pH	7.72	7.82	7.70	8.3	USEPA 1998, 9045 D	pH>7 (Alkaline) pH<7 (Acidic)
4.	Organic Matter %	0.34	0.68	0.16	0.24	APHA 2540, Edition 23, 2017	-
5.	Organic Carbon (%)	0.19	0.39	0.09	0.14	USDA Soil Method Manual, 1996 & 2014	<0.5% (low), 0.5%- 7.5% (medium), >7.5% (high)
6.	Cation Exchange Capacity (meq./100g)	17.2	11.7	12.3	8.6	USDA Soil Method Manual, 1996 & 2014	5 (sandy soils)-15 (high organic content soils)
7.	Phosphorous (mg/kg)	15.7	8.6	14.6	7.6	USDA Soil Method Manual 1996 & 2014	<10 (low), 10-24.6 (medium), >24.6 (High)
8.	Nitrate Nitrogen (mg/kg)	162	86	165	82	USDA Soil Method Manual 1996 & 2014	<96 (low) 96-192 (medium), >192 (high)
9.	Sulphur (mg/kg)	8.6	4.5	7.2	4.8	RC 353.08	<2 (very Low), 2-5 (Low) 5-20

							(Medium), >20 (High)
10.	Calcium (mg/kg)	106	250	40	216	USDA	Only considered Low for pH<4
11.	Magnesium (mg/kg)	56	95	18	105	USDA	<60 (low) 60-300 (medium) >300 (High)
12.	Chloride (mg/kg)	15	10	10	40	USDA Soil Method Manual 1996 & 2014	0-5 (very low) 5-10 (low) 10-20 (medium) 20-50 (high) >50 (Excessive)
13.	Aluminium (mg/kg)	0.04	0.02	0.03	0.03	USEPA 1640 & Oxide Conversion Chart	-
14.	Silica (%)	31.5	63.5	28	66.9	APHA 4500 SiO_2 C G 23rd Edition, 2017	-
15.	Alpha BHC (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
16.	Beta BHC (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
17.	Gamma BHC (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C,	Not Available

						23 rd. edition 2017	
18.	Lindane (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
19.	OP DDT (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	< 0.01 mg/kg
20.	PP DDT (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	< 0.01 mg/kg
21.	Endosulphan (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	< 0.0004 mg/kg
22.	Beta Endosulphan (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	< 0.0004 mg/kg
23.	Aldrin (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	< 0.00003 mg/kg
24.	Malathion (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C,	< 0.19 mg/kg

						23 rd. edition 2017	
25.	Methyl Parathion Anilophos (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
26.	Chlorpyriphos (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	0.03 mg/kg
27.	Chlordane (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
28.	DDD (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
29.	DDE (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
30.	Dieldrin (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available

31.	Endrin (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
32.	Heptachlor epoxide (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
33.	Nonylphenol (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
34.	2-Methyl (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
35.	Acenaphthene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
36.	Acenaphthylene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
37.	Anthracene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available

38.	Benza anthracene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
39.	Benza pyrene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
40.	Chrysene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
41.	Dibenza anthracene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
42.	Fluoranthene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
43.	Fluorene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
44.	Naphthalene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available

45.	Phenanthrene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
46.	PCB1254 (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
47.	tPCB (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
48.	PCDD/F (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available
49.	Toxaphene (mg/kg)	Not Detectable	Not Detectable	Not Detectable	Not Detectable	APHA 6410 B & 6440 C, 23 rd. edition 2017	Not Available

Table A17 (a): Determined parameters for the sediments of Lake 1 and Lake 2 for Freshwater ISQG

Parameters (µg/Kg)	Lake 1	Lake 2
Arsenic	0	0
Cadmium	0	0
Chromium	57.6	20.6
Copper	0	0
Lead	52.5	63.0
Mercury	0	0
Zinc	161.2	104.1
Chlordane	0	0
DDD	0	0

DDE	0	0
DDT	0	0
Dieldrin	0	0
Endrin	0	0
Heptachlor epoxide	0	0
Lindane	0	0
Nonylphenol	0	0
2-Methyl	0	0
Acenaphthene	0	0
Acenaphthylene	0	0
Anthracene	0	0
Benza anthracene	0	0
Benza pyrene	0	0
Chrysene	0	0
Dibenza anthracene	0	0
Fluoranthene	0	0
Fluorene	0	0
Naphthalene	0	0
Phenanthrene	0	0
Pyrene	0	0
PCB1254	0	0
tPCB	0	0
PCDD/F	0	0
Toxaphene	0	0
TOC	0.1	0.4

Table A17 (b): Determined parameters for the sediments of Lake 1 and Lake 2 for Freshwater PEL

Parameters (µg/Kg)	Lake 1	Lake 2
Arsenic	0	0
Cadmium	0	0
Chromium	48.4	76.2
Copper	0	0
Lead	101.8	
Mercury	0	0
Zinc	232.5	138.3
Chlordane	0	0
DDD	0	0
DDE	0	0
DDT	0	0
Dieldrin	0	0
Endrin	0	0

Heptachlor epoxide	0	0
Lindane	0	0
Nonylphenol	0	0
2-Methyl	0	0
Acenaphthene	0	0
Acenaphthylene	0	0
Anthracene	0	0
Benza anthracene	0	0
Benza pyrene	0	0
Chrysene	0	0
Dibenza anthracene	0	0
Fluoranthene	0	0
Fluorene	0	0
Naphthalene	0	0
Phenanthrene	0	0
Pyrene	0	0
PCB1254	0	0
tPCB	0	0
PCDD/F	0	0
Toxaphene	0	0
TOC	0.1	0.4

Table A18: Coordinates of sampling points for Lake 1 and Lake 2 respectively

Sampling Points	Latitude (X)	Longitude (Y)
S1	30°39′28″ N	77°04′45″ E
S2	30°39′20″ N	77°04′46″ E
S3	30°39′21″ N	77°04′52″ E
S4	30°39′24″ N	77°04′49″ E
D1	30°39′38″ N	77°04′32″ E
D2	30°39′43″ N	77°04′31″ E
D3	30°39′39″ N	77°04′36″ E

Table A19: BIS WQI values at different sampling points at different depths for Lake 1

Sampling Points	**Values**
S1(a) 2m	43.28
S1(b) 3m	40.84
S1(c) 4m	41.68
S2(a)2m	41.18
S2(b) 3m	40.04
S2(c) 4m	40.49
S3(a) 2m	37.19

S3(b) 3m	41.6
S3(c) 4m	42.21
S4 (a) 2m	40.42
S4 (b) 3m	40.21
S4(c) 4m	41.54

Table A20: BIS WQI values at different sampling points at different depths for Lake 2

Sampling Points	Values
D1(a) 1m	33.91
D1(b) 2m	34.31
D1(c) 3m	33.76
D2(a)1m	32.93
D2(b) 2m	33.87
D2(c) 3m	33.39
D3(a) 1m	32.89
D3(b) 2m	34.83
D3(c) 3m	33.78

Design of Small Scale Water Treatment Unit

The lakes are freshwater source and can be utilized as a drinking water source but since the lakes experience effects of anthropogenic and natural activities therefore, the source needs to be employed to certain degree of treatment before utilizing it as a source of drinking water.

The water treatment unit has been designed according to the following preliminary conditions:

Population (Morni Tehsil= 15 villages) = $25{,}000\ People$ [272]
Per Capita Demand (Water) = $110 - 150\ LPCD$ [273: 274]

(**NOTE:** The design has not been evaluated from monetary aspects)

The water treatment unit comprises of the following Steps:
Step 1 : Intakes
Step 2 : Conduits
Step 3 : Pumping Units
Step 4 : Screening
Step 5 : Design of Sedimentation aided with Coagulation Tank
Step 6 : Filtration Unit
Step 7 : Disinfection Unit

Intakes, Conduits, Pumping Units and Screens

A simple submerged intake structure to support starting end of pressure conduits (Cast Iron, Steel and Galvanized Iron) to draw water.

The pipe is then taken to sump well from where water is lifted through pumps (low lift centrifugal pump), the top is covered with racks or coarse screen to avoid entry of any debris.

The pipe opening is kept 2 to 2.5 m above silt level to avoid entry of any silt. Generally the structure assembly is placed at deep levels in lakes.

The outlet pipes are fitted with high lift pumps to pump water to storage tanks for further treatment.

The Intakes, Conduits, Pumping Unit and Screens for water treatment unit has been shown in Figure B17 in APPENDIX-B.

Design of Sedimentation aided with Coagulation Tank

The sediment aided with coagulation tank has been designed for complete removal of sediments from lake waters. The design has been presented below:

Avg. daily consumption $= \text{Population} * \text{Per capita demand}$

$= 25{,}000 * 130 \text{ LPCD}$

$= 3.25 * 10^6$ L

Max daily demand = $1.8 * \text{Avg. demand}$

$= 1.8 * 3.25 * 10^6$ L

$= 5.85 * 10^6$ L

Quantity of water to be treated for duration of 4 hrs. = $5.85 * 10^6 L * {}^4\!/_{24}$

$= 0.975 * 10^3\ Cumecs$

Assuming,

Depth = $4\ m$

Area = $Capacity\ /Depth$

$= 0.98 * 10^3 Cumecs/_{4m}$

$= 243.75\ m^2$

~ $244\ m^2$

Also,

Plan Area = $B * L$

Assume width of Tank = 12 m

L = $Area/\ Width$

= $244\ m^2/12\ m$

= $20.33\ m$

Dimensions of Tank = $20.33\ m\ *\ 12\ m\ *\ 4\ m$

Provide Extra depth for sludge storage at starting end = 3 m

(slope 1 in 50)

Also,

At end Extra Depth = $Length/\ Slope$

= $20.33\ m/50$

= $0.40\ m$

Total Depth at end = $3 +\ 0.40$

= $3.40\ m$

Assume Free board to be kept =0.30 m above water

Design of Floc Chamber

In addition to Length of 20.33 m of Settling Tank, Floc Chamber is to be provided at entry

Assume,

Effective depth was considered to be half of depth in tank

Depth = $3.40/2$

= $1.70\ m$

Assume,

Period of Flocculation or Detention Period = $20\ min$

Capacity of Chamber = Flow required in 20 min

= ${}^{5.85 *\ 10^3 L * 20}\!/_{24 * 60}$

= $81.25\ Cumecs$

Plan Area =$Capacity/\ Depth$

= $81.25 m^3/1.70 m$

= $47.79\ m^2$

Since width = $12\ m$

Length = $Area/\ Width$

= ${}^{47.79}\!/_{12}$

=3.99 m

Length= 3.99 m

The Design of Floc Chamber for Water Treatment Unit has been shown in Figure B18 in APPENDIX-B.

Design of Filtration Unit

Assume,

3 slow sand filters with 1 unit stand by in series

Average daily consumption =$Population\ *\ Per\ Capita\ Demand$

$=\ 25{,}000\ *\ 130\ LPCD$

$=\ 3.25\ *\ 10^6$ L

Maximum daily demand = $1.8\ *\ Average\ daily\ consumption$

$=\ 1.8*\ 3.25\ *\ 10^6$ L

= $5.85\ *\ 10^6$ L

Rate of filtration = 140 LMH

Rate of filtration per day = $140 * 24\ LMH$

Total Surface Area of Filters Required = $Max\ Daily\ Demand/\ Rate\ of\ Filtration\ per\ day$

= $5.85 *\ 10^6 L \big/ 140 * 24$

$=\ 1741.07\ m^2$

2 main units = $Area\ /2$

= $741.07/2$

= $870.54\ m^2$

~ $244\ m^2$

Assume,

$L =\ 2B$

Area = $2B.B$

$B^2 =\ 870.54/2$

B = $20.86\ m$

L = $2B$

= $41.73\ m$

Therefore,

2 units each have Length = $41.73\ m$ and Breadth = $20.86\ m$ arranged in series.

Design of Disinfection Unit

Chlorine in form of Bleaching Powder is used for Disinfection which contains 30 % available Chlorine.

Therefore,

0.3 $ppm\ or\ mg/l$ of Chlorine is required for Disinfection.

Average daily consumption = $Population\ *\ Per\ Capita\ Demand$

$= 25{,}000\ *\ 130\ LPCD$

$= 3.25\ *\ 10^6$ L

Amount of Chlorine = 0.3 $Mg/D * 3.25\ *\ 10^6\ \mathrm{L/D}$

= $0.98\ *\ 10^6\ \mathrm{Mg/D}$

= 1 KGD

Chlorine in bleaching Powder = 30%

Therefore,

100 kg of Bleaching powder = 30 kg of Chlorine

Amount of Bleaching Powder required daily = $1 *\ {}^{100}\!/_{30}$

= 3.33 Kg

Annual Consumption of Bleaching Powder = 3.33 $*\ 365$

= $1215.45\ Kg$

= 1.21 t

APPENDIX-B

LIST OF SUPPLEMENTARY FIGURES

Figure B1 : Samples collected from Lake 1 and Lake 2 respectively

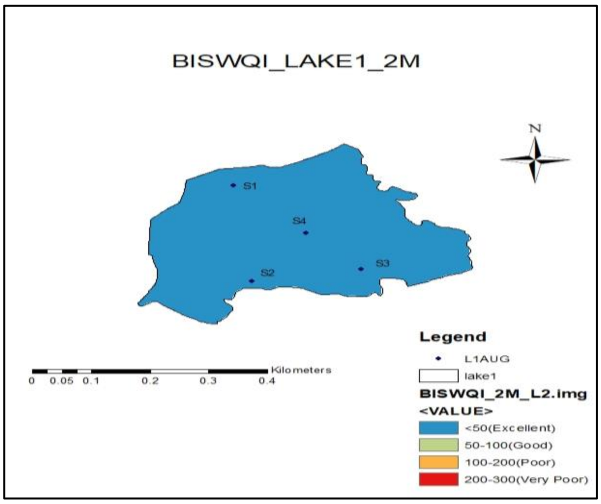


Figure B2(a): BISWQI at depth of 2m for Lake 1

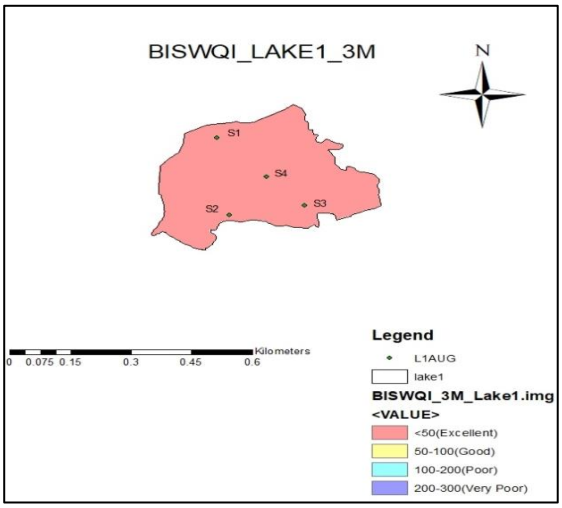


Figure B2(b): BISWQI at depth of 3m for Lake 1

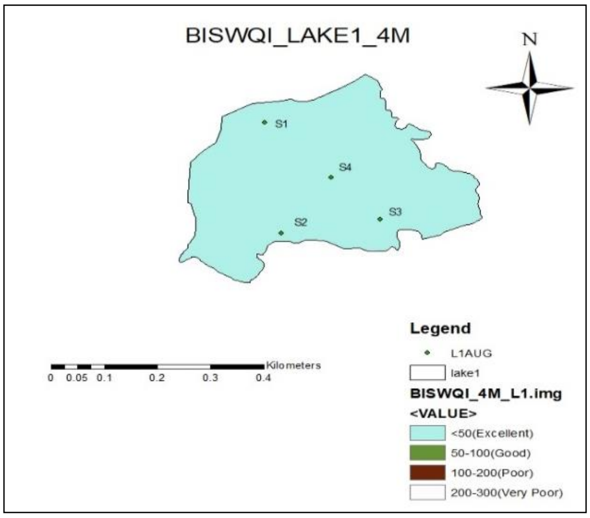


Figure B2(c): BISWQI at depth of 4m for Lake 1

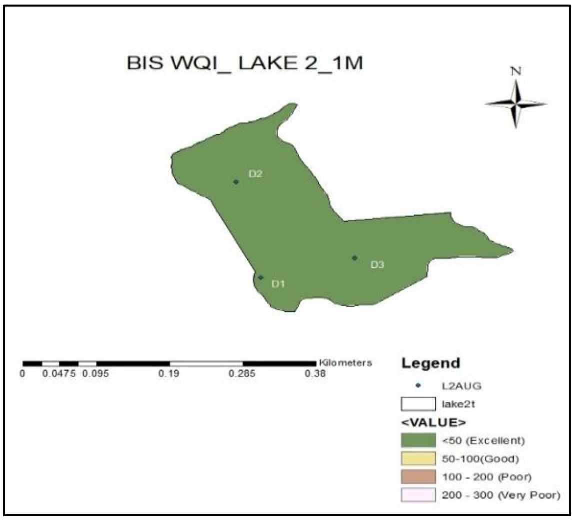


Figure B3(a): BISWQI at depth of 1m for Lake 2

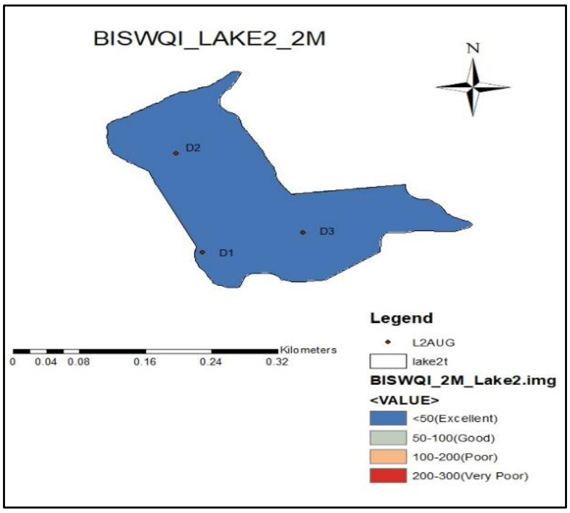


Figure B3(b): BISWQI at depth of 2m for Lake 2

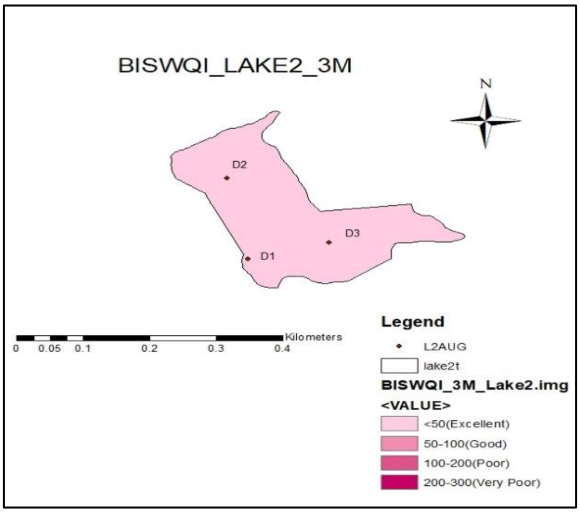


Figure B3(c): BISWQI at depth of 3 m for Lake 2

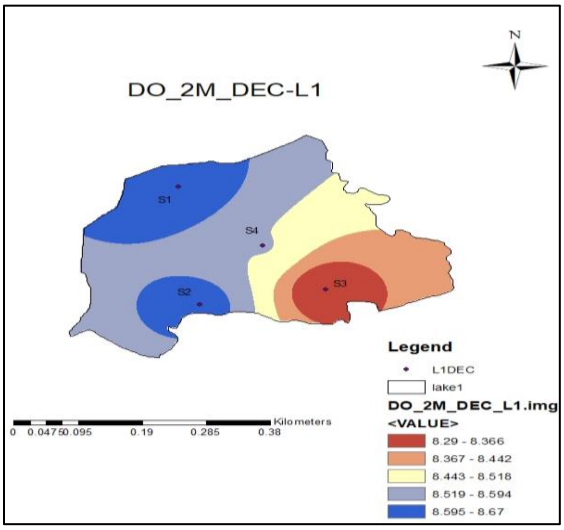


Figure B4(a): DO variation at 2m depth in Lake 1 for winter season

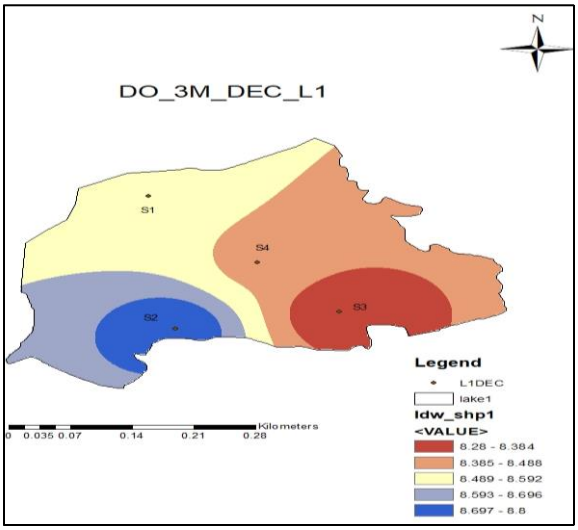


Figure B4(b): DO variation at 3m depth in Lake 1 for winter season

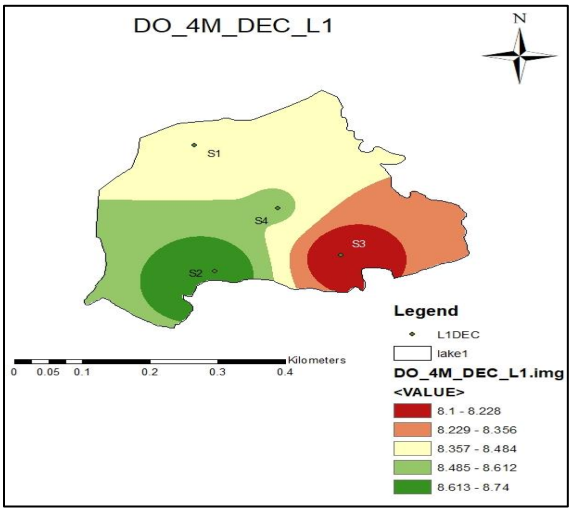


Figure B4(c): DO variation at 4 m depth in Lake 1 for winter season

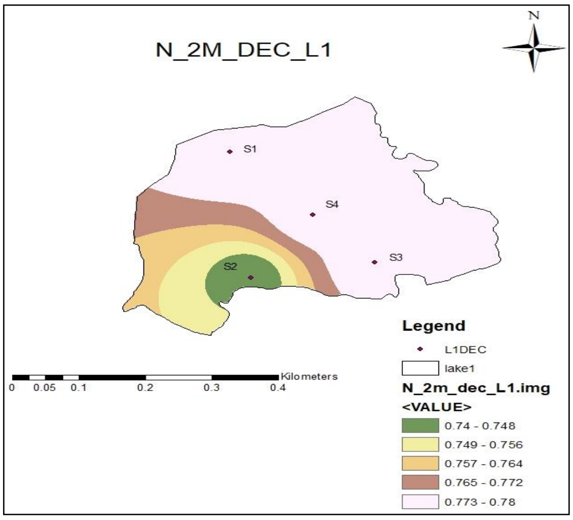


Figure B5 (a): NO_3 variation at 2m depth in Lake 1 for winter season

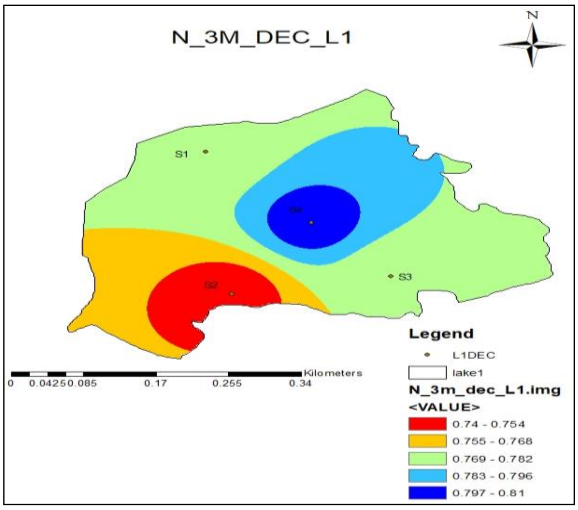


Figure B5(b): NO_3 variation at 3m depth in Lake 1 for winter season

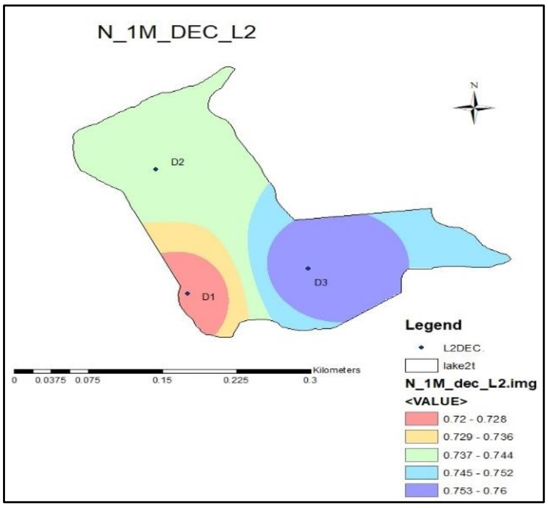


Figure B6 (a): NO_3 variation at 1m depth in Lake 2 for winter season

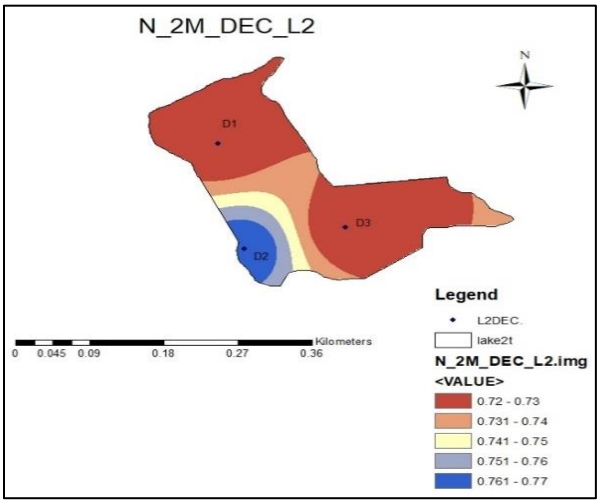


Figure B6 (b): NO_3 variation at 2m depth in Lake 2 for winter season

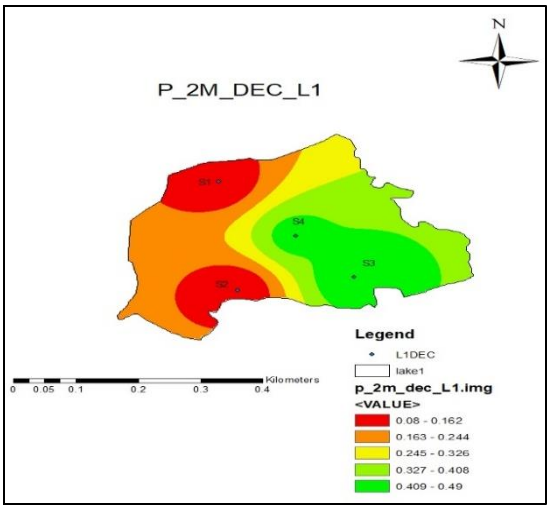


Figure B7 (a): TP variation at 2 m depth in Lake 1 for winter season

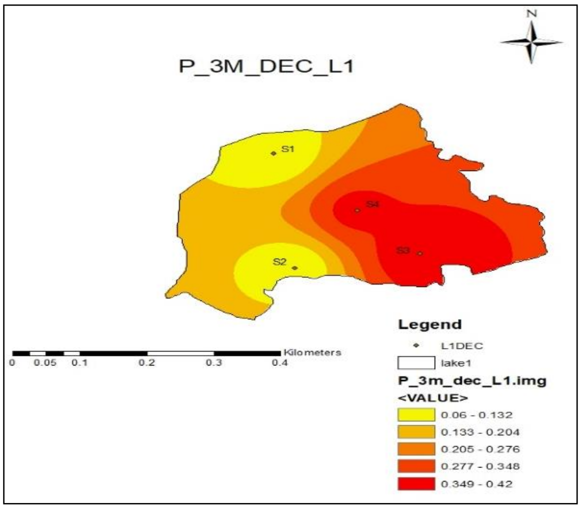


Figure B7 (b): TP variation at 3m depth in Lake 1 for winter season

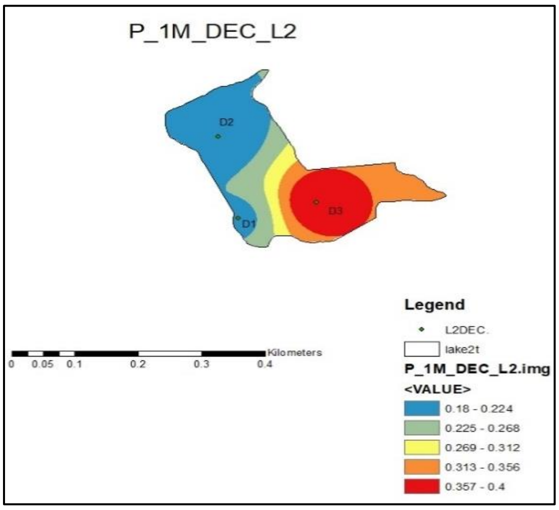


Figure B8 (a): TP variation at 1 m depth in Lake 2 for winter season

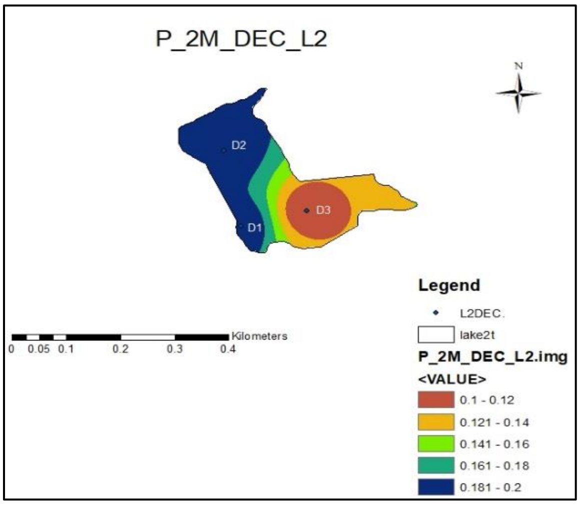


Figure B8 (b): TP variation at 2 m depth in Lake 2 for winter season

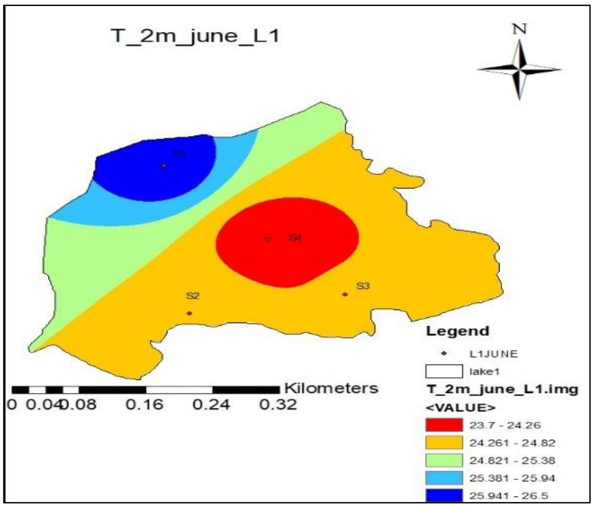


Figure B9 (a): Temperature variation at 2 m in Lake 1 for summer season

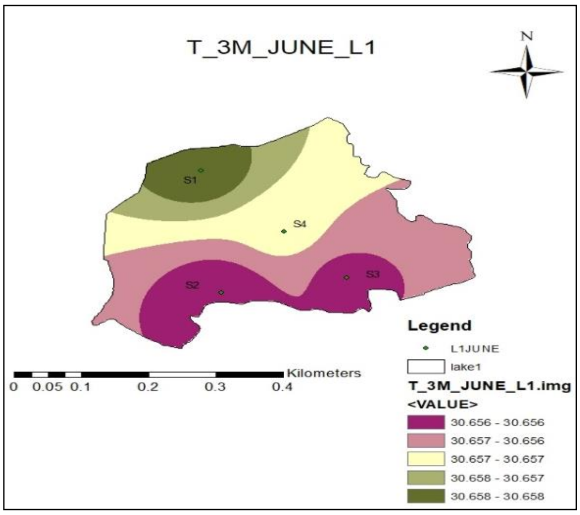


Figure B9 (b): Temperature variation at 3m depth in Lake 1 for summer season

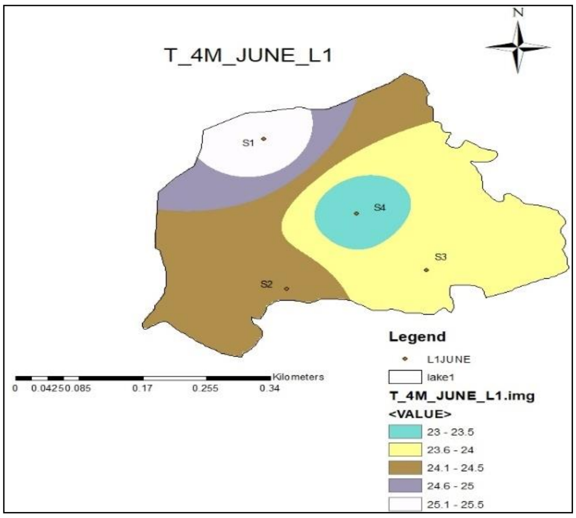


Figure B9 (c): Temperature variation at 4 m depth in Lake 1 for summer season

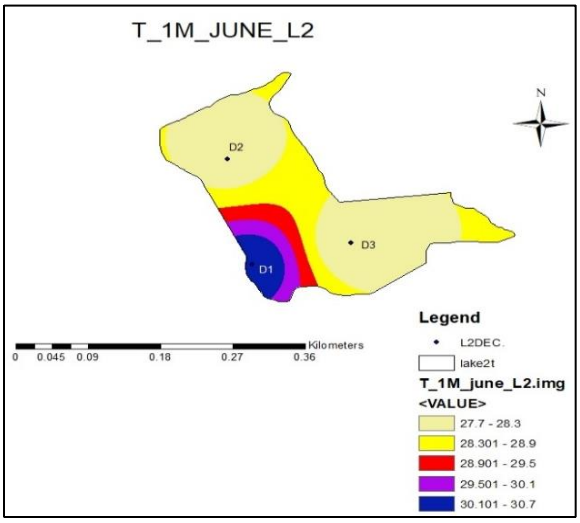


Figure B10 (a): Temperature variation at 1m depth in Lake 2 for summer season

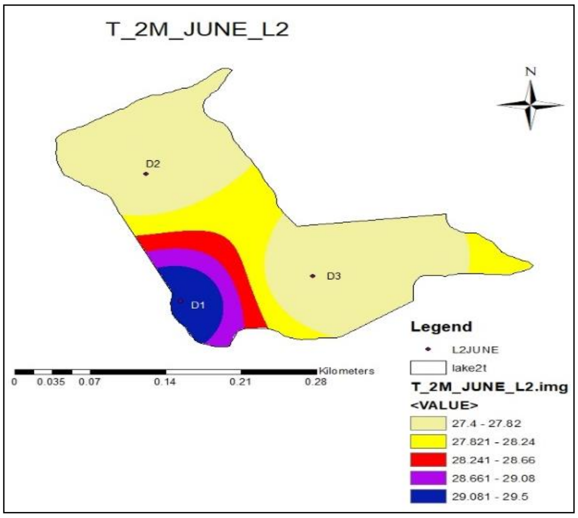


Figure B10 (b): Temperature variation at 2 m depth in Lake 2 for summer season

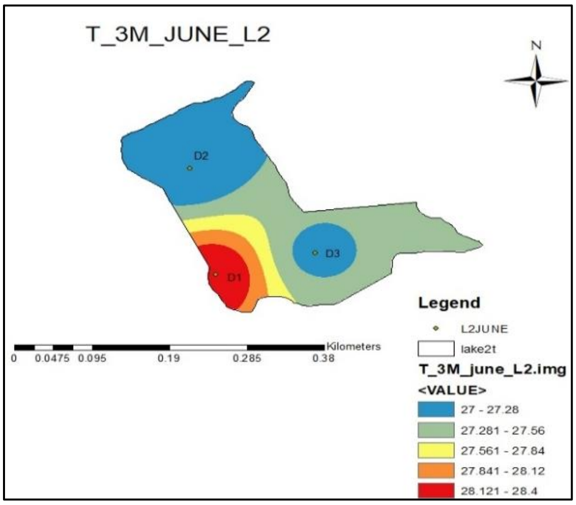


Figure B10 (c): Temperature variation at 3m depth in Lake 2 for summer season

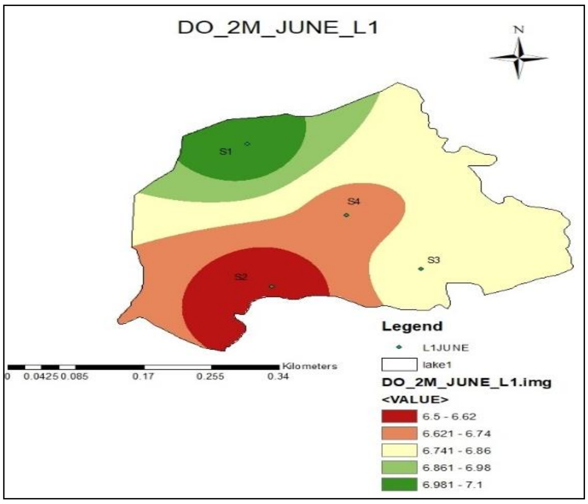


Figure B11 (a): DO variation at 2 m depth in Lake 1 for summer season

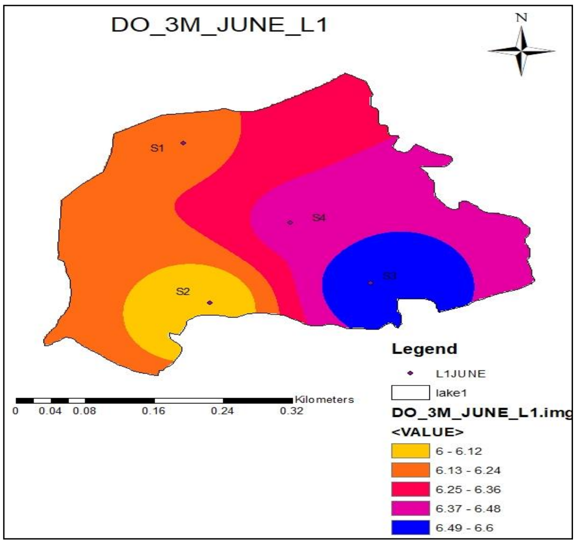


Figure B11 (b): DO variation at 3m depth in Lake 1 for summer season

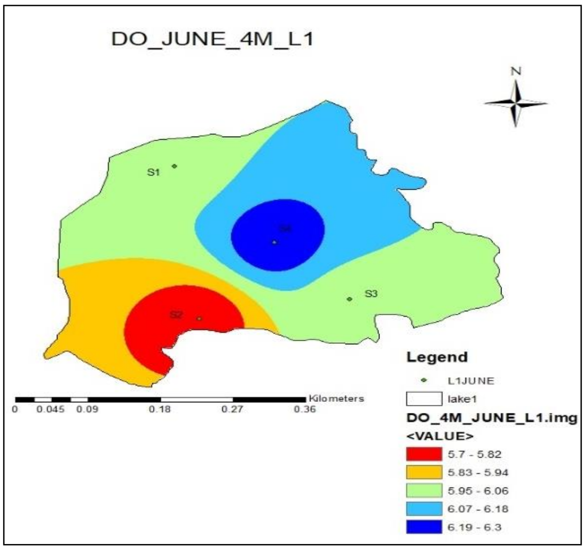


Figure B11 (c): DO variation at 4 m depth in Lake 1 for summer season

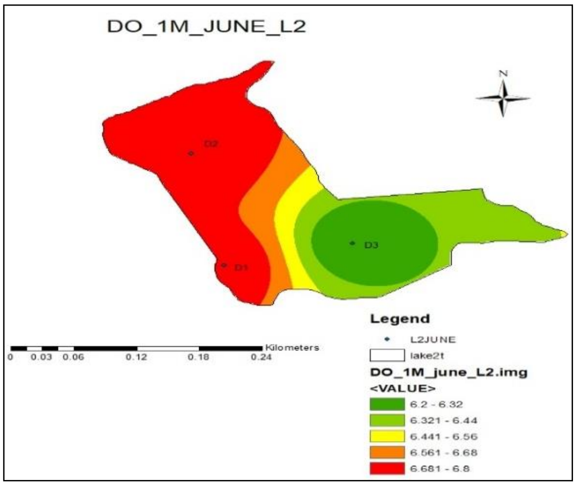


Figure B12 (a): DO variation at 1m depth in Lake 2 for summer season

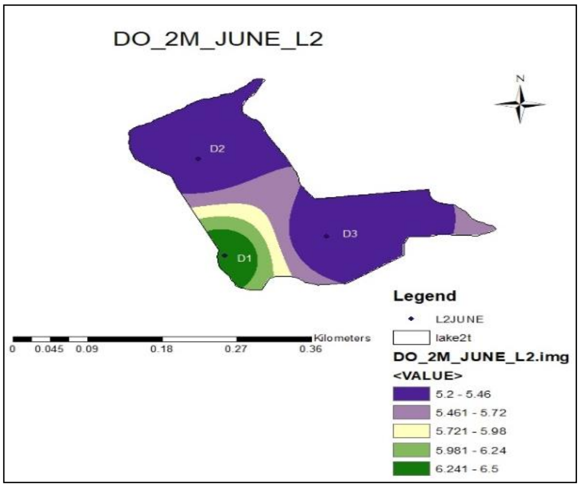


Figure B12 (b): DO variation at 2 m depth in Lake 2 for summer season

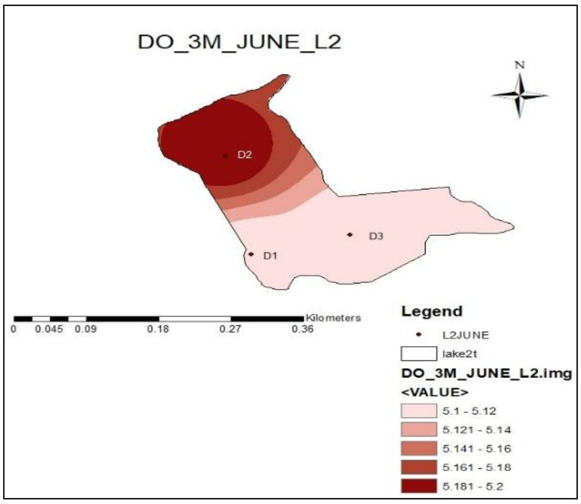


Figure B12 (c): DO variation at 3m depth in Lake 2 for summer season

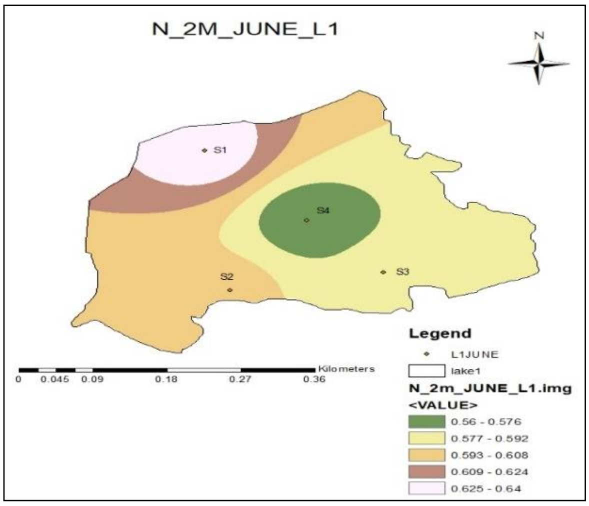


Figure B13 (a): NO_3 variation at 2 m depth in Lake 1 for summer season

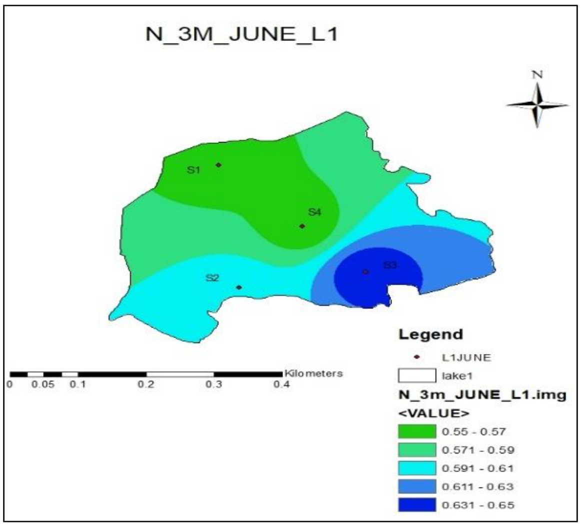


Figure B13 (b): NO_3 variation at 3m depth in in Lake 1 for summer season

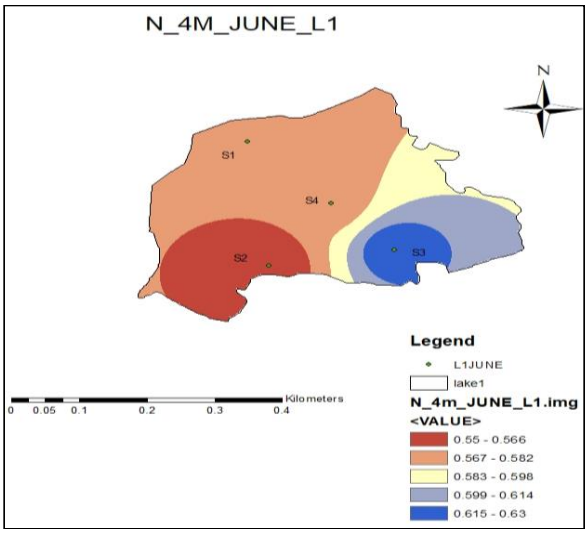


Figure B13 (c): NO_3 variation at 4 m depth in Lake 1 for summer season

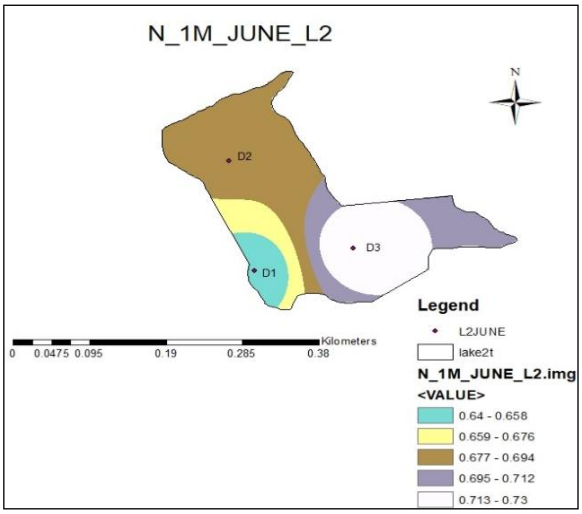


Figure B14 (a): NO_3 variation at 1m depth in Lake 2 for summer season

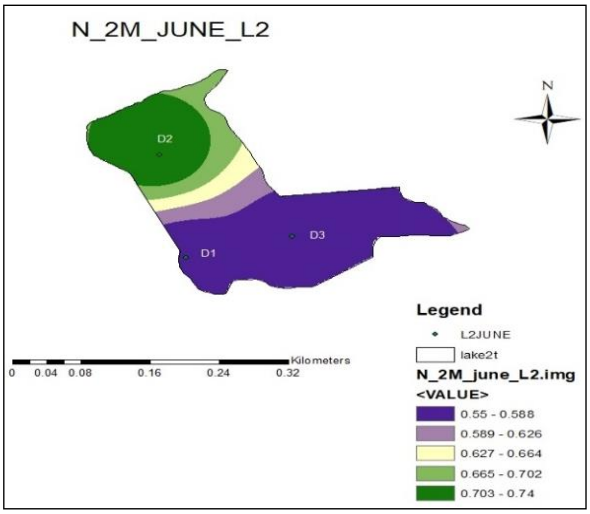
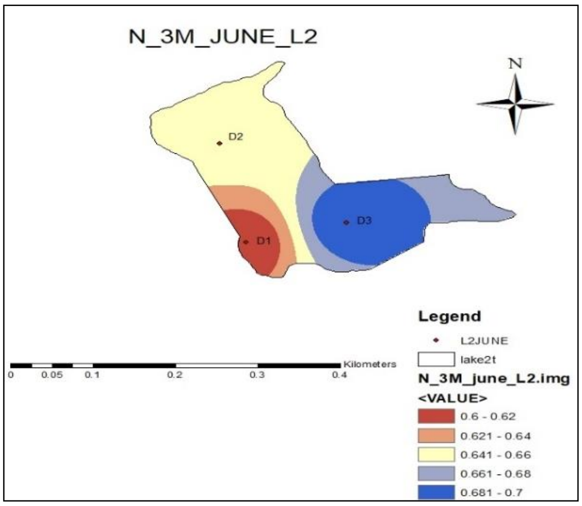


Figure B14 (b): NO_3 variation at 2m depth in Lake 2 for summer season



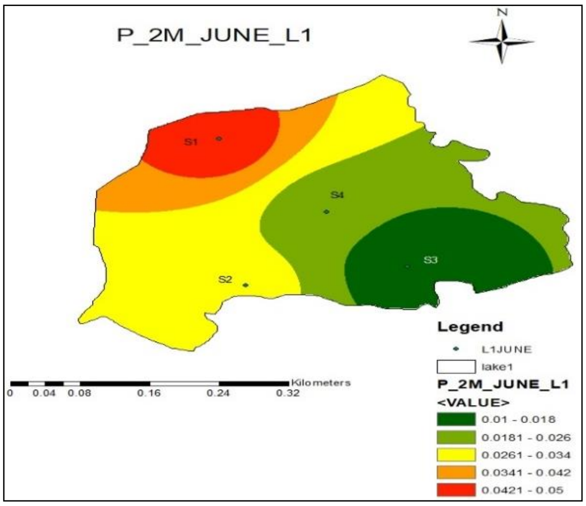
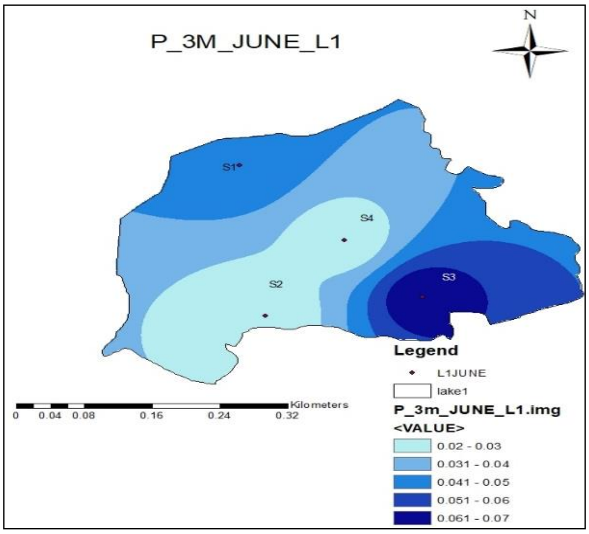


Figure B14 (c): NO_3 variation at 3m depth in Lake 2 for summer season

Figure B15 (a): TP variation at 2m depth in Lake 1 for summer season



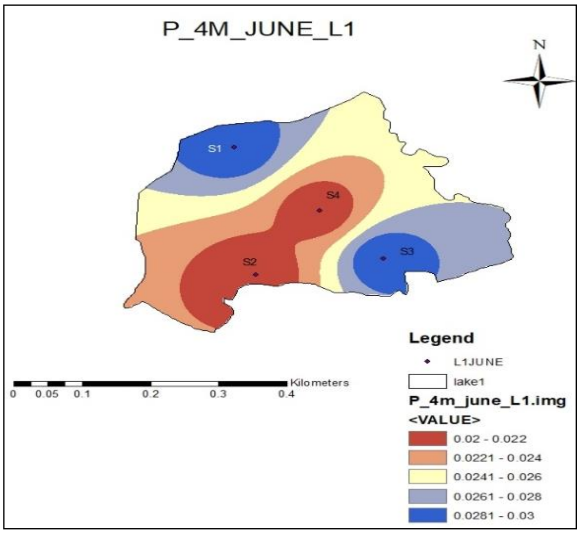
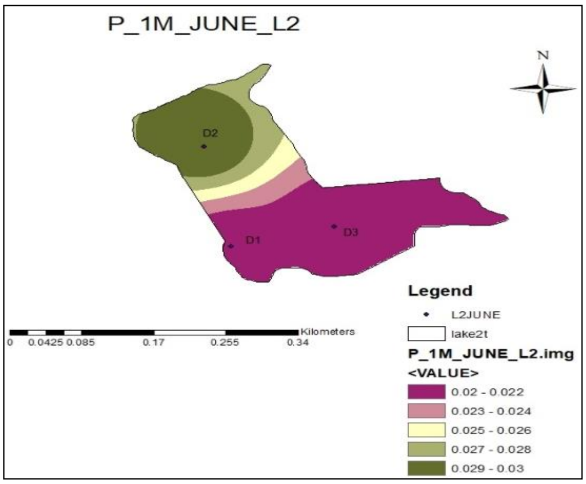


Figure B15 (b): TP variation at 3m depth in Lake 1 for summer season

Figure B15 (c): TP variation at 4m depth in Lake 1 for summer season



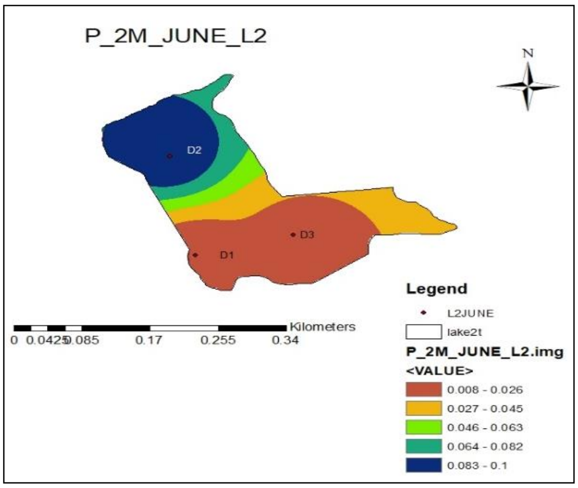


Figure B16 (a): TP variation at 1m depth in Lake 2 for summer season

Figure B16 (b): TP variation at 2m depth in Lake 2 for summer season

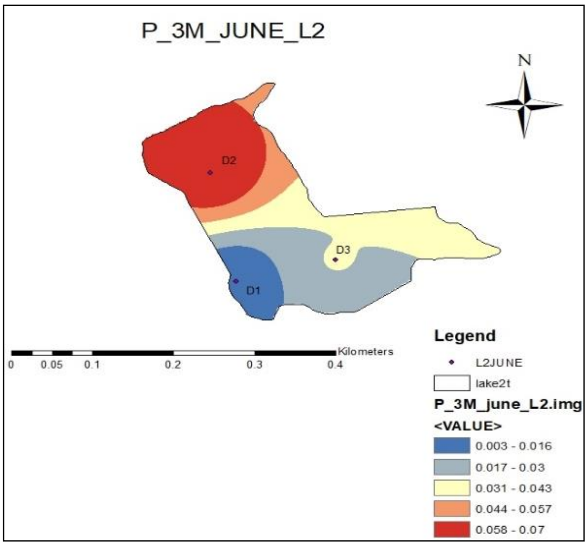


Figure B16 (c) : TP variation at 3 m depth in Lake 2 for summer season

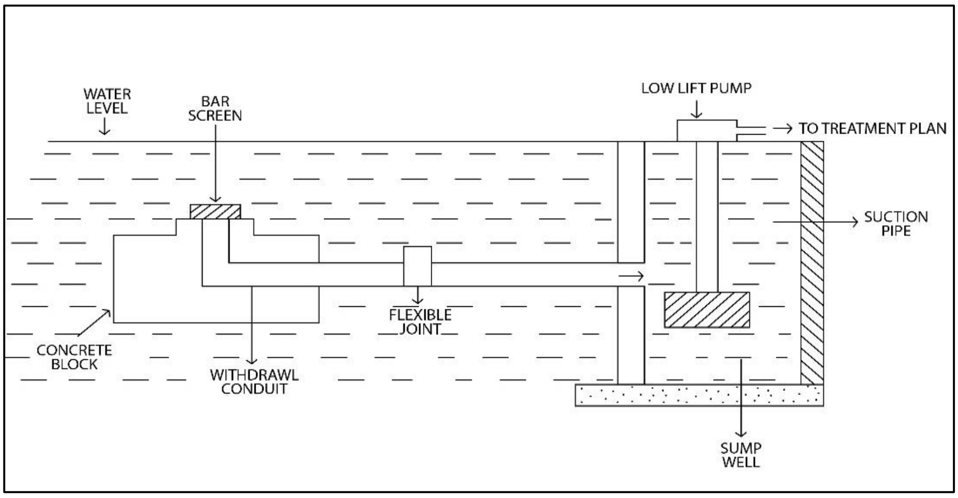


Figure B17: Intakes, Conduits, Pumping Unit and Screens for Water Treatment Unit

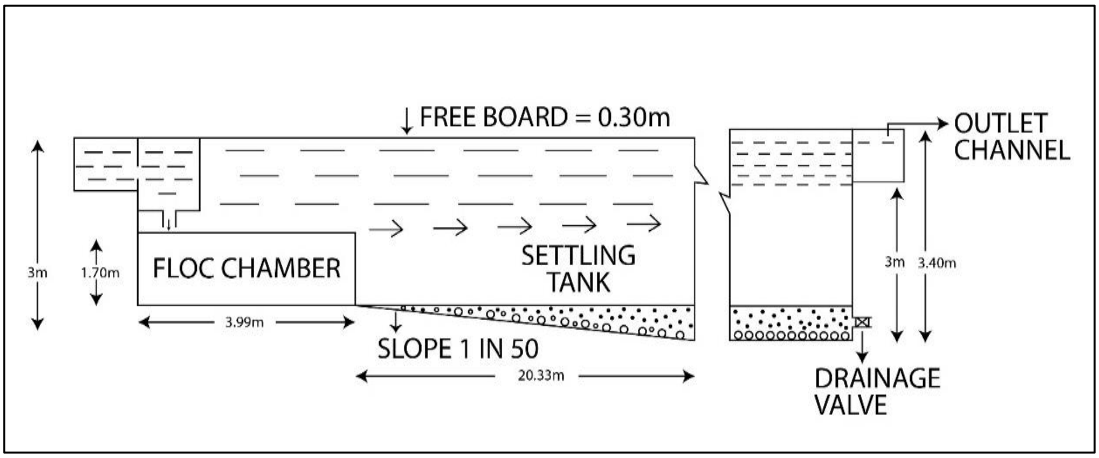


Figure B18 : Design of Floc Chamber for Water Treatment Unit