WATER QUALITY ASSESSMENT OF NUST LAKES

Submitted By

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A thesis submitted in partial fulfillment of requirements for the degree of

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Annex A To NUST Letter

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Certified that final copy of MS/MPhil thesis written by **Ms. Momina Durrani**, (Registration No. **00000275999**), of MS Environmental Science 2018 IESE-SCEE has been examined by undersigned, found complete in all respects as per NUST Statutes / Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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It is certified that the contents and form of the thesis entitled “Water Quality Assessment of NUST Lakes”, submitted by Ms. Momina Durrani, has been found satisfactory for patrial fulfillment of requirements for the degree of Master of Science in Environmental Science.

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DEDICATION

This Thesis is dedicated to my Parents, their continuous support and prayers are always with me

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Momina Durrani

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List of Abbreviations

ANOVA	Analysis of Variance
BOD	Biological Oxygen Demand
CFU	Colony Forming Unit
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
mg/L	Milligram per Liter
mg/m^3	Milligrams per cubic meter
MPN	Most Probable Number
NTU	Nephelometric Turbidity Unit
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
WHO	World Health Organization
μS/cm	Micro Siemens /centimeter

Abstract

Water is a life-giving resource that has a significant impact on public and environmental health. Water, in the form of rivers, lakes, seas, oceans, glaciers, and ice caps, covers roughly 71 percent of the earth's surface. Both natural and manmade processes have put this natural and valuable resource under threat. Pakistan has progressed from a water-stressed to a water-scarce status. NUST lakes were constructed by authorities in 2011 for storage and combating the shortage of water in campus but due to discharge of polluted water from both internal (hostels, café (C2) and residential area near lake 3) and external sources (wastewater from G-13 and H-13), the quality of water present in Lakes is deteriorating with each passing day. Present study was designed to address water quality issue of NUST Lakes. Six locations were sampled for surface water collection by following standard methods and the locations include, inlet and outlet of all 3 lakes. Samples were analyzed for physicochemical and microbiological parameters include pH, Total dissolved solids, Turbidity, Electrical conductivity, Temperature, Chemical oxygen demand, Nitrate, Nitrite, Phosphate, Total Kjeldahl Nitrogen, and Chlorophyll-A whereas for microbiological analysis MPN (most probable number) method was performed. Study revealed that contamination level at all sites significantly high especially at the inlet of Lake 1, due to direct intrusion of waste. For MPN, results ranged from 3.6×10^{2} to 1.1×10^{7} CFU/mL during the study period. For heavy metal analysis water and sediment samples were collected from 3 sites i.e., inlets for all 3 lakes at different depths. Higher concentration of heavy metals was found in sediments of all 3 lakes and Fe was found in very high concentration and the probable reason for that was soil/rock weathering. Statistical methods i.e., ANOVA, and correlation were used to identify the relationship among different parameters

Chapter 1

1. Introduction:

It is not possible to overstate the importance of water for human health, economic development, and population growth. Water is an important part of our lives and it is necessary to have reliable and continuous access to safe water. Safe water supply is an issue at both national and international level (Shahab et al., 2016). The quality of water deteriorating day by day is of high concern due to many reasons such as, increase in industrial and agricultural activities, excessive growth in population, or threats posed by climate change, among others. This might result in a substantial disturbance of the hydrological cycle, resulting in severe decreases in the availability of water for any purpose (Carrasco et al., 2019).

By 2025, in emerging countries, water withdrawal is expected to rise by 50 percent and in developed countries by 18 percent (SDPI, 2018). According to WHO, 80 percent of all human illnesses are attributed to bacterial pollution of water. In Pakistan, water availability has dropped from 5,260 cubic meters a year in 1951 to about 1,000 cubic meters in 2016. By 2025, this volume is likely to decline further to around 860 cubic meter switching country’s’ from a "water stressed” to a "water scarce" country.

Water pollution is among the most serious threats to public health in Pakistan. The drinking water quality is badly monitored and controlled. Among 120 nations, Pakistan ranks at the number 80 in terms of the quality of drinking water. The main elements that contribute towards the water quality disturbance are mostly anthropogenic activities which include, excessive municipal waste disposal, effluent, and non-selective agrochemical use in agricultural (Azizullah et al., 2011). A significant contributor to waterborne illnesses is faecally-contaminated water. The chemical characteristics of water quality have also become progressively troublesome with rapid urbanization, as unsafe chemicals in industrial effluents pose a high risk to health of humans (Aziz, 2005).

The natural and valuable resource of water has been endangered by both anthropogenic and natural activities such as the release of dangerous metals, sediments, organic and inorganic chemicals, pollution, agricultural waste, residential sewage, and so on. As a result, the quality of freshwater has been seriously compromised, leading to the modification and alteration of all freshwater products (Noreen et al., 2019).

Water, in the form of rivers, seas, lakes, oceans, glaciers, and ice caps, covers roughly 71 percent of the earth's surface. A wide range of anthropogenic activities have led to water of reduced quality and are therefore contributing to habitat degradation and eutrophication (Loucif et al., 2020). The quality of water present at specific source and region depends on it’s physical, biological and chemical properities, which are useful for controlling or determining the water quality for a specified purpose. If the values of water parameters exceeded the acceptable limit or requirement than they can pose a danger to the health of human (Hossain et al., 2020).

Among other issues, eutrophication is one of the most critical and ongoing problems with the quality of freshwater habitats. Extensive studies have shed light on many of the factors that promote eutrophication-related risk (Zou et al., 2020). Eutrophication of the lake is a major global problem due to water contamination. In eutrophic lakes the presence of algal bloom may cause a variety of environmental problems, such as hypoxia and odour (Yang et al., 2020). Specifically, increased nutrient input from many sectors including industrial, residential, and agricultural are enhancing eutrophication problems. In lakes, algae blossoms are the major impact of nutrient enrichment. Eutrophication has a negative influence on social, human, and economic well-being as it modifies the function and structure of aquatic ecosystems, leads to the loss of aquatic biodiversity, and has a negative impact on social, human, and economic well-being (Aeriyanie et al., 2020).

1.1. Lakes in Pakistan:

Fresh water environments such as lakes, which account for 0.8 percent of global water supply, are marked as an important indicator in the growth of sustainable ecosystems. Water quality has deteriorated because of human activities and contamination, and nearly 80% of freshwater habitats are experiencing water related issues.

(Saleem et al., 2019). There are many freshwater lakes in Pakistan, situated at various altitudes and latitudes. which are shown in Figure 1.1

List for Lakes in Pakistan along with coordinates are shown in Annex-A.

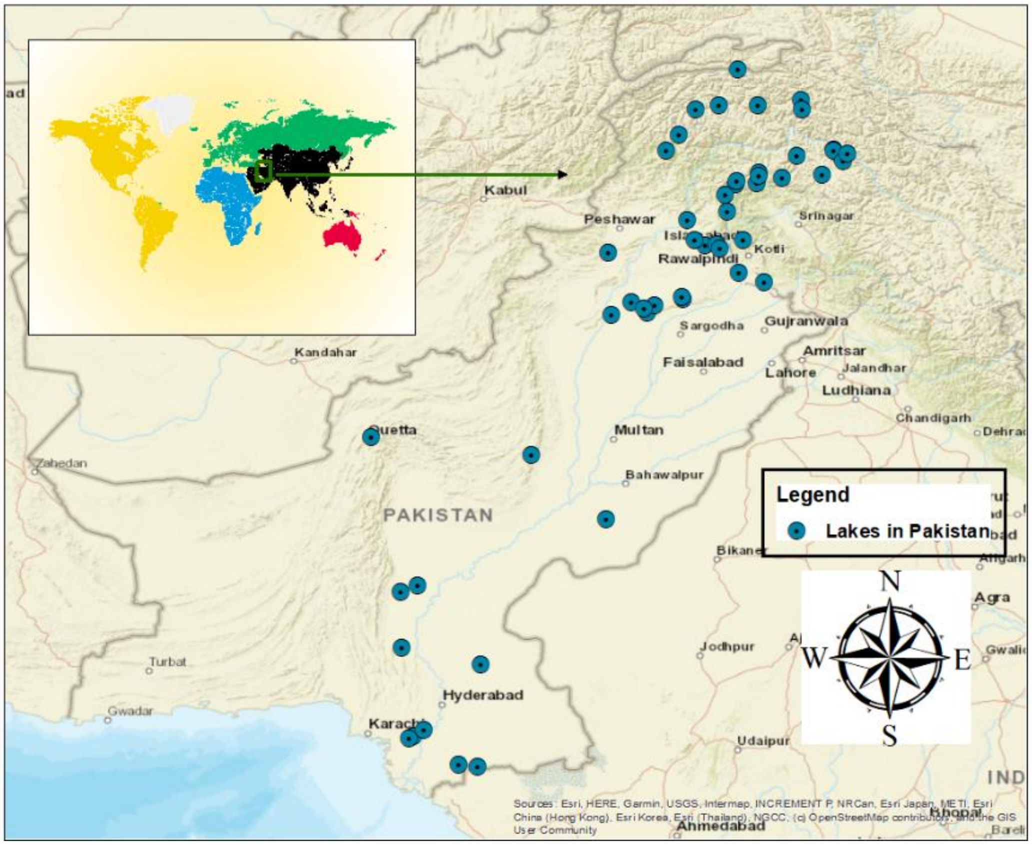

Figure 1.1: Map of Lakes in Pakistan

1.2. Present Study:

NUST lakes were constructed by authorities with the aim to store the water and to combat the shortage of water present in campus. The present study was conducted at NUST, H-12 campus Islamabad with the aim to monitor the water quality of NUST lakes so that lakes water may be further used for recharging underlying groundwater aquifer. The collected water samples were evaluated for different physico-chemical and microbiological characteristics. Further, water and sediments samples were also analysed to determine the presence of heavy metals.

1.3. Objectives:

The overall aim of the study was to monitor the quality of water present in NUST Lakes. The main objectives included:

I. Evaluation of physicochemical and bacteriological parameters of water from NUST Lakes.

II. Identification of heavy metals in sediments and water.

III. Estimation of the health status of lakes through meteorological parameters.

IV. Statistical analysis using correlation and ANOVA between different parameters.

Chapter 2

2. Literature Review

In many developing countries, including Pakistan, the issues related to pollution of water has been marked as one of the most important issues Toxic chemical contamination of streams, lakes, and surface water has a negative influence on human health as well as marine ecosystems. The physical, biological, and chemical characteristics of water are used to describe its quality. Rapid industrialization and non-selective use of chemical fertilizers and pesticides in agriculture are contaminating the aquatic environment in a variety of ways, resulting in water quality degradation and the extinction of aquatic biota (Gorde & Jadhav 2013).

Agriculture including (nutrient waste, pesticides, nutrient waste, fertilizers, and herbicides) the domestic sector (water, industry, pharmaceuticals and personal care goods, and human activities such as feeding of ducks), industry (pollution related to water, energy) and climate change are threats to water quality. Climate change will intensify human demand for freshwater, but also will have impact on ecosystems' demand for freshwater, for instance, increased evaporation (Seelen et al., 2019).

Tibebe et al., (2019) conducted a study to assess water quality of lake Tana and reported that in all seasons, higher nutrient, electrical conductivity (EC) and total dissolved solid (TDS) concentration was recorded at the effluent sampling sites of many resorts and major feeding rivers.

In a study Iqbal et al., (2016) monitor the metal content in surface sediments of Simply Lake and decreasing concentration order was observed by the determined levels of the studied metals: Fe > Mn > Zn > Co > Cr > Pb > Cu > Cd. The key sources of Co, Pb Cd, and Zn were agricultural activities, household waste, road runoff, and recreational activities. Copper, chromium, manganese and iron were derived predominantly from natural sources, while human inputs partially contributed to Cr, Cu and Mn.

In a study conducted by Ji et al., (2019) a study on Baiyangdian Lake was done and the findings showed that in most of the sampling sites, the heavy metals in sediments pose moderate to high risks. Statistical analysis findings showed that metal fractions were strongly associated with physicochemical properties, and there was a good correlation between TP, TN, and TOC.

In a study Lu et al., (2019) reported that climate change played a significant influence in the eutrophication of Lake Tianchi. Increased warmth, altered precipitation patterns, and wind-induced hydrodynamic fluctuations have all been suggested as contributing factors to increased eutrophication during the season of summer. The findings also showed that local variations in temperature and precipitation were closely related to the large-scale circulation of the atmosphere.

Mastoni et al., (2008) conducted a study to assess and monitor the water quality of Manchar Lake and found that lake water has alkaline pH, high conductivity, and hardness (as $CaCO_3$). The mean nitrate concentration was greater than phosphate.

A study was conducted by Ouma et al., (2016) on Victoria Lake to investigate the seasonal variation on the quality of water. Seasonal differences have shown that in the wet season, pH, turbidity, colour, BOD, TSS, nitrates, phosphate, and coliforms were significantly high ($p<0.001$) while EC, temperature, heavy metals, TDS, ammonia, and chloride were considerably high at the dry season ($p<0.001$). In the wet season, the elevated level of pollution was attributed to run-offs coming from storm water bearing a higher contaminant load whereas, in the dry season due to low pH and high temperature pollution load was high due to increase in ions solubility.

According to the study carried out by Khuhawar et al., (2018) at Ramser site, Indus Delta, Sindh, Pakistan. At several sites, physicochemical parameters such as COD, BOD, and elements such as Fe, Cr, As, Ni, and Zn exceeded permissible levels. Microbiological contamination at sample locations, on the other hand, indicates the presence of E. coli. The increased prevalence of anthropogenic activities at the sample locations possibly explains the existence.

A study conducted by Kazi et al., (2009) to assess the variation in water quality present in Manchar lake by using different multivariate statistical techniques. Principle component analysis helped to determine the sources or variables that were responsible for the variation of water quality. The pollution of industrial, agricultural waste and urban sewage water is the key cause of the lake's water depletion. This research highlights the importance of multivariate statistical methods for investigating and interpreting complex data sets, recognizing sources of contamination, and identifying water quality variations for efficient management of lake water.

A study conducted by Shrestha & Kazama (2007) on Fuji river basin Japan, to evaluate the spatial/temporal differences and to interpret the quality of water data for 8 years using different Multivariate statistical techniques, including cluster analysis (CA), discriminant analysis (DA), principal component analysis (PCA), and factor analysis (FA) for the monitoring of 13 sites using 12 different parameters. According to the results of factor analysis, temperature, and organic pollution, which is a point source (domestic wastewater), were the characteristics that were responsible for water quality disparities in comparatively less contaminated regions, on the other hand the primary causes of water pollution in moderately polluted regions are point sources (sewage) and non-point sources (nutrients: agricultural and orchard plantings), while point sources such as wastewater from treatment facilities and industries, as well as domestic wastewater, were the major causes in regions with significant pollution in the region.

Zeb et al., (2011) conducted a study on Siran river Pakistan & found out that due to many factors the water quality of the river in deteriorating including many human activities comprising of irrigation and release of the industrial and domestic wastewater without any treatment. Most contaminated sampling sites were near populated areas, and this pollution load is more evident in summer as compared to winter. Also, most of the parameters were in allowable limit except for COD, TSS and *E. Coli*.

A study was conducted by Baig et al., (2017) in South Taihu lake, China on cyanobacterial bloom events from 2003 to 2009 by examining correlation analyses between hydro-meteorological factors and cyanobacterial blooms. The result shows that lake was badly affected by cyanobacteria bloom. Temperature plays an important role in the growth of cyanobacterial density and chlorophyll-a concentration. Also, according to results, for cyanobacterial growth 25°C was proved to be favorable temperature. Rainfall patterns also impact the growth, as light rainfall is preferred because that brings nutrients into water, while heavy or moderate rainfall disturbs the waterbodies that in return affect the growth of cyanobacteria. However, many factors including ammonia, TN, COD and TP showed significant improvement in waterbody since 2008.

Nazeer et al., (2014) conducted a study on Soan river to find out its water quality and to estimate the concentration of heavy metals present in water and sediments. The results of the study concluded that most of samples were found contaminated with heavy metals and showed seasonal variation. Heavy metal concentrations were found to be significantly higher during the post-monsoon season, whereas the water quality index revealed that the water quality during the pre-monsoon season was comparatively better. Ni, Pb, and Cd contents in water samples were higher than the WHO limit for aquatic life or residential use. Compared to bed sediments samples, the suspended sediments samples were ore contaminated.

Zakaullah & Ejaz (2020) conducted a study on Soan river to investigate quality of water present in river using multivariate statistical approach and found out that DO, BOD, COD, turbidity, and TSS are prominent factors contributing variations in water quality.

2.1. Need to monitor water quality:

I. Some of the basic concerns that affect the water sector are:

II. As a limited resource, fresh water is increasingly becoming harder to obtain because of constant increases in its demands.

III. In terms of surface flow, precipitation, and ground water, various locations in the country are fitted differently with water and there is increased stress on the sharing of water resources.

IV. Lack of equity in allocations of water.

V. Majority of drinking water requirement is met by groundwater which is declining, and its quality is also deteriorating

VI. There is lack of awareness amongst the general public about the impending threat of water scarcity.

The quality of water is characterized by a multitude of chemical, physical, and biological interactions in the aquatic system. Periodic monitoring of water bodies with the appropriate number of water quality criteria avoids disease outbreaks and the incidence of hazards (Zeb et al., 2011).

2.2. Physico-chemicals Parameters

Approximation, variation, or degradation of physicochemical characteristics are commonly used to determine the condition of water quality. (Atique & An 2019). The quality of water relies on many of its physicochemical and biological parameters such as, pH, temperature, turbidity, Electrical conductivity, Nitrates, Nitrites, Dissolved oxygen, Total dissolved solids, Total Alkalinity, Total Hardness, Phosphate, and Chemical oxygen demand (Masood et al., 2015). For microbiological examination, faecal coliform bacteria are commonly calculated to investigate water quality. (Rowny & Stewart, 2012).

The following section specifics all parameters affecting water quality.

2.2.1. pH

One of the most important parameters in determining how corrosive water is pH. The nature of water is more corrosive when the pH value is lower. The elevated pH and low oxygen values coincide with high temperatures during the summer months due to decreased photosynthetic activity rate and assimilation of carbon dioxide and bicarbonates (Bhateria & Jain 2016).

2.2.2. Temperature

The temperature of water in a defined system controls the rate of all chemical reactions and influences the growth, reproduction, and immunity of fish. The amount of oxygen in the water reduces as the temperature rises and the rate of photosynthesis of aquatic plants; the metabolic rate of aquatic animals; and the susceptibility of species to toxic waste, parasites, and illnesses are all influenced by temperature. Weather, groundwater inflows to the stream, vegetation, impoundments, discharge of cooling water, urban strom water and other factors all contribute to the temperature change (Bhateria & Jain 2016).

2.2.3. Dissolved Oxygen (DO)

DO is an indicator of organic matter pollution and the destruction of organic compounds, as well as the water body's capacity for self-purification. For fish, the overall tolerance limit is 5 mg/L and less than 2 mg/L leads to death (Ma et al., 2020). DO is primarily regulated by the water temperature, which is directly affected by the air temperatures and indirectly influenced by the degree of vegetation cover (Chang, 2005).

2.2.4. Electrical Conductivity (EC)

Conductivity is strongly related to parameters which include pH, temperature, total hardness, total solids, calcium, chloride, chemical oxygen demand, total dissolved solids, chloride, and concentration of iron. In rivers and streams, conductivity is mainly affected by the rock's formation i.e. geology of the region from where the water flows (Bhateria & Jain 2016).

2.2.5. Turbidity

Turbidity is referred as the suspension of particles in water that interfere with the passing of light and it is mainly caused by a large range of suspended particles (Dohare et al, 2014) The cloudiness in water is due to variety of particles and is another key parameter in the study of drinking water. It is also linked to the content of diseases causing organisms in water that may derive from runoff coming from soil (Rahmanian et al., 2015).

2.2.6. Phosphate-Phosphorus (PO_4-P)

Phosphorus is frequently found as part of a phosphate molecule in nature (PO4). Phosphorus is found in aquatic habitats as both organic and inorganic phosphate. Organic phosphate is made up of a phosphate molecule and a carbon-based molecule, just like in plant or animal tissue. Phosphorus comes from a variety of sources, both natural and man-made. Soil and rocks, wastewater treatment facilities, fertilised lawn and agricultural runoff, inadequate septic systems, disturbed land areas, drained wetlands, water treatment, and commercial cleaning and runoff from animal dung storage places are all examples. Even though phosphorus is a short-term nutrient in most fresh waters, even a small increase in phosphorus can lead to the occurrence of negative consequences in a stream, including increased plant growth, algae blooms, low dissolved oxygen, and the death of some fish, invertebrates, and other aquatic animals (Bhateria & Jain 2016). Eutrophication is caused by TN and TP, which results in excessive algae growth, which depletes DO through decomposition (Chang, 2005).

2.2.7. Total dissolved solids (TDS)

Total dissolved solids are inorganic chemicals and trace quantities of organic material that are present in water as a solution (Rahmanian et al., 2015). Fertilizers from farms and lawns can bring a range of ions to a stream. High TDS concentrations can also be caused by runoff from salted roadways in the winter. TDS levels in lakes and streams are often found to be in the 50 to 250 mg/L range. (Rowny & Stewart, 2012).

2.2.8. Nitrate-Nitrogen (NO_3-N)

Nitrate is mostly present in the form of N_2 compound (oxidizing state) in raw water. The main source of nitrate in water is from chemical and fertilizer factories, domestic and industrial discharge (Dohare et al., 2014). Also, the rise in nitrate concentration in ground and surface water is the result of various agricultural activities (Nas and Berktay, 2006). Increased nitrate-nitrogen levels in surface water cause various issues, such as reduced water oxygen levels, resulting in effects on marine organisms, plants, and algae (Davie, 2003).

2.2.9. Nitrite-Nitrogen (NO_2-N)

Nitrites are a comparatively short-lived form of nitrogen that bacteria rapidly turn nitrites into nitrates. When nitrite and iron react in the human body (in blood), this will cause **Blue baby syndrome** disease which create methemoglobin which stops oxygen level (Gupta et al., 2017)

2.2.10. Total Kjeldahl Nitrogen (TKN)

TKN is a representation of both ammonia and nitrogen in the organic form. Human and animal waste, as well as some fertilizers and industrial waste, are common causes of ammonia/ammonium.

2.2.11. Ammonia (NH_3)

Natural and anthropogenic sources of ammonia include the breakdown or decay of biological waste matter, gas exchange with the environment, forest fires, animal and human waste, and the nitrogen fixation process, while additional sources include commercial fertilisers and various industrial operations. Direct sources of ammonia in aquatic environments include urban effluent discharges and livestock excretion of nitrogenous waste, while indirect sources include nitrogen fixation, air deposition, and agricultural runoff (US, EPA).

2.2.12. Chemical Oxygen Demand (COD)

The amount of oxygen required for the chemical oxidation of organic materials is measured by COD. Elevated COD levels can induce oxygen depletion to harmful levels for aquatic life due to microbial breakdown. (Dohare et al, 2014).

2.2.13. Chlorophyll-a

The algae that develop in a body of water is measured by chlorophyll-a. A chlorophyll-a level may be used to indicate the trophic status of water. While algae are a normal element of freshwater ecosystems, too many algae can produce aesthetic issues such as green scums and unpleasant smells, as well as decreasing amounts of dissolved oxygen. When algae is present in abundance, it can generate toxins that are harmful to human health. (US EPA).

2.2.14. Microbes in water

Bacteria are single-celled species that are normally found in lakes, rivers, and streams. Total Coliforms, E. coli and Fecal coliforms were originally thought to show the presence of faecal contamination in water bodies and e. coli is a preferred indicator and its existence provides clear proof of faecal pollution from warm-blooded animals.

2.3. Heavy Metals

Heavy metal contamination has become a global concern in recent decades because of their toxicity, widespread origins, non-biodegradable properties, and accumulative behavior in water bodies (Javed et al., 2017). High concentration of heavy metals in sediments pose a high risk to human health because that result in transmission of heavy metals to water and eventually consumes by living organisms and hence enter the food chain. Both natural and anthropogenic causes contribute to the presence of heavy metals in water bodies. Most metals are found in natural environments in very low concentrations and are often extracted from rock and soil weathering. Smelting and mining processes, atmospheric deposition, dumping of untreated/partially treated urban and industrial effluents, metal chelates from various industries, and excessive use of heavy metal-containing fertilizers during agricultural activities are major anthropogenic sources of heavy metal contamination. (Iqbal & Shah 2014). Following table 2.1 represent the sources and impacts of all the heavy metals selected for this study.

Table 2.1: Heavy Metals Sources and Impacts

Heavy Metals	**Sources of Heavy Metals**		**Impacts**
	Natural	**Anthropogenic**	
Cadmium (Cd)	Weathering of underlying bedrock or from parent material such as glacial till.	Aerial deposition Sewage sludge Manure Phosphate fertiliser	Itai-itai disease Renal disjunction Lung diseases Bone defects Increase blood pressure
Chromium (Cr)	Weathering of Cr-containing rocks Leaching from topsoil and rocks	Electroplating Leather tanning Textile industries	Skin irritation Long exposure can cause kidney and liver damage
Copper (Cu)	Deposits due to geology Volcanic activities Erosion and Weathering of soils and rocks	Mining activity Agricultural practices Electrical & Metal manufacturing Sludge	Anemia Kidney and liver damage Stomach and intestinal irritation
Cobalt (Co)	Emission from volcanoes Weathering of rocks Decomposition of plants	Production of chemicals and alloys Domestic sewage Run-off from urban & Agricultural sector	Problems related to Vision, Heart & Thyroid

Nickle (Ni)	Dust carried by the wind Weathering of rocks and soils Volcanic eruptions Forest fires Presence of vegetation.	Waste dumping of Cd-Ni batteries Water from Sewage Use of Ni-based paint in the housing sector	Decreased in body weight Liver and Heart damage Skin problems/irritation
Iron (Fe)	Weathering of rocks and soil Geological process Soil composition Precipitation	Waste from industries Refining of iron ores Corrosion of iron containing pipes & metals	Diabetes Stomach problems Vomiting Nausea Hemochromatosis
Lead (Pb)	Volcanic emissions Forest fires Various erosional processes	Oxidation, or the deterioration of lead-containing components in the water distribution system. Plumbing takes places in buildings or household	Toxic biochemical effects Kidney problems Gastrointestinal problems Acute or chronic damage to nervous system
Manganese (Mn)	Direct deposition from atmosphere Wash-off from other surfaces & plant Leaching from plant tissues Material such as dead plants excreted or shredded	Discharges from municipal sector Sewage sludge Mineral and mining and activities Production of steel, alloy, and iron that causes emissions	

Zinc (Zn)	--	Discharges from smelter slags Zinc-containing commercial items, such as fertilisers and wood preservatives	Growth impartment Diarrhea Vomiting Kidney failure Lung failure

Chapter 3

3. Material and Methods:

Methodology designed to achieve research objectives were based on following phases (Fig 3.1)

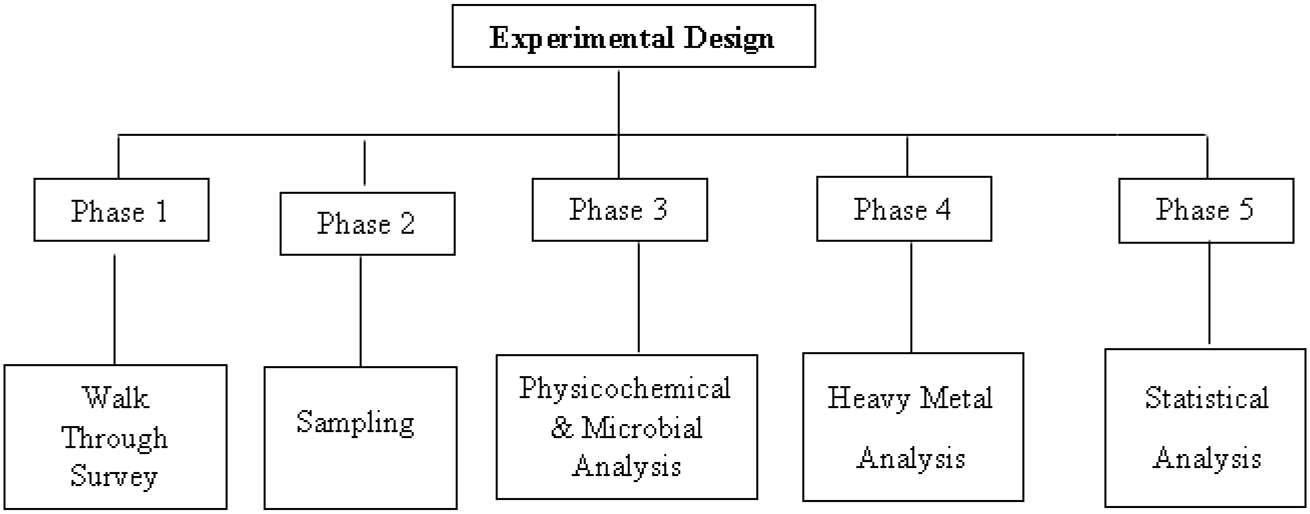

Figure 3.1: Methodology Phases

3.1. Description of Study Area

Lakes on the campus of National University of Science and Technology (NUST), Pakistan's were used as a research location. These three lakes (1, 2 and 3) were constructed in 2011 and have a surface area of 1.5, 2 and 2.25 acres, a height of 25, 16 – 20 and 25 feet, and a storage capacity of 0.17, 0.16, and 0.74 GL, respectively. (PMO, NUST). The climate in the research area is sub-humid, with considerable seasonal variations in temperature and precipitation. In the winter, the temperature in Islamabad ranges from 3 to 17 degrees Celsius, while in the summer, it ranges from 24 to 34 degrees Celsius (Malik & Nadeem, 2011).

3.2. Sampling Site Selection and Analysis

Water samples were taken at six different locations, including the Inlet and Outlet of Lakes 1, 2, and 3, as depicted on the map (Figure 3.2). Using sterile sampling bottles, a total of 108 surface water samples were collected from all sampling locations throughout the course of six months (October 2019 to March 2020). The bottles were washed 2-3 times with the sample water before collecting samples. Sampling points along with their coordinates are shown in Table 3.1. Different physico-chemical analyses were done to investigate the water quality parameters, including pH, temperature, pH, dissolved oxygen, electrical conductivity, total dissolved solids, and turbidity of water (Saeed & Hashmi, 2013)

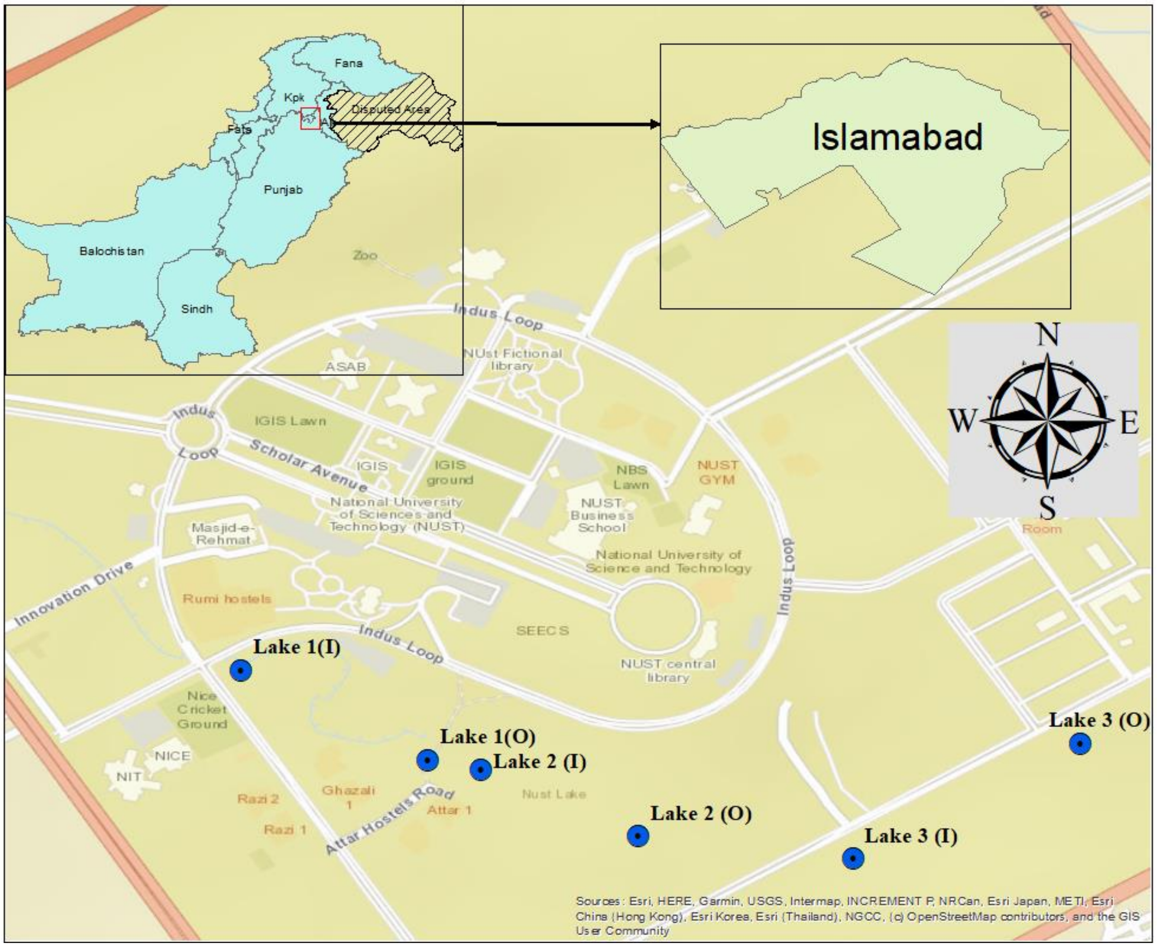

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Figure 3.2: Map of selected sampling sites

Table 3.1: Sampling locations along with their coordinates

Sr.	Sampling Location	Sampling Points	No. of Samples	Coordinates (Latitude, Longitude)	Location of sampling points
1	**Lake 1**	Inlet	18	33°38'31.43"N 72°59'10.48"E	Opposite to NICE Cricket Ground
		Outlet	18	33°38'26.72"N 72°59'20.46"E	Left side of bridge behind Attar Hostel
2	**Lake 2**	Inlet	18	33°38'26.21"N 72°59'23.08"E	Right side of bridge behind Attar Hostel
		Outlet	18	33°38'22.72"N 72°59'31.29"E	Opposite to Saddle club
3	**Lake 3**	Inlet	18	33°38'21.56"N 72°59'42.53"E	Opposite NUST Sports Complex
		Outlet	18	33°38'27.58"N 72°59'54.45"E	Opposite NUST Sports Complex

3.3. Water Quality Analysis

3.3.1. Physicochemical Analysis

For physicochemical analysis 13 different parameters were selected and parameters along with instrument and methods used are shown in Table 3.

Table 3.2: Physico-chemical Parameters

Parameters	Units	Instruments/Method Used	Protocol
pH	-	pH meter (HACH 156)	

Temperature	◦C	HACH session 1	APHA, 2017
Electrical conductivity (EC)	µS/cm	Conductivity meter (Ino Lab 720)	
Dissolved Oxygen (DO)	(mg/L)	DO meter (HACH 156)	
Turbidity	NTU	Turbidity meter (HACH 2100 P)	
TDS (total dissolved solids)	mg/L	Gravimetric method	
TSS (total suspended solids)			
Nitrates (NO_3^-)		Spectrophotometer (Colorimetric method)	
Nitrites (NO_2^-)			
Ammonia (NH_3^-)		Kjeldhal Assembly	
Total Kjeldahl Nitrogen (TKN)			
Chemical Oxygen Demand (COD)		COD Digester (Closed Reflux method)	
Phosphates (PO_4^{3-})		Spectrophotometer (colorimetric method)	
Chlorophyll-A	mg/m^3	UV- Spectrophotometer	

❖ On-site Analysis

pH, temperature, turbidity, electrical conductivity, and dissolved oxygen were performed on-site using portable measuring instruments/meters.

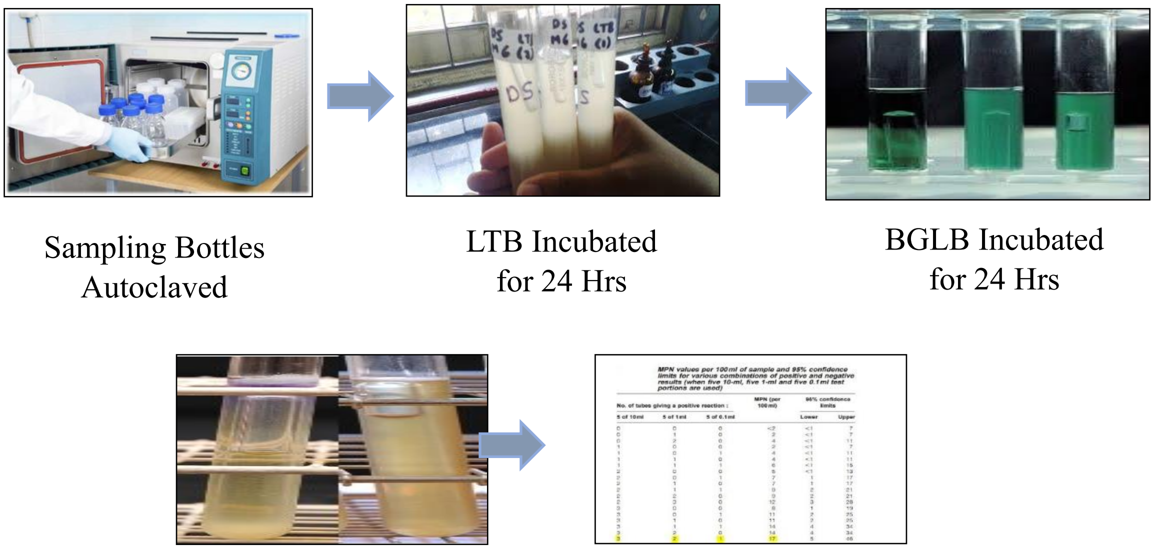
❖ Laboratory Analysis

Chemical oxygen demand, Total kjeldahl nitrogen, Nitrates, Nitrites, Phosphates, Total dissolved solids, total suspended solids, and chlorophyll-A were analyzed in laboratory using standard methods within 3-5 hours of sample collection.

3.3.2. Microbiological Analysis

For microbiological analysis most probable number (MPN) technique was performed

MPN is a three-phase test, process flow diagram as shown in Figure 3.3


Sampling Bottles Autoclaved

LTB Incubated for 24 Hrs

BGLB Incubated for 24 Hrs

EC Broth Incubated for 24 Hrs

MPN index

Figure 3.3: MPN Method process flow diagram

1. Presumptive test for Coliform

2. Confirmatory test for Coliform

3. Completed test for Fecal Coliform

PREPARATION OF MEDIA

I. **Laural Tryptose Broth (LTB):** 10 LTB tubes were prepared for each sample. For the preparation of LTB tubes, 17.8 g of media was dissolved in 500 mL of distilled water. 10 mL each of the solution was added in 10 tubes containing an inverted durham tube. Tubes were then autoclaved at 121°C for 15 minutes at 15 psi. After that they were placed in incubator to monitor sterility for 24 hours at 37˚C.

II. **Brilliant Green Bile Broth (BGLB):** 10 BGLB tubes were prepared for each sample. To prepare BGLB tubes, 20 g of media was dissolved in 500 mL of distilled water. 10 mL each of the solution was added in 10 tubes containing an inverted durham tube. Tubes were then autoclaved at 121°C for 15 minutes at 15 psi. After that they were placed in incubator to monitor sterility for 24 hours at 37˚C.

III. **Escherichia coli (EC) Broth:** 10 tubes of EC were prepared for each sample. For preparation of EC tubes, 18.5 g of media was dissolved in 500 mL of distilled water. 10 mL each of the solution was added in 10 tubes containing an inverted durham tube. The tubes were then autoclaved at 121°C for 15 minutes at 15 psi. After that they were placed in incubator to monitor sterility for 24 hours at 37˚C.

For the samples collected from lakes MPN serial dilution method was used.

Dilution Preparation for MPN:

I. For each dilution to be prepared, firstly in tubes 9 ml of distilled water was autoclaved at 15 psi for 15 minutes.

II. Then, add 1 mL of pure sample to each of 3 tubes containing 9 mL of autoclaved distilled water, this makes dilution of 0.1 ml.

III. From 0.1 ml dilution tubes. add 1 ml of diluted sample to each of 3 tubes containing 9 ml of autoclaved distilled water, this makes dilution of 0.01 ml.

IV. From 0.01 ml dilution tubes. add 1 ml of diluted sample to each of 3 tubes containing 9 ml of autoclaved distilled water, this makes dilution of 0.001 ml.

3.4. Heavy Metal Analysis

Both the water and sediment samples were analyzed for heavy metal contamination.

- **Water Analysis**

To remove suspended particles from each water sample, sample was filtered through 0.45 mm pore size filter paper and analytical grade nitric acid (one part) was added in each sample for preservation of metal contamination. Next, prepared samples were stored in pre-cleaned bottles within refrigerator (Saleem et al., 2019).

- **Sediment Analysis**

Grab sampling was used to collect sediment samples from sampling locations. Sediment samples were dried at 40 degrees Celsius to eliminate all moisture content, and then coarsely ground using a mill and pestle (Rajeshkumar et al., 2018). A freshly prepared acid combination containing 9 mL HNO3 and 3 mL HCl was used to digest around 1-2 g of dried sediment samples. The residue of the digested sample was diluted with distilled water up to 25 ml after digestion. (Javed et al., 2016).

- **Sample Analysis**

For the analysis of samples Atomic Absorption Spectrophotometer were used to determine the concentration of selected trace metals in water and sediment samples.

3.5. Meteorological Parameters

Data for meteorological parameters were collected from US-Pak Center for Advanced Studies in Energy (USPak-CASE), NUST for six months i.e. from October 2019 to March, 2020. Data for Direct Normal

Irradiance (W/m^2), Ambient Temperature (˚C), Wind Speed (m/s) and Relative Humidity (%) were collected and compared with physico-chemical parameters.

3.6.Statistical Analysis

To assess the complex relationship between the variables statistical method was used. For which, IBM SPSS 22 (SPSS Inc., Chicago, IL, USA) and Microsoft Excel 2016 were used.

3.6.1. Descriptive Statistics

Descriptive statistics was applied to summarize and describe the basic features of the data gathered in the present study.

3.6.2. Correlation

Correlation was applied between physico-chemical parameters and between heavy metals as well to measure the amount of variation or dispersion between parameters. Correlation was applied among meteorological and physico-chemical parameters to measure the impact of meteorological parameters on water quality.

3.6.3. ANOVA

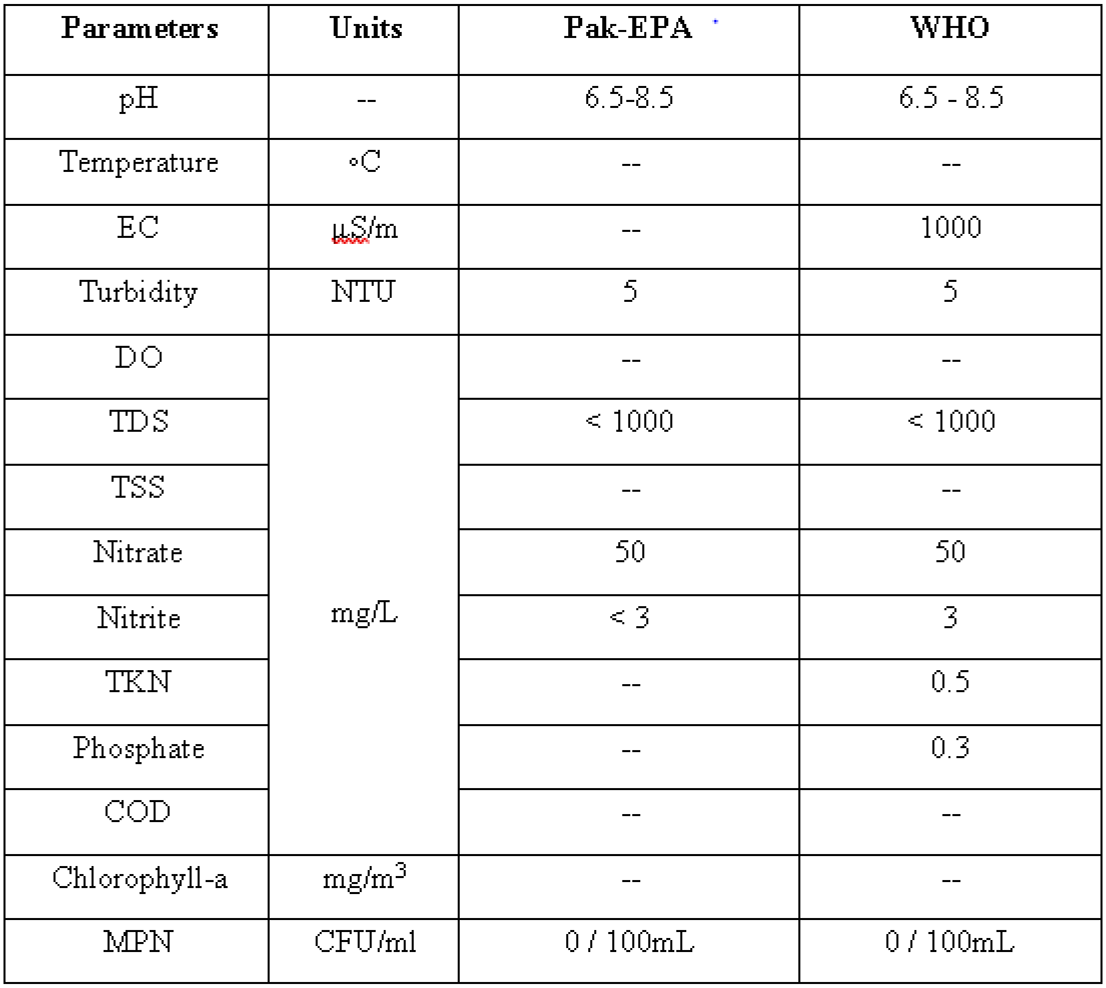
ANOVA was applied and the basic purpose was to measure significant differences between groups.

Chapter 4

4. Result and discussion

The purpose of this research was to examine the concerns with water quality. Water samples obtained from NUST Lakes were tested using WHO and Pak-EPA standards to determine physicochemical and microbiological characteristics as shown in Table 4.1.

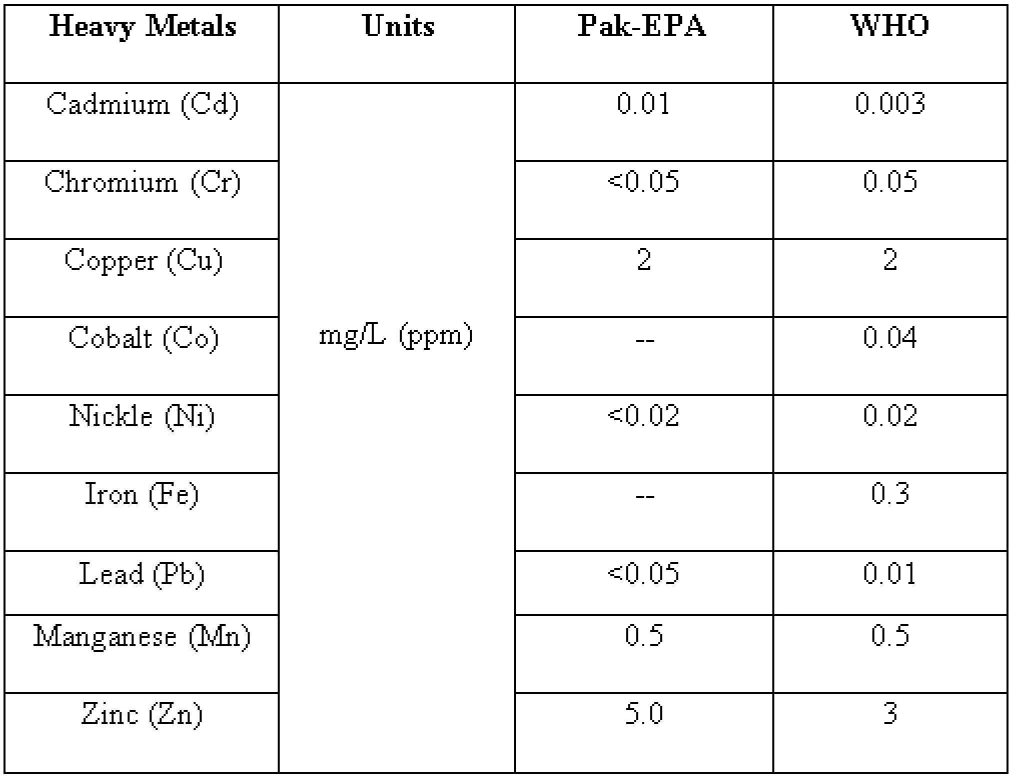
Table 4.1: Physicochemical and microbiological standards for water quality assessment



Parameters	Units	Pak-EPA	WHO
pH	--	6.5-8.5	6.5 - 8.5
Temperature	°C	--	--
EC	µS/m	--	1000
Turbidity	NTU	5	5
DO	mg/L	--	--
TDS		< 1000	< 1000
TSS		--	--
Nitrate		50	50
Nitrite		< 3	3
TKN		--	0.5
Phosphate		--	0.3
COD		--	--
Chlorophyll-a	mg/m^3	--	--
MPN	CFU/ml	0 / 100mL	0 / 100mL

For heavy metals analysis out, of 6 sampling sites, 3 sampling sites were selected for water and sediment sample collection i.e., inlet of lake 1, lake 2 and lake 3. The reason for the selection of these three sites was that all the lakes are inter-connected and the water of one lake falls into the subsequent lake and because of the presence of coarse particles at that sites. The obtained results were analyzed against the WHO and Pak-EPA standards as shown in Table 4.2.

Table 4.2: WHO and Pak-EPA permissible limits for Heavy Metals



Heavy Metals	Units	Pak-EPA	WHO
Cadmium (Cd)	mg/L (ppm)	0.01	0.003
Chromium (Cr)		<0.05	0.05
Copper (Cu)		2	2
Cobalt (Co)		--	0.04
Nickle (Ni)		<0.02	0.02
Iron (Fe)		--	0.3
Lead (Pb)		<0.05	0.01
Manganese (Mn)		0.5	0.5
Zinc (Zn)		5.0	3

4.1.Walk-through surveys and water sample collection

NUST Lakes were constructed by authorities for the collection and storage of rainwater so that the water can be further used, but due to direct discharge of wastewater from the surroundings sources including wastewater from hostels, café (C-2) and residential area near lake 3 and external sources including G-13 and H-13, these lakes get polluted, resulting in the destruction of aesthetic quality of lakes. Excessive discharge of untreated waste, effluents, and runoff into the lakes are the main causes of pollution.

Lake 1

At lake 1, the water looked murky, and a significant amount of foam formation was observed because of wastewater intrusion (from surrounding hostels) and excessive nutrients input (Fig 4.1). Algal and excessive vegetative growth was also observed. Unpleasant odor, direct dumping of garbage and wastewater from surrounding was observed. During sampling at regular time intervals, water from a few inlets feeding water to the Lake 1 was observed.

Figure 4.1: Lake 1 Sampling points

Lake 2

At lake 2, foaming was observed, and water intrusion was sensed (likely due to the external water discharge) at the sampling sites (Fig 4.2), however, no apparent source could be seen due to limited mobility, owing to heavy vegetation. Direct discharge from surrounding, plastic bags, massive algal growth and unpleasant odor in water were observed. Water at this lake was more turbid, probably due to the presence of ducks and their fecal material, which may further increase the concentration of suspended particles in water.

Figure 4.2: Lake 2 Sampling points

Lake 3

The water quality at lake 3 looks quite well, compared to two other lakes, but excessive plant growth and moderate algal growth was observed (Fig 4.3). Like the other two lakes, this lake also had an unpleasant odor.

Figure 4.3: Lake 3 Sampling points

4.2.Correlation with Meteorological Parameters

Meteorological variables such as changes in DNI **(direct normal irradiation)**, ambient temperature, wind speed, and rainfall patterns will affect water quality and even water ecosystems, and specific effects will vary among different regions and types of water bodies, to observe that change data for some variables were obtained shown in Figure 4.4.

During sampling period maximum DNI (136.9 W/m^2) was observed in the month of October due to maximum ambient temperature which was (21˚C) while wind speed remains constant with little variation throughout the sampling period which ranges from (1.6 to 2.5 m/s) during sampling period. Maximum rainfall which was (111.6 mm) observed in the month of January whereas minimum (16.02 mm) was observed in the month of December.

Throughout the sampling period changes in meteorological parameters were observed which in turn impact the water quality. According to Zhang et al., (2017) water quality in highly eutrophic lakes may be sensitive to meteorological factors, whereas water quality in mesotrophic lakes was not influenced by meteorological variations due to improved buffer capacity and the regulation effect of algae production.

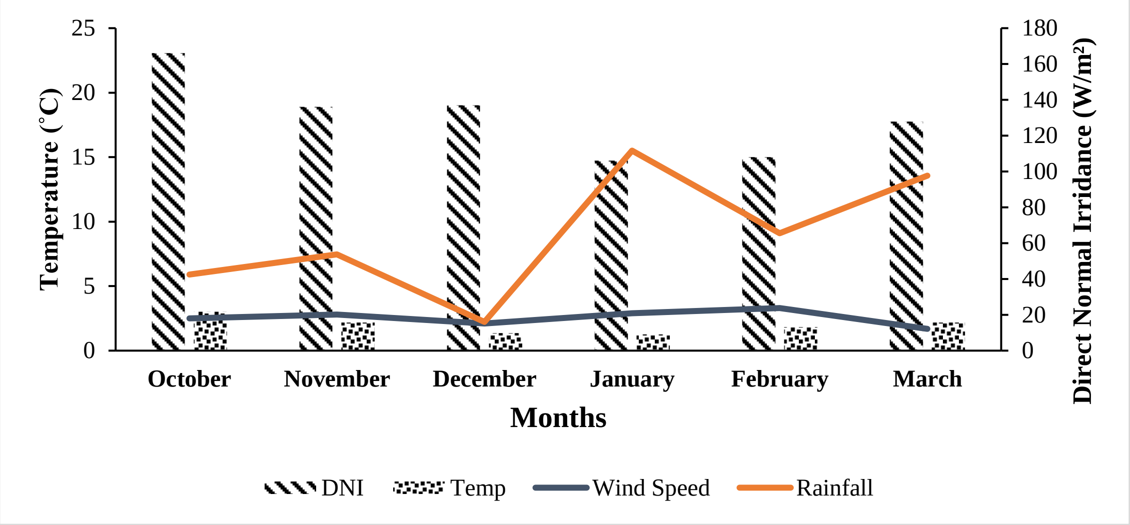


Figure 4.4: Meteorological Variation during sampling period

4.3.Physicochemical and Microbial Analysis:

4.3.1. pH

The value for pH ranged from 7.49-8.44 during the study period. The pH of all the sampling sites was found to be alkaline which is probably due to the buffer system developed by carbonates and bicarbonates (Loucif et al., 2020). The pH profile of all the sampling sites showed a decreasing trend and maximum values were observed in the month of October. The pH at the lake 1 inlet was slightly high as compared to other locations, because of the direct intrusion of nutrients and organic load.

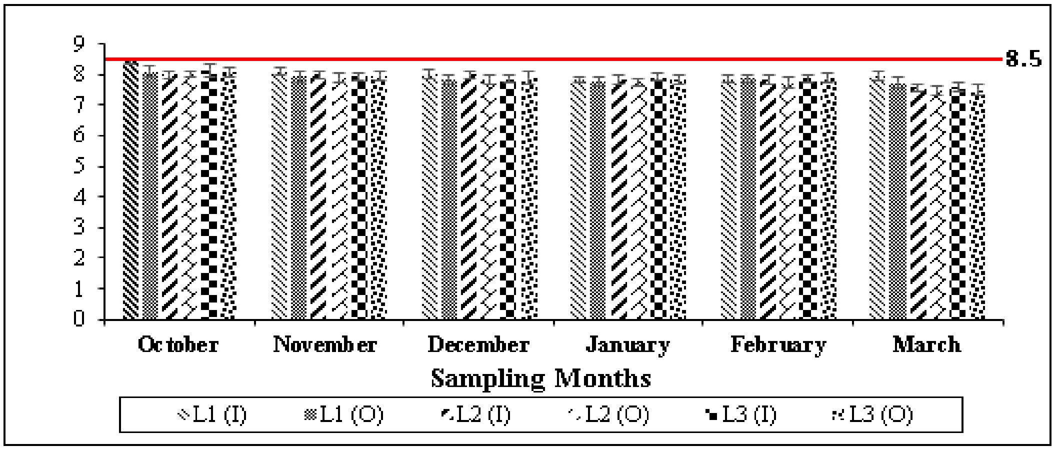


Figure 4.5: Average profile of pH at all sampling sites

4.3.2. Temperature

The temperature ranged from 13.10-26.50˚C during the study period. The temperature of lakes is impacted by many factors including presence of vegetation, season, time of the day and total dissolved solids present in water (Tibebe et al., 2019). The temperature profile of all the selected sites showed a decline from 26.50˚C to 13.10˚C. In October, due to slightly warm weather the temperature of all the sampling sites were around 26˚C and with the weather getting cold, the temperature of lakes also decreased and was lowest in the month of January. Overall, temperature at all sampling sites remained constant with slight variation.

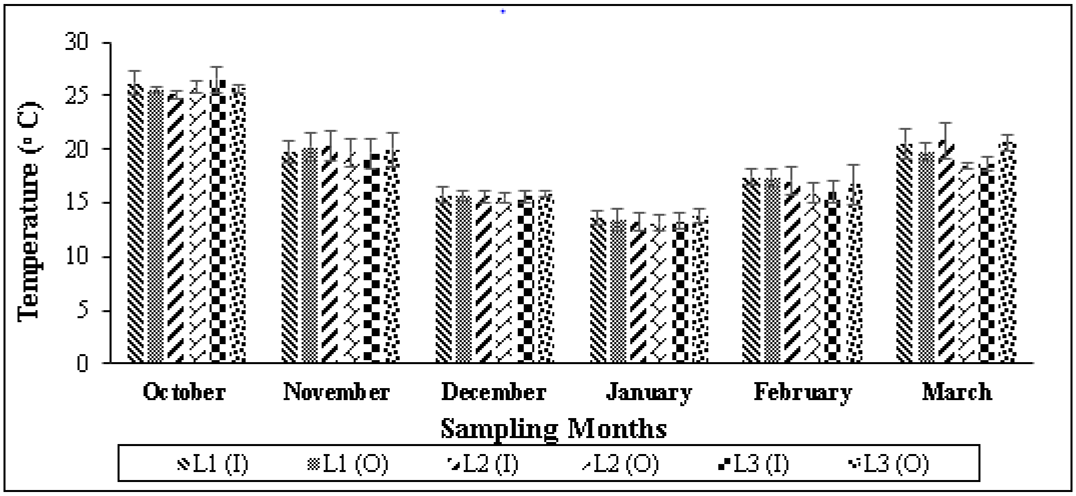


Figure 4.6: Average profile of temperature at all sampling sites

4.3.3. Electrical Conductivity

The value for EC ranged from 582-1516 µS/cm during the study period. During study period mostly the value for EC was above the permissible limit by WHO i.e., 1000 µS/cm. The maximum conductivity was recorded in the month of January. Most of the time, decreasing trend of EC value was found from L1 › L2 › L3 in different months, which was probably due to the dilution factor resulting in the decrease of conductivity. Lake 1 inlet shows high EC trend throughout the study, because of the direct discharge of wastewater. Electrical conductivity shows direct relation with dissolved solids, and high values of EC were indicator of contaminants in surface water (Wang et al., 2019). The probable reason for the high EC in the month of January could be runoff because that brings pollutants such as dissolved solids, nutrients, dirt, animal waste directly to streams and lakes.

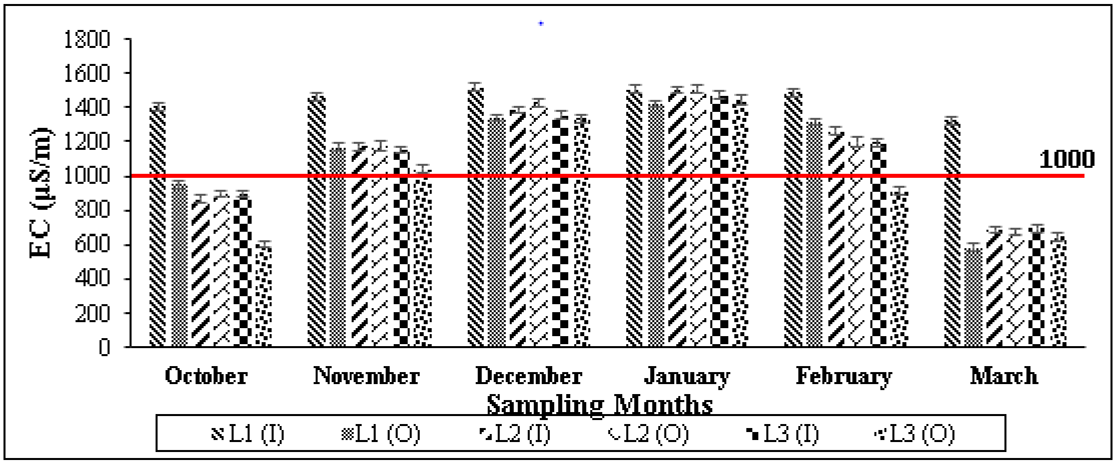


Figure 4.7: Average profile of EC at all sampling sites

4.3.4. Dissolved oxygen

The DO ranged from 6.90-11.60 mg/L during the study period. Maximum values were observed during winter in the month of December and January which was 11.25 and 10.75 respectively, while low values were observed in the remaining months. DO is affected by temperature level in a water body and is found to be critical for the survival of aquatic organisms for aerobic respiration. During sampling period, all the sites showed almost similar trend with little variation. Ali et al., (2004) also reported the same results and observed maximum values in winters due to temperature variations. Dissolved oxygen shows inverse relationship with water temperature.

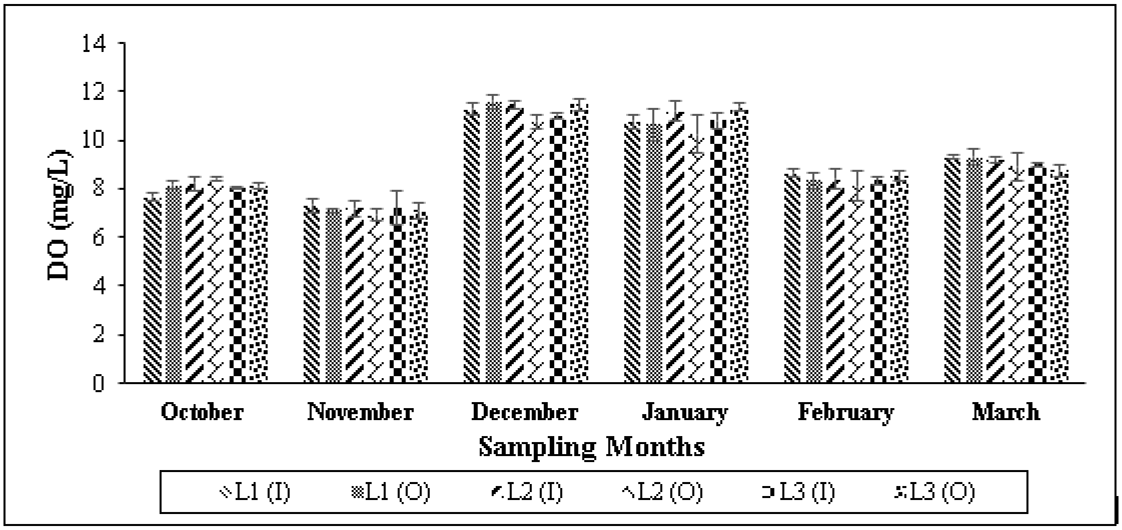


Figure 4.8: Average profile of DO at all sampling sites

4.3.5. Turbidity

The turbidity ranged from 10.00-98.30 NTU during the study period. In all the months', turbidity recorded was higher than the permissible limits. High turbidity forms the lake water cloudy and the probable reason for high turbidity include silt, mud, algae, presence of vegetation and waste. Ouma et al., (2016) also reported high turbidity in surface water and associated the high turbidity with high coliform load. Turbidity also shows decreasing trend of value from L1 › L2 › L3 and the probable reason for the high turbidity at lake 1 is direct disposal of untreated water, and at lake 2 presence of ducks could be the probable reason for turbidity.

4.3.6. TDS

The value of TDS ranged from 322.50-878.33 mg/L during the study period. Presence of organic and inorganic content in water represent the TDS values in water. The values for TDS were within the range but were at the higher end. TDS shows linear relationship with EC, and just like EC, maximum value of TDS was observed in January and most of the time decreasing trend of TDS was found from L1 › L2 › L3 in different months. Maximum values of TDS were observed at lake 1 inlet, and sometimes at lake 2 outlet due to mixing of pollutants from anthropogenic activities, such as the mixing of sewerage probably from hostels and garbage dumping.

Indeed, high concentration of TDS enhances the nutrient status of water body which results into eutrophication of aquatic ecosystem (Pradeep et al., 2012)

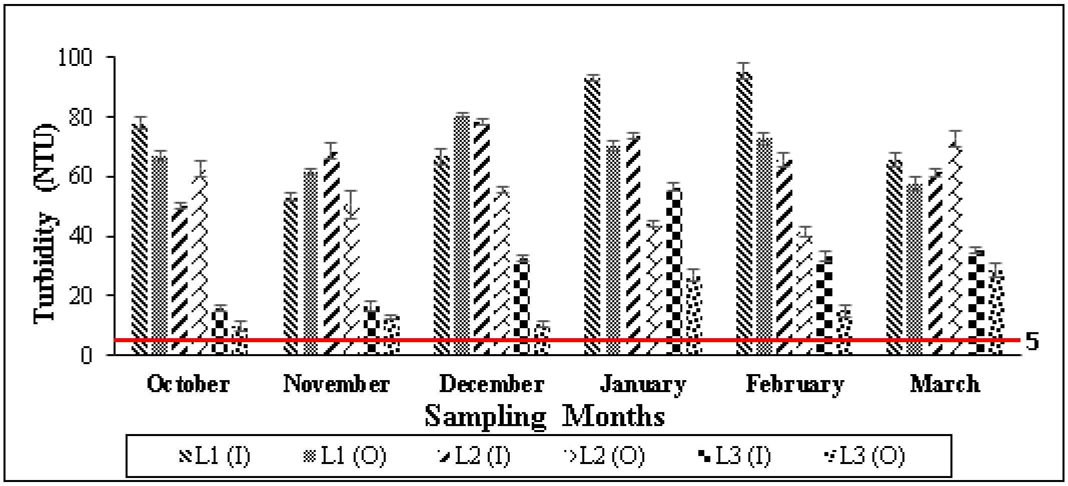


Figure 4.9: Average profile of turbidity at all sampling sites

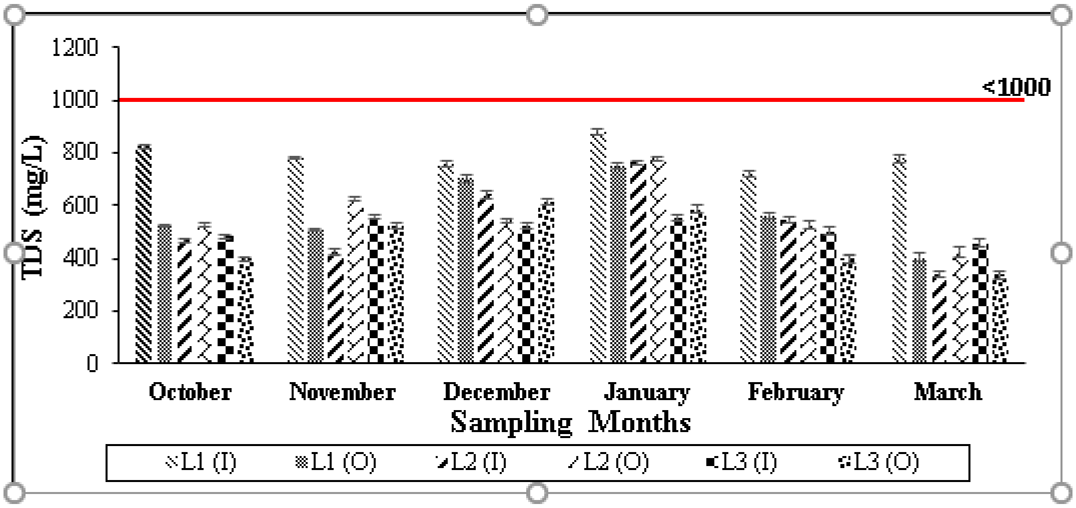


Figure 4.10: Average profile of TDS at all sampling sites

4.3.7. TSS

The values of TSS ranged from 15-115 mg/L during the study period. In a water body, high TSS may often be associated with higher mean concentrations of bacteria, nutrients, clay, silt, plankton, and metals in water. In all the sampling months almost, similar values were observed with little variation and most of the time decreasing trend of TSS was observed from L1 › L2 › L3 in different months. Mostly high values were observed at lake 1 inlet and sometimes at lake 2 outlet as well. The suspended solids result in the turbid appearance of water and this also depends on landscape features, seasonal regimes of rainfall and discharges in water body (Loucif et al., 2020).

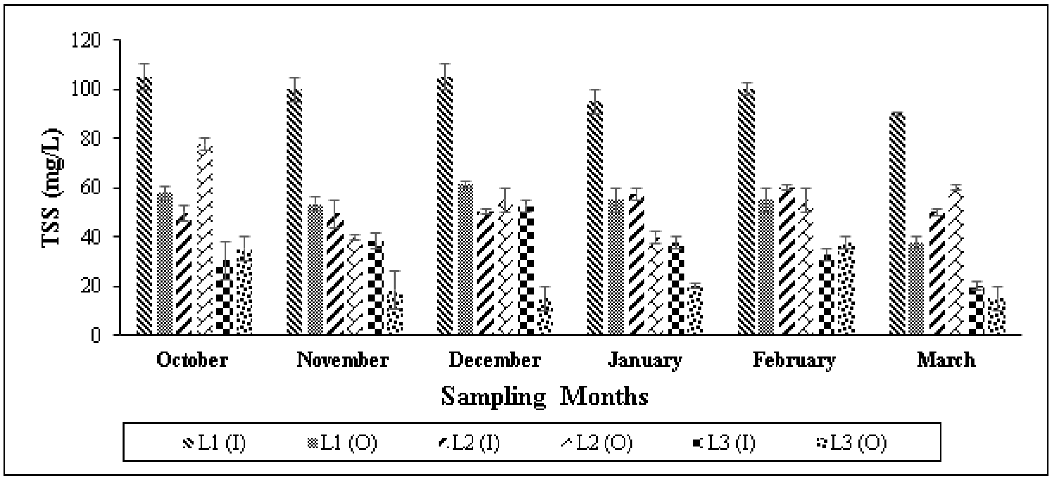


Figure 4.11: Average profile of TSS at all sampling sites

4.3.8. Nitrate-Nitrogen

The value of Nitrates ranged from 3.86-12.44 mg/L during the study period. The concentration of nitrates was found to be within the permissible limit. Nitrates may occur naturally in surface and groundwater. The possible source of nitrates in the lake water could be runoff carrying large amount of nutrients with the effluent into the lakes. Other than that, direct disposal of untreated wastewater, animal waste and decaying plant debris were also the key causes of nitrate. The value for nitrates remains constant with little variation throughout the study period, and lake 1 shows the maximum values for nitrates throughout the study period.

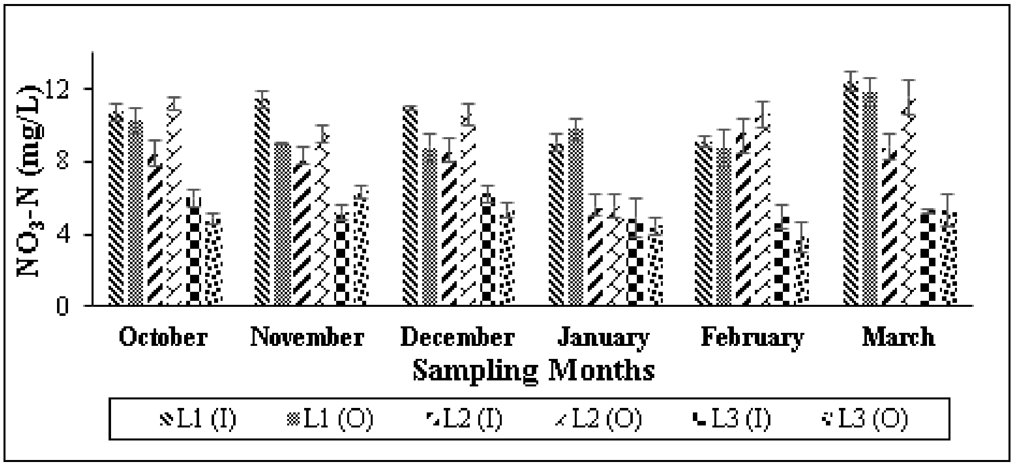


Figure 4.12: Average profile of Nitrate-nitrogen at all sampling sites

4.3.9. Nitrite-Nitrogen

The value of Nitrites ranged from 26-168 mg/L during the study period. When ammonium is transformed into nitrates by microscopic organisms, then typically nitrite (NO_2) is form as an intermediate product and is therefore occasionally raised in water body for long period of time. Nitrite is also a transitional product, as nitrate transforms to nitrogen gas through denitrification. In these lakes the concentration of nitrite was far above the permissible limit. Mostly elevated concentration of nitrite was observed at lake 1 inlet because of direct discharge of organic wastes or sewage at this point.

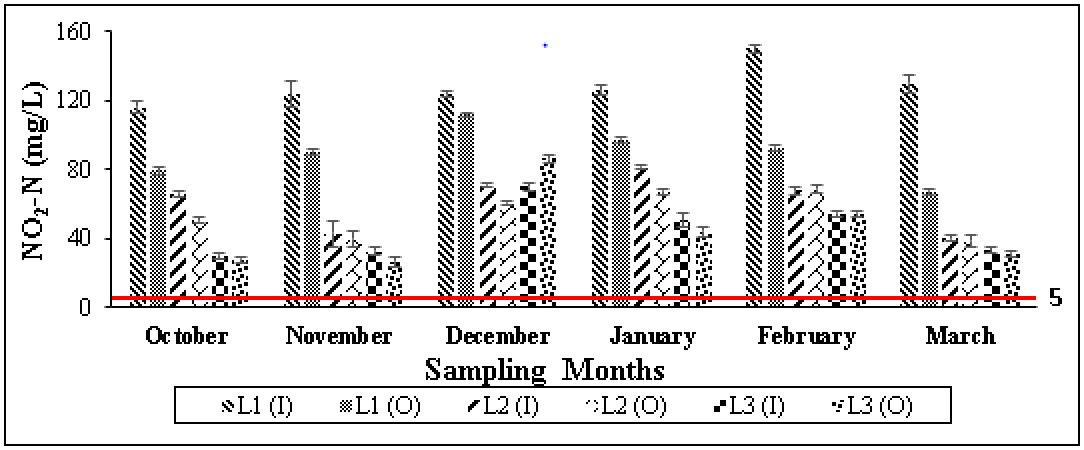


Figure 4.13: Average profile of Nitrites-nitrogen at all sampling sites

4.3.10. Total Kjeldahl Nitrogen

The values of TKN ranged from 25.20-86.83 mg/L during the study period. The values for TKN for all sampling sites exceed the WHO permissible limit. TKN is a measure of both organic forms of nitrogen and ammonia. The maximum value of TKN were observed during the month of January, and like all other parameters lake 1 inlet depicts the high values due to direct discharge of nutrients rich water. Typically, in surface water the fraction of organic nitrogen of TKN is much higher than the ammonium-nitrogen fraction, and in surface water where algae growth and phosphate content is high, the values for TKN is also elevated. Kanownik et al., (2019) also reported high values of total nitrogen in surface water during winters as compared to summers, due to low temperature and negligible nitrogen uptake during this period by Phyto benthos, algae and macrophytes.

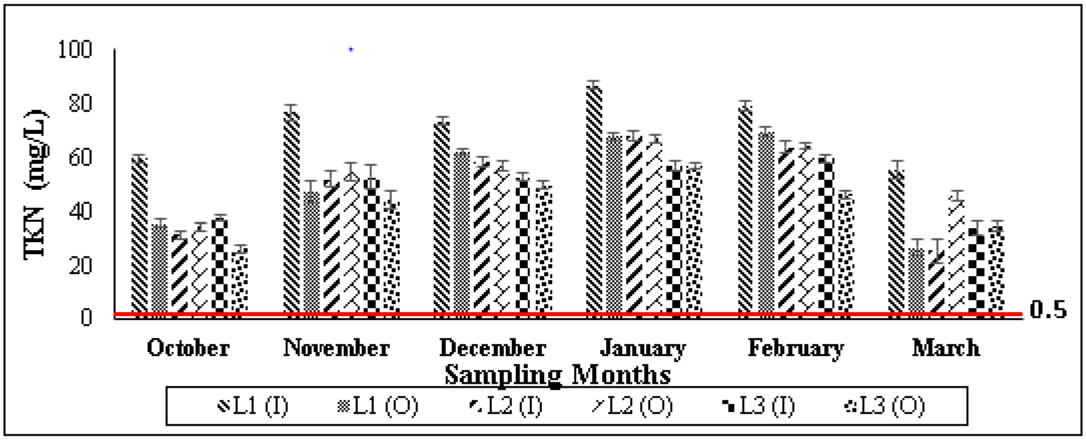


Figure 4.14: Average profile of TKN at all sampling sites

4.3.11. Phosphate-Phosphorous

The values of phosphate ranged from 2.25-30.57 mg/L during the study period. The values for phosphates were also far above the permissible limit by WHO. The values for phosphate remain constant throughout the study period with little variations and show decreasing trend in values from L1 › L2 › L3. Possible causes of phosphate in lakes could be discharge of human waste, animal waste and detergents. Rain and runoff may also be the one source of high phosphate concentration in lakes.

Aeriyanie et al., (2020) also reported that in eutrophic urban lake, total phosphorus shows little variation in both wet and dry seasons, and throughout the study period the concentration of total phosphorous exceeded 10 mg/L which indicated persistent eutrophication in the lakes.

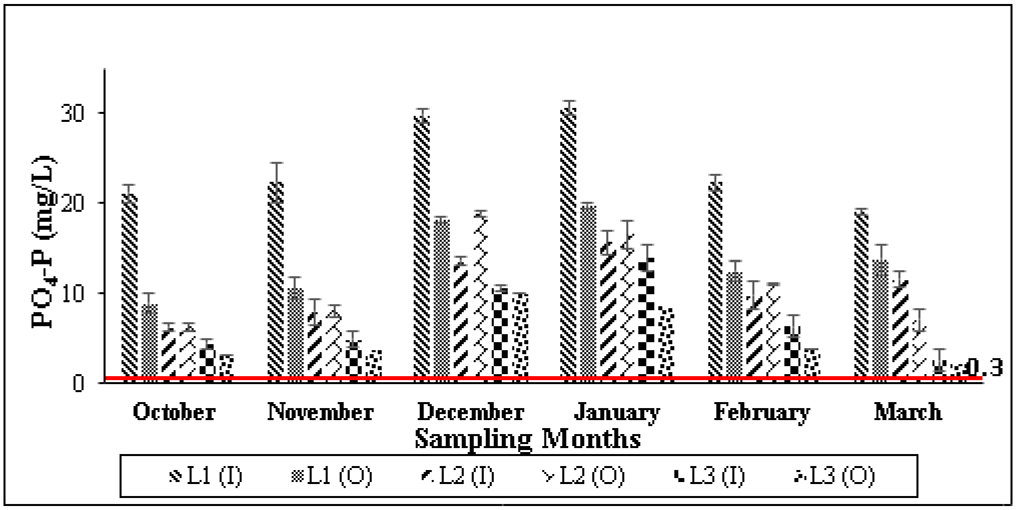


Figure 4.15: Average profile of phosphate at all sampling sites

4.3.12. Chemical Oxygen Demand

The values of COD ranged from 23.35-216 mg/L during the study period. COD is an important parameter to assess the quality of water bodies. Maximum values were observed in the month of October and showed decreasing trend with the decrease in temperature. Almost all sampling sites showed moderate to high value of COD, but like all other parameters COD was also measured high at lake 1 inlet showing the pollution load that is caused by the mixing of sewage water from hostels as well as from external sources (G-13 and H-13) and high COD concentration in water shows the presence of all forms of organic matter, both biodegradable and nonbiodegradable in water and hence, indicates the level of pollution in water ecosystem (Zeb et al., 2011).

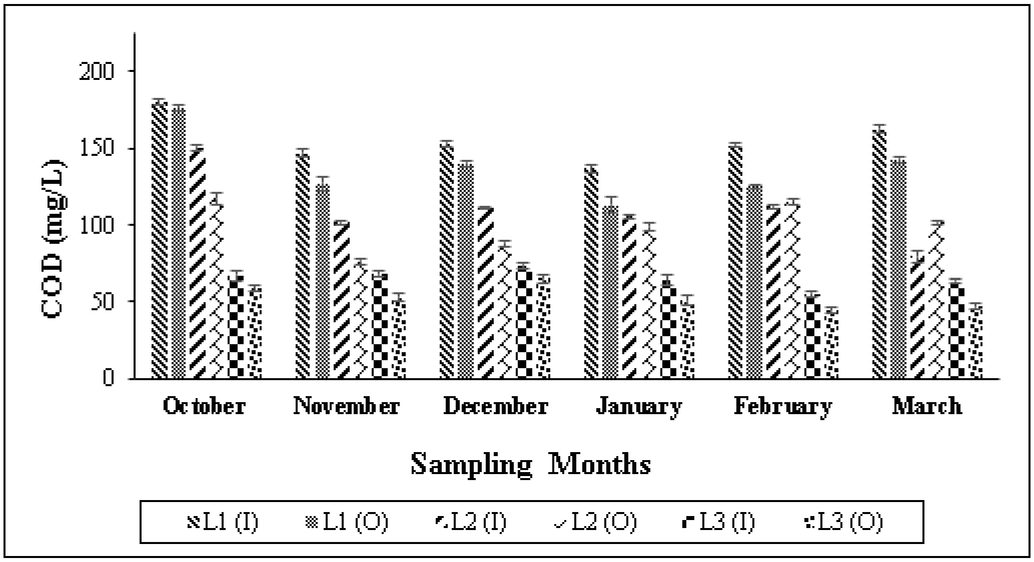


Figure 4.16: Average profile of COD at all sampling sites

4.3.13. . Chlorophyll-A

The value of chlorophyll-a ranged from 4.34 -67.80 mg/m^3 during the study period. Throughout the sampling period concentration for chlorophyll remained constant with little variation. Maximum concentration was observed at lake 2 outlet due to excessive vegetation and algal growth. High levels of nutrients i.e., nitrogen and phosphate act as a limiting factor and results in the excessive algae, thus makes water appearance green and causes odor problem.

Tibebe et al., (2019) also reported that according to OECD, 1982 classification of trophic state, 8.00 µg/L of chlorophyll-a concentration is the threshold for eutrophication and in his study, all the sampling sites were found to have chlorophyll-a concentrations far above the prescribed limit. The possible causes might be nutrient, high wind, turbidity, rainfall in relation with plenty of plankton in lake.

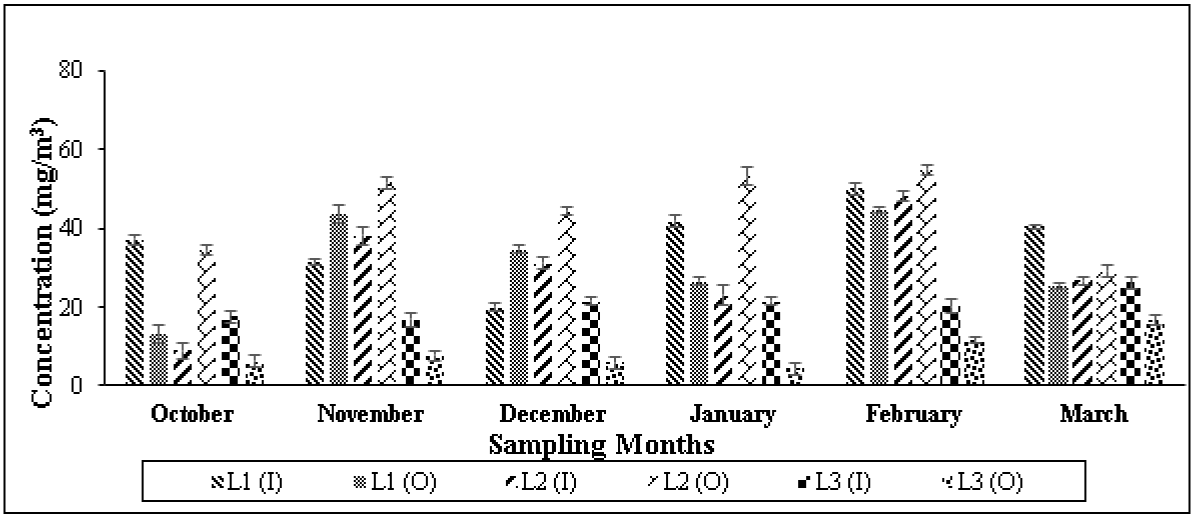


Figure 4.17: Average profile of chlorophyll-a at all sampling sites

4.3.14. MPN

For the bacteriological analysis, MPN with serial dilution was performed. The results ranged from 3.6×10^{2} to 1.1×10^{7} CFU/mL during the study period. All the sampling sites showed constantly high results throughout the study which, shows the high E. coli in the lakes water and these agents are mainly derived from humans and animal feces, surface water receiving wastewater discharges and rainwater (Table 4.3).

Table 4.3: Microbial profile of sampling sites

Sampling Points	October	November	December	January	February	March
L1 (Inlet)	1.1×10^{7}	4.6×10^{6}	2.1×10^{6}	2.1×10^{5}	1.1×10^{6}	1.1×10^{6}
L1 (Outlet)	4.6×10^{5}	7.4×10^{4}	1.2×10^{5}	1.6×10^{4}	4.6×10^{5}	2.4×10^{5}
L2 (Inlet)	9.3×10^{4}	9.2×10^{3}	2.4×10^{4}	2.1×10^{3}	9.3×10^{4}	9.2×10^{3}
L2 (Outlet)	4.6×10^{4}	9.2×10^{3}	1.6×10^{4}	4.6×10^{4}	4.6×10^{3}	4.3×10^{3}
L3 (Inlet)	4.3×10^{3}	3.6×10^{2}	3.6×10^{2}	3.6×10^{2}	2.3×10^{2}	3.6×10^{2}
L3 (Outlet)	3.6×10^{3}	3.6×10^{3}	1.1×10^{2}	1.1×10^{1}	1.5×10^{2}	1.1×10^{2}

4.4.Heavy Metals Analysis

An attempt was made to identify the presence of heavy metals in water and sediments for the better understanding of pollution status of lakes and these metals are recognized as an essential predictor of aquatic degradation. The concentration of heavy metals in water samples was nominal as no industrial zone is located near the lakes but only few metals were found to be exceeding the permissible limit including Cd, Co, Fe and Mn in water samples. Most of the heavy metals were found in the samples taken for lake 1. The possible reason for the presence of these metals in water include natural processes such as, atmospheric deposition, erosion, and weathering of rock as well as anthropogenic inputs, such as, untreated wastewater and urban waste (Iqbal et al., 2013).

While in the sediment samples most of the selected heavy metals were found to be higher than permissible limits including Cd, Co, Fe, Ni, Pb and Mn. Among all metals the concentration of Fe was far more than the permissible limit in all the lakes. Ultimately, heavy metals accumulate on the sediment by suspended matters directly during adsorption and sedimentation processes. Evaluating the content of heavy metals and their contamination in sediments contributes to better understanding of their behavior in the aquatic environment. Javed et al., (2018) also reported the higher concentration of Fe in sediments of Namal Lake, Pakistan. The high content of iron in the sediment is due to the transport of iron minerals that are formed during soil/rock weathering and eventually settle in the form of insoluble oxides at Lake. The results for heavy metals are shown in Table 4.4.

Cadmium (Cd)

Cadmium is extremely toxic, even at very low concentrations, and can damage organs like the kidneys, liver, and lungs. As a result, trace and ultra-trace Cd determinations in environmental and biological samples are now more common.

Copper (Cu)

Although copper does not decompose in the atmosphere, but it accumulates in animals and plants. Some of the absorption of copper into the body is essential for the health of human. Acute industrial exposure may result in chronic copper poisoning through copper mists, dust or fumes.

Chromium (Cr)

Chromium is carcinogenic in nature, encourages allergic and asthmatic reactions, and is 1000 times more toxic than trivalent chromium. Diarrhea, gastrointestinal, intestinal bleeding, cramps, liver, and kidney damage are all side effects of hexavalent chromium exposure.

Cobalt (Co)

Apart from natural cobalt concentration in the environment, cobalt contamination has been on the rise in recent years. It is commonly found in combination with other metals like Cu and Ni.

Nickel (Ni)

Nickel might enter the environment through both anthropogenic and natural sources, such as weathering of minerals and rocks. More than 90% of the nickel in the marine setting is contained in sedimentary particulate matter. Nickel is an essential trace element for marine species, but at higher concentrations, it can be harmful.

Iron (Fe)

Iron may be found naturally in lakes, rivers, and underground water. Natural deposits, iron ore mining, industrial wastes, and corrosion of iron-containing metals can all release iron into the water.

Lead (Pb)

Lead contaminates the soils, air, and water as it is emitted into the environment. Lead dust will last forever in the atmosphere. Adults who are exposed to lead can experience high blood pressure, cardiovascular symptoms, hypertension, and reduced kidney functioning.

Manganese (Mn)

Manganese is a limiting nutrient in lakes and plays a role in the control of other nutrients as well. It oxidizes much like iron and is insoluble in the oxidized state. Manganese is used in a variety of manufacturing processes and consumer goods. Municipal wastewater discharge, sewage sludge, emissions produced during alloy, steel, and iron processing, and to a lesser extent emission from the combustion of fuel additives, are the major man-made causes of potential manganese.

Zinc (Zn)

Most zinc in lakes, rivers, and streams does not dissolve and instead settles at the bottom. Any of the fish in these waters may have high zinc levels. High levels of zinc are often found in soil, water, and air, along with high levels of other metals such as lead and cadmium.

Table 4.4: Concentration of Heavy Metals in lakes (Water & Sediments)

Sr. No.	Heavy Metals	Permissible Limit	Samples/Sampling Sites					
			Lake 1		Lake 2		Lake 3	
			Water	Sediments	Water	Sediments	Water	Sediments
1.	Cadmium (Cd)	**0.003**	**0.0066**	**0.0719**	**0.0155**	**0.063**	**0.0166**	**0.0642**
2.	Chromium (Cr)	**0.05**	0.0001	0.0587	0.0005	0.044	0.0006	0.0049
3.	Copper (Cu)	**2**	0.0021	0.0554	0.0037	0.0695	0.0008	0.0569
4.	Cobalt (Co)	**0.04**	**0.1082**	**0.3966**	**0.0649**	**0.1947**	**0.1298**	**0.3101**
5.	Nickel (Ni)	**0.02**	0.0289	**0.4175**	0.0212	**0.2767**	0.0272	**0.3201**
6.	Iron (Fe)	**0.3**	0.1447	**8.6007**	0.1262	**16.7858**	0.167	**5.2465**
7.	Lead (Pb)	**0.01**	**0.009**	0.0122	**0.0029**	**0.301**	**0.004**	0.0102

8.	Manganese (Mn)	**0.5**	0.1048	**1.0887**	0.1033	**1.0846**	0.0992	**1.2916**
9.	Zinc (Zn)	**3**	0.1094	0.2149	0.0989	0.1873	0.1346	0.291

4.5.Statistical Analysis

Correlation coefficient was carried out to determine significant correlation among variables.

4.5.1. Correlation among Physico-chemical Parameters

Most of the parameters show positive correlation with each other as shown in Table 4.4

pH didn't show any significant relationship with any of the parameter. Temperature shows a negative correlation with EC and DO as with the decrease in temperature water holds more oxygen molecules and this result in increased DO level.

EC shows a strong positive correlation with TKN and TDS due to direct intrusion of waste and also due to elevated levels of dissolved matter in water. TDS shows a positive correlation with PO_4 due to direct to nutrient rich water directly into water.

Turbidity and NO_3-N shows a positive correlation with COD with indicates the excess availability of nutrients and also results in persistent eutrophication. Turbidity didn't show any significant relation with TSS but they both are related in a way that high concentration of TSS results in turbid appearance of water.

PO_4 shows a positive correlation with TKN and NO_2-N as these all act as a limiting factor and higher values causes high productivity and ultimately leads to eutrophication of lakes.

4.5.2. Correlation among Heavy Metals

Results indicated that most of metal showed positive linear correlation which is due to the discharge of polluted in lakes shown in Table 4.5

Table 4.5: Correlation Matrix Physico-chemical Parameters

	Ph	**Temp (°C)**	**EC (μs/cm)**	**DO (mg/L)**	**Turbidity (NTU)**	**TDS (mg/L)**	**TSS (mg/L)**	**NO_3-N (mg/L)**	**NO_2-N (mg/L)**	**TKN (mg/L)**	**COD (mg/L)**	**PO_4-P (mg/L)**	**Chl-A (mg/m^3)**
pH	**1**												
Temperature (°C)	**.478**** **.003**	**1**											
EC (μs/cm)	**.291** **.085**	**-.607**** **.000**	**1**										
DO (mg/L)	**-.270** **.111**	**-.666**** **.000**	**.431**** **.009**	**1**									
Turbidity (NTU)	**.020** **.907**	**-.160** **.352**	**.372*** **.025**	**.198** **.247**	**1**								
TDS (mg/L)	**.340*** **.043**	**-.363*** **.030**	**.817**** **.000**	**.351*** **.036**	**.486**** **.003**	**1**							
TSS (mg/L)	**.351*** **.036**	**.198** **.246**	**.190** **.267**	**-.012** **.944**	**.546**** **.001**	**.457**** **.005**	**1**						
NO_3-N(mg/L)	**.117** **.496**	**.215** **.207**	**.066** **.700**	**-.126** **.463**	**.654**** **.000**	**.280** **.098**	**.497**** **.002**	**1**					
NO_2-N(mg/L)	**.264** **.120**	**-.223** **.191**	**.626**** **.000**	**.264** **.119**	**.646**** **.000**	**.768**** **.000**	**.630**** **.000**	**.505**** **.002**	**1**				
TKN (mg/L)	**.103** **.549**	**-.642**** **.000**	**.883**** **.000**	**.296** **.080**	**.473**** **.004**	**.802**** **.000**	**.311** **.064**	**.162** **.344**	**.676**** **.000**	**1**			
COD (mg/L)	**.366*** **.028**	**.207** **.226**	**.272** **.108**	**-.029** **.868**	**.752**** **.000**	**.524**** **.001**	**.654**** **.000**	**.785**** **.000**	**.770**** **.000**	**.312** **.064**	**1**		
PO_4-P (mg/L)	**.161** **.349**	**-.398*** **.016**	**.694**** **.000**	**.443**** **.007**	**.676**** **.000**	**.810**** **.000**	**.579**** **.000**	**.507**** **.002**	**.850**** **.000**	**.736**** **.000**	**.642**** **.000**	**1**	
Chl-A (mg/m^3)	**-.104** **.546**	**-.200** **.243**	**.368*** **.027**	**-.128** **.456**	**.619**** **.000**	**.370*** **.026**	**.337*** **.044**	**.509**** **.002**	**.434**** **.008**	**.512**** **.001**	**.429**** **.009**	**.443**** **.007**	**1**

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

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

Table 4.6: Correlation Matrix Heavy Metals

	Cd mg/L (ppm)	Cr mg/L (ppm)	Cu mg/L (ppm)	Co mg/L (ppm)	Ni mg/L (ppm)	Fe mg/L (ppm)	Pb mg/L (ppm)	Mn mg/L (ppm)	Zn mg/L (ppm)
Cd mg/L (ppm)	**1**								
Cr mg/L (ppm)	**.776** **.070**	**1**							
Cu mg/L (ppm)	**.965**** **.002**	**.749** **.087**	**1**						
Co mg/L (ppm)	**.885*** **.019**	**.693** **.127**	**.765** **.076**	**1**					
Ni mg/L (ppm)	**.979**** **.001**	**.797** **.058**	**.923**** **.009**	**.947**** **.004**	**1**				
Fe mg/L (ppm)	**.796** **.058**	**.808** **.052**	**.896*** **.016**	**.494** **.319**	**.724** **.104**	**1**			
Pb mg/L (ppm)	**.406** **.424**	**.501** **.312**	**.596** **.212**	**.002** **.996**	**.286** **.583**	**.865*** **.026**	**1**		
Mn mg/L (ppm)	**.974**** **.001**	**.652** **.160**	**.972**** **.001**	**.850*** **.032**	**.952**** **.003**	**.766** **.076**	**.406** **.425**	**1**	
Zn mg/L (ppm)	**.861*** **.028**	**.378** **.460**	**.813*** **.049**	**.843*** **.035**	**.849*** **.033**	**.492** **.321**	**.118** **.824**	**.922**** **.009**	**1**

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

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

4.5.3. Descriptive Statistics

Statistical methods were used in this analysis to uncover complex relationships between variables. Basic parameters such as mean, minimum, maximum, range, standard deviation, variance, standard error, and skewness were estimated and calculated using Excel 2016. Summary statistics of all physicochemical parameters is shown in (Annex-B)

4.5.4. ANOVA

One-way ANOVA was used to explain the statistical differences in physicochemical parameters. F is the test statistic for one-way ANOVA; F statistics measure major differences within and between groups in one-way ANOVA (Annex-C)

Chapter 5

5. Conclusions and Recommendations

5.1.Conclusions

1. Only pH, TDS and Nitrates were found within the permissible limit of WHO and remaining all the physico-chemical parameters examined in this study exceeded the threshold established by WHO which shows an excessive and persistent level of pollution in lakes.
2. High concentration of turbidity, nitrogen, phosphates, and chlorophyll-a show that the lake is subjected to eutrophication.
3. All the three lakes were found to have high level of microbiological contamination which shows the direct discharge of sewage waste and poor quality of water.
4. Concentration of heavy metals in sediments were higher than water. Fe was present in excessive concentration in sediments for all three lakes.
5. Concentration of heavy metals in water is nominal as no industrial activity occured at the surrounding of lakes.
6. Meteorological variables were found to have an impact on quality of lakes water because water with poor quality is more vulnerable towards changes cause by climatic factors as compared to healthy water systems.

5.2. Recommendations

1. Identification and characterization of dominant algal species should be studied in detail.
2. Seasonal patterns and impacts of different variants like rain, water inflow should be studied in detail for the better understanding of all the factors.
3. Responsible authorities should make sure that no grey water or sewage inflow to the lakes occur.
4. Proper regular management and cleaning of lakes should be done, so that the lakes may be prevented from further degradation.
5. Wastewater treatment plants should be installed in the premises of lakes.

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Appendices

List of Lakes in Pakistan (ANNEXURE-A)

Lakes	**Location**	**Coordinates (Latitude, Longitude)**
Chitta Katha Lake	Azad Jammu Kashmir	34.9196 N, 74.5214 E
Banjosa Lake (Artificial Lake)		33.8101 N, 73.8158 E
Mangla Dam Lake (Artificial Lake)		33.2167 N, 73.7360 E
Ratti Gali Lake		34.8302 N, 74.0613 E
Saral Lake		34.9628 N, 74.0998 E
Subri Lake		34.1929 N, 73.3106 E
Baghsar Lake		33.0448 N, 74.1980 E
Jahlar Lake	Punjab/ Federal Capital Territory	32.4981 N, 72.0876 E
Khabikki Lake		32.3713 N, 72.1249 E
Namal Lake		32.4114 N, 71.4802 E
Swaik Lake		32.7355 N, 72.7226 E
Uchhali Lake		32.3334 N, 72.0108 E
Rawal Lake (Islamabad)		33.7027 N, 73.1261 E
Simli Lake (Islamabad)		33.4341 N, 73.2034 E
Attabad Lake	Gilgit Baltistan	36.2013 N, 74.523 E
Khalti Lake		36.1500 N, 73.2153 E
Karambar Lake		36.5302 N, 73.4226 E
Katpana Lake		35.1900 N, 75.3433 E
Naltar Lake		36.1423 N, 74.0454 E
Lower Kachura Lake		35.2648 N, 75.2644 E
Phander Lake		36.1021 N, 72.5647 E
Rama Lake		35.3304 N, 74.7856 E
Rush Lake		36.1028 N, 74.5257 E
Satpara Lake		35.2294 N, 75.6295 E
Sheosar lake		34.5928 N, 75.1404 E
Upper Kachura Lake		35.2648 N, 75.2644 E
Jarba Zhou lake		35.2143 N, 75.4200 E
Khalti Lake		36.1500 N, 73.2153 E
Drigh Lake	Sindh	27.5680 N, 67.9300 E
Hadero Lake		24.8325 N, 67.8600 E

Haleji Lake	Sindh	24.8059 N, 67.7795 E
Hamal Lake		27.449 N, 67.632 E
Keenjhar Lake		24.9525 N, 68.0358 E
Manchar Lake		26.4490 N, 67.6424 E
Shakoor Lake		24.1414 N, 69.0417 E
Chotiari Lake (Artificial Lake)		26.815 N, 69.348 E
Hanna Lake	Baluchistan	30.2558 N, 67.0986 E
Ansoo Lake	Khyber Pakhtunkhwa	34.4849 N, 73.4035 E
Dudipatsar Lake		35.0104 N, 74.0520 E
Kundol Lake		35.2515 N, 72.2553 E
Mahodand Lake		35.7139 N, 72.6510 E
Saiful Maluk Lake		34.8769 N, 73.6944 E
·Siri Lake		34.6312 N, 73.4920 E
Khanpur Lake (Artificial Lake)		33.8018 N, 72.9305 E
Tanda Lake (Artificial Lake)		33.5748 N, 71.3795 E
Tarbela Lake (Artificial Lake)		34.0936 N, 72.4820 E

Descriptive Statistics – (Annexure -B)

Variable	**Sampling Points**	**Mean**	**Min.**	**Max.**	**Range**	**Std. Dev**	**Variance**	**Std. error**	**Skewness**
pH	L1(Inlet)	8.0256	7.83	8.44	0.61	0.22	0.050	0.09120	1.582
	L1(Outlet)	7.8711	7.72	8.1	0.37	0.13	0.018	0.05592	0.866
	L2(Inlet)	7.8722	7.58	8.0	0.41	0.16	0.026	0.06591	-1.344
	L2(Outlet)	7.7816	7.47	8.01	0.53	0.18	0.032	0.07415	-0.808
	L3(Inlet)	7.8855	7.58	8.14	0.55	0.17	0.031	0.07301	-0.577
	L3(Outlet)	7.8577	7.49	8.08	0.59	0.19	0.039	0.08082	-1.384
Temp. (˚C)	L1(Inlet)	18.83	13.5	26.1	12.6	4.41	19.45	0.80066	0.734
	L1(Outlet)	18.65	13.4	25.5	12.1	4.23	17.90	1.72724	0.621
	L2(Inlet)	18.67	13.2	25.1	11.9	4.26	18.16	1.73989	0.319
	L2(Outlet)	18.07	13.1	25.8	12.7	4.44	19.79	1.81619	1.071
	L3(Inlet)	18.26	13.3	26.5	13.2	4.61	21.31	1.88497	1.241
	L3(Outlet)	18.76	13.8	25.6	11.8	4.22	17.88	1.72665	0.696
EC (µS/cm)	L1(Inlet)	1450	1324	1516	192.3	73.3	5378.1	29.939	-1.214
	L1(Outlet)	1129	582	1421	839	314.9	9920	128.5	-1.240
	L2(Inlet)	1144	683	1501	818	312.6	9772	127.6	-0.577
	L2(Outlet)	1146	672	1507	835	316.5	1002	129.2	-0.496
	L3(Inlet)	1128	692	1473	781	289.1	8360	118.0	-0.519
	L3(Outlet)	997	602	1444	842	347.4	1207	141.8	0.166
DO (mg/l)	L1(Inlet)	9.144	7.3	11.2	3.95	1.611	2.596	0.6578	0.259
	L1(Outlet)	9.186	7.1	11.6	4.5	1.683	2.834	0.6872	0.398
	L2(Inlet)	9.275	7.2	11.4	4.25	1.712	2.933	0.6992	0.392
	L2(Outlet)	8.888	6.9	10.7	3.85	1.423	2.027	0.5812	0.051
	L3(Inlet)	9.061	7.2	11.0	3.8	1.538	2.367	0.6281	0.381
	L3(Outlet)	9.205	7.1	11.4	4.35	1.789	3.202	0.7305	0.524
Turbidity (NTU)	L1(Inlet)	75.33	53.2	95.3	42.1	16.65	277.4	6.80	0.085
	L1(Outlet)	68.3	57.3	80.7	23.4	8.32	69.5	3.40	0.193
	L2(Inlet)	66.2	50	78.3	28.3	9.95	99.12	4.06	-0.676
	L2(Outlet)	54.45	41.5	72.5	31.0	11.6	136.8	4.77	0.571
	L3(Inlet)	31.7	16	56.3	40.3	14.80	219.1	6.04	0.685
	L3(Outlet)	17.4	10	28.9	18.9	8.35	69.74	3.40	0.805

Variable	**Sampling Points**	**Mean**	**Min.**	**Max.**	**Range**	**Std. Dev**	**Variance**	**Std. error**	**Skewness**
TDS (mg/l)	L1(Inlet)	789.0	717	878.3	160.8	55.3	3068.1	22.61	0.625
	L1(Outlet)	574.1	403	752.5	349	130.5	1703	53.2	0.315
	L2(Inlet)	529.2	342	761.5	419	153.3	2350	62.5	0.495
	L2(Outlet)	569.0	423	777.5	354	120.4	1451	49.19	1.017
	L3(Inlet)	511.0	456	553	96.5	39.02	1522	15.93	-0.215
	L3(Outlet)	476.0	338	615	277	113.6	1291	46.3	0.1006
TSS (mg/l)	L1(Outlet)	99.16	90	105	15	5.84	34.1	2.38	-0.66
	L2(Inlet)	53.28	37.5	61.2	23.7	8.218	67.5	3.35	-1.802
	L2(Inlet)	52.75	49.3	60	10.66	4.720	22.2	1.92	1.076
	L2(Outlet)	54.58	40	77.5	37.5	14.00	196.0	5.71	0.654
	L3(Inlet)	34.86	20	52.5	32.5	10.94	119	4.46	0.451
	L3(Outlet)	23.47	15	37.5	22.5	10.11	102	4.12	0.839
NO_3-N (mg/l)	L1(Inlet)	10.62	9.01	12.4	3.42	1.34	1.799	0.54	-0.1295
	L1(Outlet)	9.74	8.75	11.8	3.08	1.18	1.407	0.48	1.2781
	L2(Inlet)	8.12	5.47	9.55	4.07	1.39	1.947	0.56	-1.675
	L2(Outlet)	9.84	5.55	11.5	5.99	2.21	4.896	0.90	-1.969
	L3(Inlet)	5.42	4.87	6.24	1.36	0.56	0.323	0.23	0.716
	L3(Outlet)	5.01	3.85	6.35	2.49	0.85	0.728	0.34	0.309
NO_2-N (mg/l)	L1(Inlet)	131.2	115	168	52.3	18.69	349.5	7.63	2.120
	L1(Outlet)	78.22	40.5	111	71.2	26.79	717.8	10.9	-0.209
	L2(Inlet)	53.21	40.1	71.0	30.9	13.11	172.0	5.35	0.667
	L2(Outlet)	53.22	38.5	68.5	30.02	13.84	191.6	5.65	0.050
	L3(Inlet)	41.40	27.3	70.2	42.85	17.10	292.5	6.98	1.253
	L3(Outlet)	45.73	26.9	86.5	59.5	22.51	507.0	9.19	1.462
TKN (mg/l)	L1(Inlet)	71.7	55.3	86.8	31.53	12.04	145.0	4.91	-0.403
	L1(Outlet)	51.3	26.6	69.4	42.85	17.79	316.5	7.26	-0.401
	L2(Inlet)	49.68	25.2	68.0	42.85	17.63	310.9	7.19	-0.624
	L2(Outlet)	53.73	34.2	67.1	32.85	12.20	149.0	4.98	-0.725
	L3(Inlet)	48.75	33.6	59.4	25.75	10.55	111.4	4.31	-0.756
	L3(Outlet)	42.89	26.0	57.0	31.00	11.05	122.2	4.51	-0.484

Variable	Sampling Points	Mean	Min.	Max.	Range	Std. Dev	Variance	Std. error	Skewness
PO$_4$-P (mg/l)	L1(Inlet)	24.14	19.0	30.5	11.55	4.81	23.20	1.96	0.706
	L1(Outlet)	13.90	8.85	19.7	10.93	4.25	18.10	1.73	0.408
	L2(Inlet)	10.75	6.2	15.5	9.39	3.51	12.33	1.43	0.120
	L2(Outlet)	11.27	6.23	18.7	12.46	5.23	27.35	2.13	0.701
	L3(Inlet)	7.111	2.55	13.8	11.30	4.27	18.30	1.74	0.861
	L3(Outlet)	5.296	2.24	10.0	7.775	3.18	10.15	1.30	0.902
COD (mg/l)	L1(Inlet)	132.8	98.9	180	81.03	34.7	1208	14.19	0.343
	L1(Outlet)	108.1	32.8	175	143.1	52.3	2741	21.37	-0.302
	L2(Inlet)	73.98	23.3	150	127.2	46.8	2193	19.12	0.843
	L2(Outlet)	75.72	41.9	117	75.68	28.85	832.4	11.77	0.523
	L3(Inlet)	62.13	54.7	68	13.22	5.83	34.09	2.38	-0.671
	L3(Outlet)	51.63	42.3	63.5	21.16	8.39	70.40	3.42	0.426
Chl-A (mg/m^3)	L1(Inlet)	39.61	19.9	67.0	47.13	15.63	244.5	6.38	0.983
	L1(Outlet)	31.37	13.1	44.7	31.64	12.07	145.9	4.93	-0.355
	L2(Inlet)	29.33	8.91	48.1	39.20	13.39	179.4	5.46	-0.186
	L2(Outlet)	44.63	29.1	54.8	25.74	10.70	114.6	4.37	-0.662
	L3(Inlet)	27.24	16.8	59.7	42.80	16.25	264.3	6.63	2.218
	L3(Outlet)	8.758	4.34	16.6	12.33	4.564	20.83	1.86	1.237

ANOVA – (Annexure -C)

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.767	5	.153	12.821	.000
	Within Groups	.359	30	.012		
	Total	1.126	35			
Temperature (°C)	Between Groups	565.980	5	113.196	361.963	.000
	Within Groups	9.382	30	.313		
	Total	575.362	35			
Electrical Conductivity (µs/cm)	Between Groups	2156297.627	5	431259.525	12.251	.000
	Within Groups	1056019.648	30	35200.655		
	Total	3212317.275	35			
Dissolved Oxygen (mg/L)	Between Groups	78.229	5	15.646	219.923	.000
	Within Groups	2.134	30	.071		
	Total	80.363	35			
Turbidity (NTU)	Between Groups	942.708	5	188.542	.281	.920
	Within Groups	20141.658	30	671.389		
	Total	21084.366	35			
Total Dissolved Solids (mg/L)	Between Groups	225148.765	5	45029.753	2.377	.063
	Within Groups	568331.268	30	18944.376		
	Total	793480.034	35			
Total Suspended Solids (mg/L)	Between Groups	2878.697	5	575.739	.692	.633
	Within Groups	24953.470	30	831.782		
	Total	27832.167	35			
Nitrate (mg/L)	Between Groups	24.771	5	4.954	.730	.606
	Within Groups	203.520	30	6.784		
	Total	228.290	35			
Nitrite (mg/L)	Between Groups	7488.918	5	1497.784	1.179	.343
	Within Groups	38126.408	30	1270.880		
	Total	45615.326	35			
Total kjeldahl nitrogen(mg/L)	Between Groups	5148.710	5	1029.742	8.741	.000
	Within Groups	3534.164	30	117.805		

	Total	8682.874	35			
Chemical Oxygen Demand(mg/L)	Between Groups	33232.213	5	6646.443	3.691	.010
	Within Groups	54021.321	30	1800.711		
	Total	87253.534	35			
Phosphate(mg/L)	Between Groups	482.158	5	96.432	2.072	.097
	Within Groups	1396.535	30	46.551		
	Total	1878.693	35			
Chlorophyll-A(mg/m^3)	Between Groups	2676.480	5	535.296	2.369	.063
	Within Groups	6778.005	30	225.934		
	Total	9454.485	35			

Correlation among Meteorological and Physioc-chemical parameters (Annexure-D)

Parameters	Direct Normal Irradiance (W/m²)	Wind Speed (m/s)	Rainfall (mm)
pH	**-0.605**	**0.752**	-0.577
Temperature	**0.718**	0.277	**-0.845**
EC	0.376	0.417	-0.234
DO	**-0.635**	0.394	**0.772**
Turbidity	-0.168	0.105	-0.434
TDS	0.210	**0.767**	-0.138
TSS	0.138	**0.605**	-0.224
Nitrates	-0.359	0.236	0.092
Nitrites	0.091	**0.651**	-0.349
TKN	0.263	**0.748**	-0.100
Phosphates	0.106	**0.649**	-0.240
COD	0.401	-0.429	-0.551
Chlorophyll-A	-0.279	-0.497	0.505