A 3D WATER QUALITY ASSESSMENT OF RAWAL LAKE, ISLAMABAD

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This thesis is submitted in partial fulfillment of

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Rizwan Shabbir Qazi

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List of Abbreviations

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CDA	Capital Development Authority
DO	Dissolved Oxygen
TN	Total Nitrogen
EC	Electrical Conductivity
EPA	Environmental Protection Agency
NTU	Nepthelometric Turbidity Unit
NOM	Natural Organic Matter
RL	Rawal Lake
TOC	Total Organic Carbon
WHO	World Health Organization
USEPA	United States Environmental Protection Agency
WWTP	Wastewater Treatment Plant
POI	Point of Interest
WASA	Water and Sanitation Authority
X	North to South dimension
Y	East to West dimension
Z	Vertical/Depth dimension

ABSTRACT

Rivers, natural lakes and reservoirs are great assets for developing countries like Pakistan. Water quality of these water systems is being influenced by the contaminated inflows from different sources. To check the water quality, appropriate monitoring is necessary. Rawal lake is a source of fresh water for inhabitants of Rawalpindi and Islamabad. Flows from the upstream of Rawal Lake and its surrounding villages are highly polluted which degrade the water quality of reservoir. So an initiative was taken to determine the water quality of Rawal Lake in 3 dimensions. The purpose of this study was to assess different water quality parameters so that they can be monitored to check the contamination level of Rawal Lake. The water quality can be assessed by finding different parameters like pH, turbidity, dissolved oxygen, temperature, electrical conductivity, phosphate-phosphorus, total nitrogen and total organic carbon as defined by World Health Organization (WHO) and United States Environmental Protection Agency (USEPA). A research plan was developed to allocate the coordinates of the “points of interest” (POI) on the surface as well as at various depths up to 9m of Rawal Lake within the premises of circle of influence having a radius of 300m. Water samples were collected on monthly basis from March to September 2013 consecutively. The data collected was compared with different standards like World Health Organization (WHO) and United States Environmental Protection Agency (USEPA). It was concluded that the considered parameters were within the permissible limits except phosphate-phosphorus. The high concentration of phosphate-phosphorus is an alarming situation which enhance the algal growth. This algal growth is the main reason behind the eutrophication which consume the dissolved oxygen. The environmentally worst terrible state of Rawal Lake can only be cured by legitimate lake environmental supervision, watershed management, and execution of environmental legislation.

CHAPTER 1

INTRODUCTION

1.1 Background

According to the national drinking water policy (2009), access to safe drinking water is the basic human right of every national and water treatment will be a primary part of all drinking water supply systems. As suggested by the Millennium Summit held in New York (2000), Pakistan is committed to accomplish the Millennium Development Goals (MDGs) on supply of harmless/safe drinking water to all citizens by 2015. In this context, Government of Pakistan is devoted to reduce the number of people to minimum by 2015, who don't have safe excess to sustainable clean water supply.

Pakistan being a developing country have limited resources and economic development, due to which it is facing a severe difficult situation of natural resource scarceness, particularly that of meeting the requirements of sustainable clean water supply due to rapid population growth. The majority of crisp water bodies everywhere throughout the world are getting dirtied, therefore diminishing the water potability (Gupta, *et.al.,* 2005). The life of everything is reliant on water which is present in nature in numerous structures like sea, waterway, lake, precipitation, glaciers and groundwater and so on. However, entirely clean water does not exist for any apparent time frame in natural surroundings (Chakarabarty, *et.al.,* 2009). A lake is a substantial waterway encompassed via land, occupied by different aquatic life frames, for all viable reason, unadulterated water is considered to have minimum dissolve or suspended solids and unbearable gasses and also low in natural life. Such good quality water may be obliged just for drinking purposes while other uses like horticulture and industry, the nature of water can be very adaptable and water contaminated up to certain degree is generally be viewed as pure (Goel, 2006). Lakes are likewise subjected to different common procedures occurring in the earth like water cycle, with remarkable progressive exercises; human adverse activities are the significant explanation behind stifling a few lakes to death. Untreated rainstorm water spillover and sewage releases into the lakes are few of one of the basic reasons where different supplements (nutrients) enter the amphibian biological communities bringing about their death. From all the water quality issues confronting lakes all around, eutrophication is of absolute concern. Eutrophication is a term used to portray the maturing of a lake, brought about by the aggregation of nutrients, residue, sediment and natural organic matter in the lake from the joining watershed (Trisal, and Kaul, 1983). Eutrophication portrays the organic response of water bodies to nutrient enhancement, the consequent outcome of which is the advancement of essential production to annoyance extents and its primary driver is extreme expansion of nitrogen and phosphorus.

The Rawal Lake, constructed in 1960 on Korang River, East of Islamabad, is amongst the key water supply source for millions of residents in Rawalpindi and outskirts (southern sides) of Islamabad. Potable Water is supplied after conventional water treatment. The lake is fed by 4 major streams: Bhara Kahu, Malpur, Banni Galla and Nurpur Shahan and 43 small tributaries.

1.2 Problem Statement

The water quality of Rawal Lake has seen decline in recent years, due to the development of heavy infrastructure, housing sector, parks, gardens and recreational activities that led to improper disposal of sewage, in the catchment area. Effluent of the stone industry and poultry farms located upstream at Bara Kahu, also contributing a heavy contamination to the lake water. While the large volume of the water in the lake is still capable of diluting this mess, the rapid degradation and everyday rise in pollution adds substantial volume of pollutants into the lake would soon reduce its natural water quality. Whilst water quality in the top layers of Rawal lake may be fine due to its exposure to sunlight, wind-shear and boating activities, there has been great uncertainty about water quality of Rawal lake in various directions and depths. This study was the first attempt to examine Rawal lake water quality in X, Y and Z dimensions.

1.3 Objectives of the Study

Rawal Lake is the largest water source for over a million residents of Rawalpindi and Islamabad. Keeping track of its water quality is important for ensuring the long term use and sustainable water source. Ongoing climate change and rain fall patterns are adding uncertainties to the water availability from surface sources and droughts can be expected in times of the past monsoon season. It is therefore important to investigate changes in water quality of the Rawal Lake with space and time so that would be well prepared if water has to be taken out from a deeper aquatic zone. The objectives of the study are as follows:

1. To study the Spatial variations in selected water quality parameters with respect to depth in Rawal Lake.

2. To study the Temporal variations in selected water quality parameters with respect to depth in Rawal Lake.

1.4 Scope of the Study

The present investigation aimed to provide an overview of seasonal variations in Rawal lake water quality in a 3D cylinder of 300m radius. The status and standard of the lake water was checked and compared with the standard guidelines for water of such lakes. Various water quality parameters were compared with that of other lakes in order to determine the likelihood for further improvement and precautionary measures to be taken.

According to present investigation, samples were collected from Rawal lake center in 300m radius of influence in X and Y dimension with interval of 100m and also in Z-dimension with interval of 3m from surface up to 9m depth of water. Samples of water were then tested on site and in laboratory for selected parameters in order to investigate water quality of Rawal Lake. The whole investigation comprises on 7 monthly surveys from March to September 2013. The devised program of water sampling was executed to find out the physico-chemical factors that can alter the lake water quality. Water samples from lake were taken during late winter and early fall seasons to cover the worst case scenarios of lake water conditions as these seasons are characterized by the high temperature and light and therefore high algal growth. This study is limited to water quality sampling and analysis within certain circle at approximate Centre of the lake. Study duration was also limited to 7 months which covered some seasonal variations. A comprehensive study for all the surface area and depth of the lake supplemented with water quality modelling would help determining the extent of eutrophication today and for next 10-25 years for all seasonal and climate change impacts. Though the current study is not a very comprehensive one covering a full way analysis of all water parameters, it specifically targeted to find out the existing quality of the lake water and compare the surface water parameters with the water at different depths. The study gives an insight about the need for further detailed study, proper management and effective actions for improving water quality.

CHAPTER 2
LITERATURE REVIEW

2.1 Water Quality

Water quality is essential in lakes for few bases, mainly for supporting freshwater biota and for aesthetics, social and psychic reasons. Just considered the water we drink and the water we used to take bath, cooking or hygienic with. The term water quality is used to define as the physical, chemical, and biological features of water, commonly refers to appropriateness for a specific or selected use. Alan Levere, quoted "The water quality of rivers are the best indicator and true image of what's happening in the catchment upstream." The quality of water properly determines the geology of the catchment area. For example, mineral rich rock and soil may results mineral rich water. Water quality monitoring is generally a practice of taking samples and examining water condition and features. This section will explain several water features which have an impact on the selected use of water sources and monitoring to measure the concentration of these features.

2.2 Water Quality Parameters

The features of water like DO, pH, TOC and temperature etc. are important to be water quality parameters. Generally these parameters may refers to be physical or chemical in natural environment. Many of the physical features involve in water quality and are not bound to temperature, dissolved oxygen and suspended solids.

The portion of constituents like heavy metals, nutrients and pesticides, which are dissolved in water or in the form of suspended particles are chemical parameters. Biological parameters mention to be a part of the living environment, from microscopic algae to macrophytes and fishes. This research mainly focuses on Physico chemical Parameters such as: Dissolve oxygen, Temperature, Electrical conductivity, PH, Turbidity, Total organic carbon, total nitrogen and phosphate phosphorus.

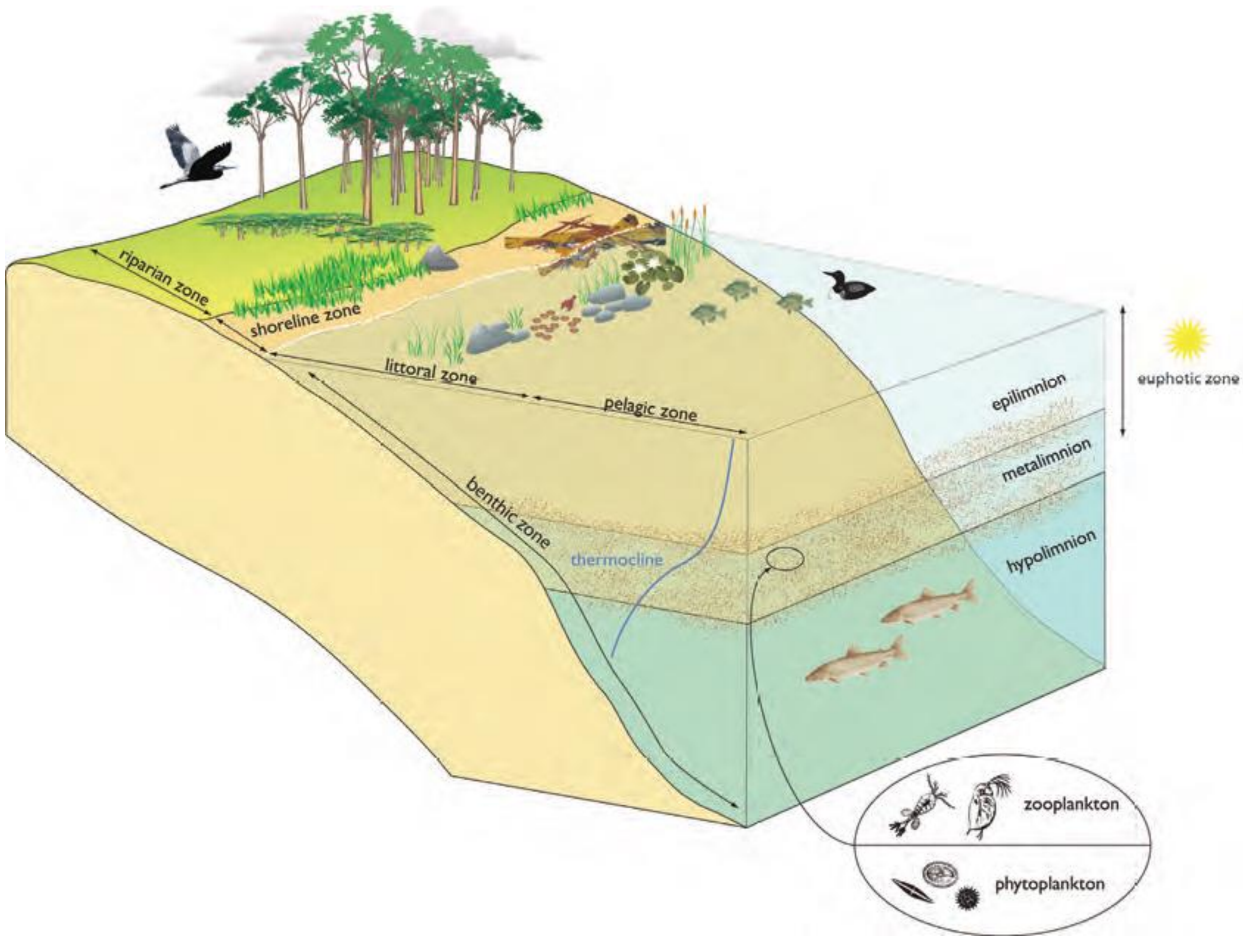

Figure-2.1: 3D view of Lake and their surrounding (Slideshare.net)

2.2.1 pH

It is a level of the degree of action of hydrogen particles in a solution, subsequently in its acidic or basic quality. pH is notified on a log scale that normally goes from 0 to 14 , with 7 as refers to be neutral. Every supply life form lives inside of a particular pH range.

The range of survival for a large portion of the freshwater animals ranges from 4.5 to 9. A man contribution to high pH primarily as nutrient spillover (fertilizers), which clues to opened up algal growth development and higher pH. Low pH results particularly harming to marine creatures. Low pH worsen physical and natural elements of marine life through decline of chemicals movement and productivity.

2.2.2 Electrical conductivity

It is the capacity of a material to conduct an electrical current, it is measured in micro Siemens per centimeter (µS/cm). It conducts an electricity with the help of Ions like potassium, sodium, and chloride which give its capacity to conduct electric currents. Also, it is a sign of the quantity of soluble salts in a watercourse. It oftenly used for an estimation of the quantity of TDS rather than calculating individual dissolved component.

2.2.3 Nutrients

These are the synthetic components which are vital to living organism's lifecycle. The two basic nutrients necessary for aquatic life are nitrogen and phosphorus. Several nutrients are constituents of the water's TDS, like ammonia is mixed entirely into the solution. At elevated levels, they are reflected as impurities. High amount of nutrients results in improved production of algae other than usual. Decomposing algae rugs can originate obscene smell and tastes. When the algae needs an energy for decaying and this energy is in the form of dissolve oxygen which it takes from water and consequently dissolve oxygen depletion starts from water. The units used to measure nutrients are milligrams per liter (mg/L). Both phosphorus and nitrogen are effected by natural processes that change their structure and change their chemistry as well. In environment, nitrogen and phosphorus discharge from the soil and from decomposed flora and fauna. Manures, sewage, and other animals left-over are major sources of nutrients. So, from this process, nutrients cycles around atmosphere. Recycling of nutrient all over the world's lakes is a great problem. So, the governments around the world sets some standard levels. As the levels of nutrients may differ in different watersheds, the USEPA is functioning to improve nutrient criteria founded on regional features.

2.2.3.1 Phosphorus

Phosphorus termed as the controlling nutrient for plant growth, reason is less supply comparative to nitrogen. Generally the Phosphorus presence in the form of phosphate ($PO_4^{-3)}$. And phosphate is divided into 3 main types based on chemical constituents. Phosphate related to plants or animals tissues referred to be as organic phosphate and vice versa. These types remain existing in marine system besides it might either dissolved in water or suspended in the aquatic bodies.

Inorganic phosphate is also known as orthophosphate (reactive phosphorous). This form is massively available to plants and animals. That's why it can be valuable sign of probable problems with extreme algal development.

In order to check the whole phosphorus presence in water, test should be taken for total phosphorus which brings full picture of phosphorus magnitude in aquatic body. Following figure explains phosphorus sources.

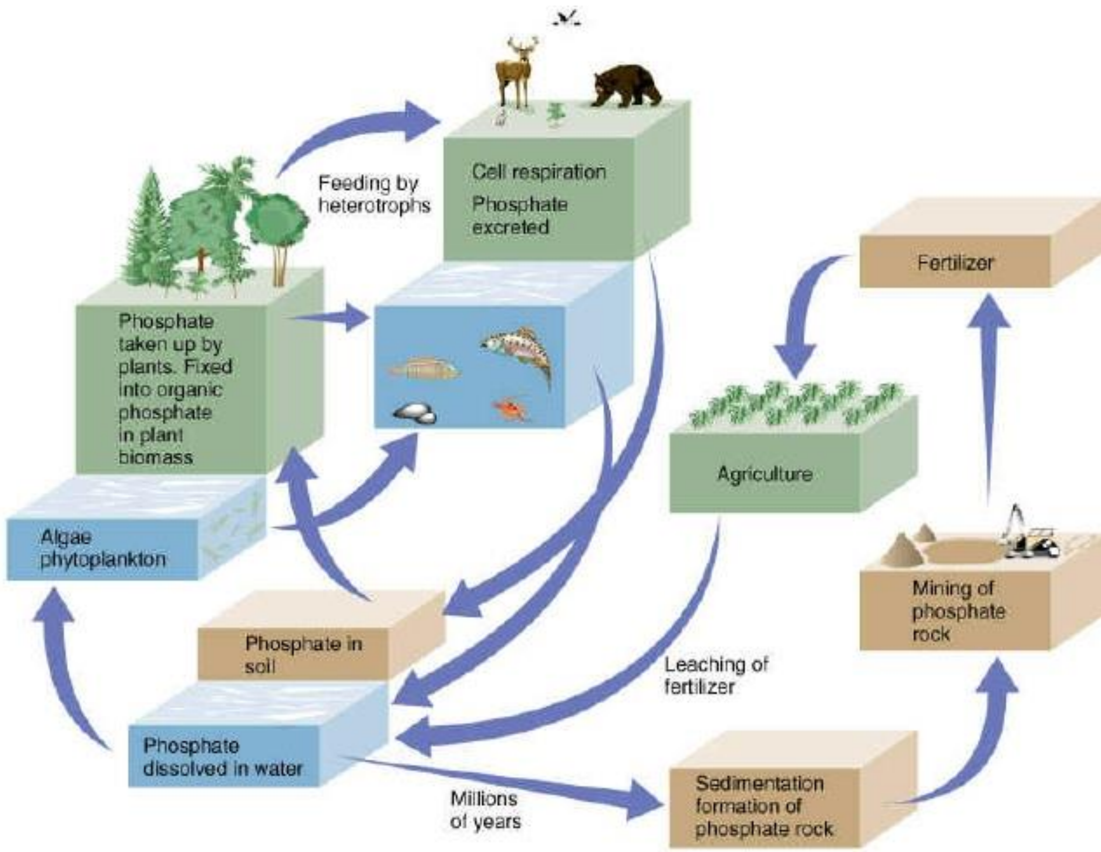

Figure-2.2: Phosphorus sources and species. (ramp-alberta.org)

2.2.3.2 Nitrogen

It is very important constituent on earth. Nitrogen might covert into different biological & chemical changes whether it will exist freely in atmosphere or entangled withsoil.so it can easily said that nitrogen interaction with other organisms and changes its nature with ability to come back to its original stable form , this phenomenon is said to be nitrogen cycle. Some of the commonly occurring forms of nitrogen are nitrate (NO_3), nitrite (NO_2) and ammonia (NH_3). Here NO_2 is less stable then nitrate that's why it is universal truth NO_2 are rare in nature then NO_3. The important phenomenon which makes all these components together is called nitrification.

Order of decreasing oxidation state:

Nitrate → Nitrite → Ammonia → Organic Nitrogen

(Stable) → → →→ → →→ → → (Unstable)

2.2.4 Dissolved Oxygen (DO)

Dissolve oxygen is very important constituent to observe reliability of water body in terms of fisheries and other aquatic animals. Because, aquatic plants and animals uses dissolve oxygen as an important factor throughout their lifetime (nourishment) and after death as well (as a catalyst for decaying). There are some major sources of dissolve oxygen in water like air present in atmosphere, turbulence in water and the process of photosynthesis. It depends on temperature of reservoir. Generally warm waters are not good in accumulating handsome amount of oxygen but colder water have it. It can be measure in milligrams per liter (mg/L), additionally it measures as a percentage of saturation.

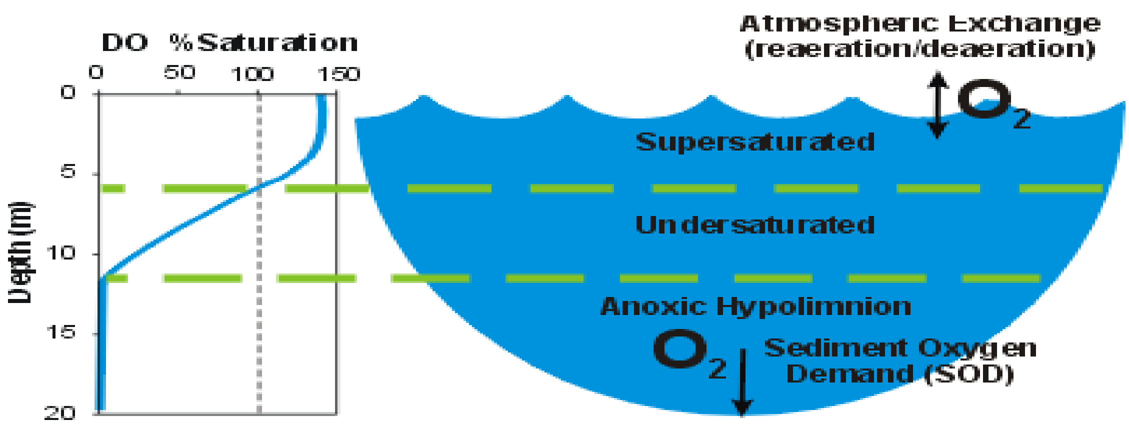

Figure-2.3: Dissolve oxygen distribution profiles in Lakes and reservoirs. (upstatefreshwaterinstitute.org)

2.2.5 Water Temperature

Water temperature is an important characteristic of marine environment for two reasons. First important aspect is that, it effects almost every other water quality parameter. Marine entities are adjusted to certain temperature ranges. Aquatic organism becomes more susceptible to disease as the higher and lower standard limits are closer. Watercourse temperature is synchronized by, the streams surface area, sun, volumetric capacity of water body, and several other factors.

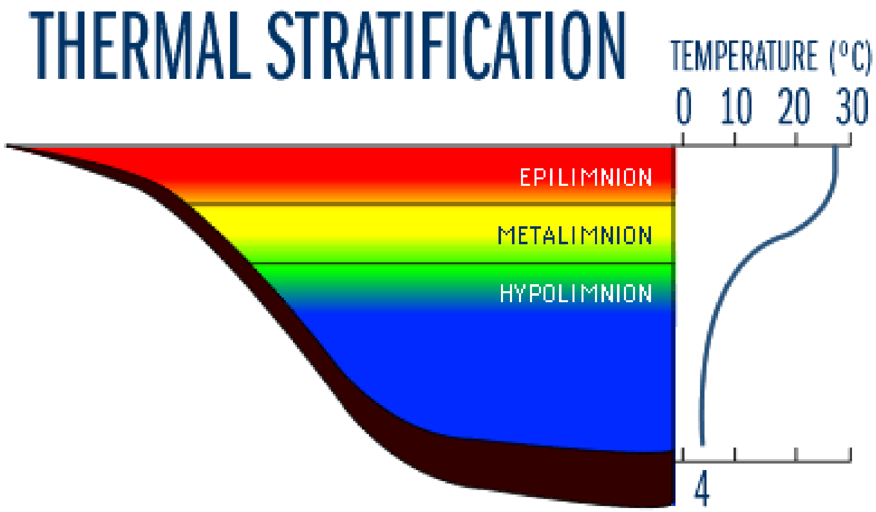

Figure-2.4: Temperature stratification in deep lakes and reservoirs. (lakeaccess.org)

2.2.6 Turbidity

It measures the clarity or transparency of water or how much the light is able to pass through water. Turbidity measures the amount of suspended particulate matter in water. It is defined as the measure of cloudiness of water, caused mainly by solid particles including soil particles and small fauna and flora (animals and plants) of the habitat. A healthy habitat usually contain moderate low level of turbidity with judicious aggregate of aquatic plants, required to run the food chain of eco-system. While higher levels of the said parameter impose quiet a number of problems to the reservoir. Light needed by aquatic plants for photosynthesis is directly blocked by the higher level of turbidity. A rise in the surface temperature beyond the normal limit due to the absorption of heat by suspended particles near the surface is another problem caused by the inclined levels of above discussed parameter. Turbidity of water has a negative relation with that of dissolved oxygen in water. Turbidity level increase due to eroded particles of soil in flood/runoff, sediments and nutrient inputs that cause plankton blooms. Cloudy or opaque appearance of water occur due to high turbidity which can also increase the temperature of water because the heat can be absorbed by suspended particles present in water body which makes hindrances for light to get enters into deep water. High levels of turbidity indicates high level of suspended particles. Turbidity is an optical property, but it cannot directly indicate the type or amount of solids. It measures in Nepthelometric Turbidity Units (NTU).

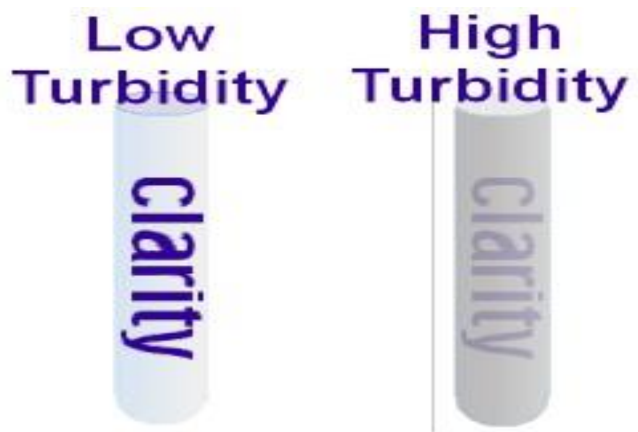

Figure-2.5: Classification of turbidity. (metroninstruments.com)

2.2.7 Total Organic Carbon

Many chemicals enter in channels through rainfall runoff. Many organic contaminants also come from Domestic and industrial waste water. Accidental spills or leaks, industrial organic wastes likewise contribute natural contaminants in different sums. A percentage of the contaminants may not be totally uprooted by treatment forms; in this manner, they could turn into an issue for drinking water sources.

Organic contaminations can conveniently be determined in a comparatively short time by total organic content (TOC). In order to measure the TOC, an infra-red detection based system analyzer is used. The produced carbon dioxide is taken in to the analyzer by means of carrier gas, to measure its wavelength of absorption. The concentration of carbon dioxide is calculated by a processor installed on the analyzer and mg/L is the unit to express the total amount of carbon. Chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are also critical methods to calculate an organic contaminations, but not more efficient then TOC to express the organic chemical content of water.

Measure of carbon containing compounds can easily be determined in a source by TOC. Amount of carbon in a fresh water is a direct criterion to indicate the organic quality of water course. Therefore, it is vital to know about the total amount of carbon. Carbon or organic content is positively correlated with that of oxygen consumption in a habitat, as more organic content means higher rate of population /colonization of microorganisms. More the microorganisms, more will be the oxygen consumption, which as an alarming situation for aquatic life, as either the oxygen level is lowering or toxic level of stream is rising with it. Waste water treatment plants and industrial waste both contribute as major sources of carbon content in the line.

TOC is an extremely sensitive, non-specific measurement of all organics present in a sample. If the concentration of TOC is low, it definitely confirms the deficiency of possibly detrimental organic chemicals, whether present in drinking water or the water being used in industry.

2.3 PAST STUDIES

Surface water sources that provide bulk of water are relatively more prone to contamination and need better protection. Such sources are affected by characteristics of catchment area and climate conditions. For treated supplies, these mostly need advanced water treatment facilities to make water safe for human consumption. The surface water sources needs stringent regulations to protect catchment area, reservoir (lake) and environment (WQAR-REIP, 2009).

Rawal Lake is located in the south-east of Islamabad at a longitude of 73^0 7' E and Latitude of 33^0 41' N. Its catchment area is 280 Sq. Km. Rawal dam is partly arched gravity dam (Stonemasonry) with crest level at 531 m and crest length of 213.5 m. Max height of the dam is 40.7m with saddle length and width as 2131.4 m and 7.3 m respectively. Spillway is of Ogee Type Gated Structure with a discharge capacity of 2898 m^3/sec. the reservoir of Rawal lake has live storage of 66186 m^3 acre feet, dead storage of 6927 m^3 and gross capacity of Gross Capacity 73113 m^3 acre feet. Left Bank Canal is 8 Km long and has a capacity of 1.4 m^3/sec. Right Bank Canal is 2.4 Km long and has a capacity of 70 Cusecs. This reservoir is one of the major sources of water supply providing 19.5 mgd to Rawalpindi and 2.5 mgd to Islamabad. In 2002 it has a command area of 500 acres. Rawal Lake and its catchment range is a key assets for Rawalpindi and for the locale at this very moment. Proper administration of this asset is vital if full advantages are need to be exploited and kept up for what's to come. Most clear advantage of this resource is the procurement of water supplies for Rawalpindi. The real water contamination wellsprings of Rawal Lake are recognized presently

- Human settlements
- Poultry wastes
- Recreational Activities
- Fishing
- Motor Boating
- Hotels, Restaurants
- Solid waste from recreational activities
- Agricultural and Life-stock farming
- Deforestation by Illegal wood cutting, slow recovery of forest because of low plantation and Forest Fires
- Erosion and Sedimentation, and
- Climate change Effect

All of the above mentioned sources of pollution lead to the eutrophication of Rawal Lake directly or indirectly which is very serious concern for authorities presently and in future as well. It has been observed that nutrient levels in the incoming water streams and out flow have marginal change that shows poor biodiversity regarding water quality improvement by flora and fauna. This concludes that lake is not harvested for organic products by humans or animals. Therefore energy and mass balance needs to be amended by applying right strategy. The higher turbidity level and low transparency has caused low population of primary procedures (phytoplankton) that reduced the population of primary consumers, hence disturbing the whole food chain, resulting in to eutrophication of the lake.

Heavy organic/inorganic load and poor performance of ecosystem cause depletion of dissolved oxygen (DO). The low DO further deteriorate the ecosystem in a vicious circle. Low DO reduces aerobic organism, thus resulting in eutrophication of lake and if this circle continued for the next 2-3 decades the lake would be life less and considered dead.

Irfan, (2010) conducted a water quality survey of the Rawal Lake from Sept. 2009 to Feb 2010 but samples were collected at six points within the circle of influence of major feeding streams. No depth samples were collected and analyzed. Relatively close in to conducting some grab sampling for a very limited time none has established any relationship between Lake's depths.

Ghumman, (2011) also conducted water quality survey on several Lakes including Rawal Lake and concluded that the water quality of streams and natural lakes in poor nations are being despondent due to polluted recharge. It is an urgent need of definite water quality check for forthcoming scheming and supervision of fresh water assets. The quality of Rawal Lake had been inspected and concluded that the water coming from upstream and its neighboring settlements to recharge Rawal lake were massively polluted. Parameters like pH, turbidity, alkalinity, nitrite, dissolved oxygen, chloride, total dissolved solids (TDS), and coliforms were inspected. The samples of water from various locations of Korang River were investigated. Majority of the data was taken by in-situ sampling and field visits while longstanding material info were taken from various departments. After thorough investigation to make a trend of expanding or diminishing of estimations of variables for more than quite a while it was inferred that the concentration of seven contaminants was higher when contrasted with as far as possible under ecological models. These variables need pressing consideration. The worst terrible state of Rawal Lake must be solved by legitimate lake natural monitoring, watershed administration, and implementation of environmental laws.

Latif, *et. al*., (2003) discusses the impact of chlorophyll and dissolved Oxygen on water-quality of Kalar Kahar and Rawal lakes. A Spectrophotometer was used to investigate Chlorophyll and Dissolved Oxygen was inspected in field by DO meter. The maximum recharge of lake water is from rainfall especially in monsoon and remaining by little precipitation in December and January. That rainwater is needed all over the year for drinking purposes in Rawalpindi cantonment and for minor portion of Islamabad. Samples of water were taken from 5, 7.5 and 10 meters of depth for temporal studies. Differential layers of dissolved Oxygen was noted in Rawal Lake prior to wet season in summer. The quality of water worsens with depth, because the respiration overdoes the process of photosynthesis.

Ramzan, *et. al.,* (2013) carried out a study on Eutrophic effect on Rawal Lake. The purpose of this study was to investigate the presence of Eutrophication in Rawal lake by analyzing phosphorus loading. Parameters inspected during this study were microscopic organisms, sediment attached phosphorus and free phosphorus present in lake. During this study samples were collected on weekly basis and sediments data were taken and examined from 2007 to 2008. It was concluded that on October 2007 Rawal lake was oligotrophic but rapidly changes its condition to change into Eutrophic in 2008 due to huge phosphorus loading. Results of this study clearly showed the presence of Eutrophication at center and on banks of Rawal lake. The reason behind the contamination was noticed as poultry wastes, sewerage lines and use of fertilizers on farmland in catchment area of Rawal lake.

Chandra, *et. al.,* (2012) have done research on Assessment of Water Quality Values on Porur Lake Chennai, Hussain Sagar Hyderabad and Vihar Lake Mumbai, India. The objective of their study was to measure different lakes including Porur lake Chennai. In order to achieve their goals, samples of water from 6 different locations were taken and then tested and analyses for electrical conductivity, PH, turbidity, total dissolve solids, total alkalinity, nitrates, sulphate, chlorides and dissolve oxygen. Also they had conducted different tests on some heavy metals like nickel, chromium, iron & zinc. At last, they concluded that there were clear variation in almost all the parameters, which shows significant increase in pollution because those parameters were out of range as describe by world health organization and bureau of Indian standards.

Taylor, *et. al.,* (1995) carried out an assessment on Lochaber lake in Nova scotia. The purpose of this study was to investigate the impacts of infrastructural development and agricultural farmland use on Lochaber lake. Previous reports suggested no proper action had taken on these issues. So initiated a proper survey sampling on lake 7 different points in lake and on inlets as well. They also carried out similar survey on 13 different location on lake for bacteriological inspections. After thorough investigation for whole season it was being concluded that Lochaber lake was not amongst over productive nutrient rich Lake in broad spectrum however, there were some points of concern at inlets of some streams recharging Lochaber lake. Those nutrients rich streams are noticed to be polluted due to runoff infrastructural development, housing schemes and agricultural lands. Same results are being concluded in terms of bacterial investigation.

Irenosen, *et.al.,* (2012) taken out thorough water Quality survey on Owena Dam in order to inspect whole wet and dry season. The basic purpose of this survey was to study physic-chemical and microbiological characteristics by using standard method for analyzing water and waste water mutually put-out by American Public Health Association, American Water Works Association and Water Pollution Control Federation. The conclusion of this research was significant seasonal changes in many investigated parameters with some shows significant spatial variations. The features of water from lake clearly shows good as in case of many parameters investigated with very less chemical toxins presence if , compared it to water quality standards for drinking water and standards for reservoirs as well. But still some of the inspected parameters like color, turbidity, iron and microbial biomass were recorded to be beyond the standard limits of drinking water quality standards which needs to be properly monitored prior to supply water to residential areas.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Area

This study area consist of Rawal Lake. It was completed in 1962 by WAPDA then later, in 1967 it was transferred to Irrigation Department of Punjab for operation and maintenance. Rawal Lake is located at Latitude 33^0 $42^'$ N and Longitude 73^0 $7^'$ E in Park area of Islamabad. The catchment area of Rawal Lake extends 15 km From Rawalpindi town up to the Murree Hills. The location of Rawal Lake is shown in **Figure 3.1.**

Figure-3.1: Satellite image of Rawal lake Islamabad. (Google Earth, 2011).

3.2 Rawal Watershed

The characteristics of Rawal Watershed are given in Table 3.1

Table-3.1: Characteristics of Rawal Watershed

Catchment area	273 km²
Latitude / Longitude	Latitude 33° 42' N & Longitude 73° 7' E
River and main tributaries	Main Korang River and its tributaries, Shahdara & its tributaries
	Nurpur & its tributaries.
Meteorological Stations	Rawal dam observatory located at Rawal Dam site
	Latitude 33° 40' 40″N & Longitude 73° 6' 36″ E& Elevation 543.7 m
Discharge station	Located at Rawal Dam site
	Latitude 33° 43' 15″N & Longitude 73° 8' 12″E

3.2.1 Location

The Rawal watershed extends from north east of Islamabad to Murree hills. The location map of Rawal Watershed is shown in **Figure 3.2.**

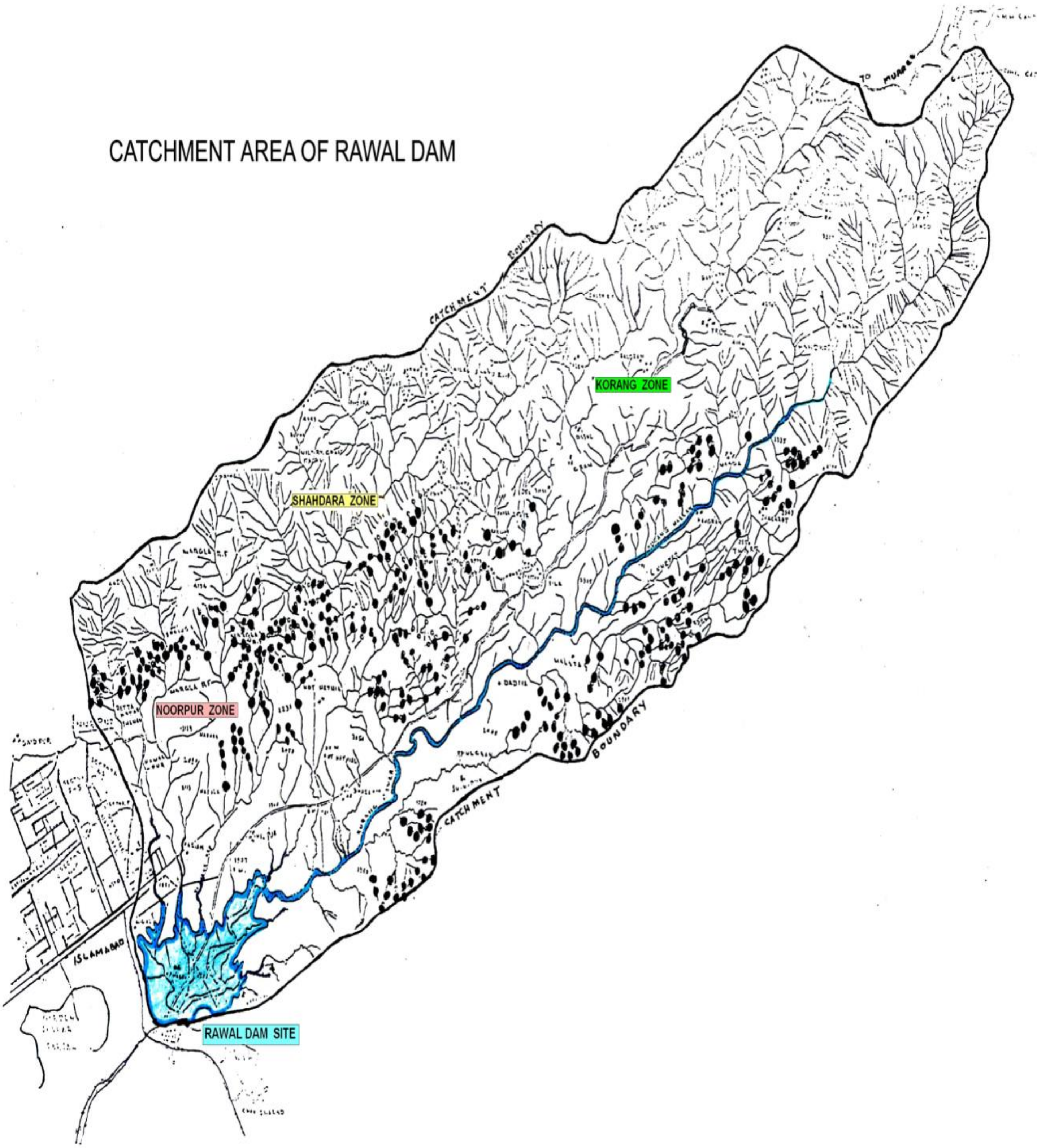

Figure-3.2: Rawal Lake Catchment Area Map (Small Dam Organization Punjab)

3.2.2 Climate

The Rawal Lake has tropical climate in upstream catchment. It has cold snowy winters, cool summer with escalated rain. The downstream catchment has four seasons, these are winter (December – February), hot weather (March-May) Monsoon (June-September) and transition period (October-November).

3.2.3 Precipitation

The catchment area of Rawal Lake is situated in the Outer Himalayas retaining high altitude. Precipitation is received in a year around winter and summer is the season in which maximum precipitation is received. The heavy rainfall months are July,August and September and the average annual precipitation in catchment area of Rawal Lake is 1435 mm**.**

3.2.4 Temperature

The temperature data of catchment area of Rawal Lake for duration of 38 years i.e. 1975-2012 was analyzed and it was observed that average annual maximum temperature is 21^{0} C and average annual minimum temperature is 11^{0} C.

3.2.5 Humidity

In catchment area of Rawal Lake humidity is high during the period of Monsoon and moderate during the non-monsoon period. The relative humidity in the catchment of Rawal Lake ranges from 36-76 %.

3.2.6 Geology and Physiography

The geology of Rawal Lake catchment area is loosely cemented sandstone and friable sandy shale the soil here is sand, silt and clay. The physiography of the catchment area is hilly. The hills range between elevation of 500 m at western end and 2200m on its east end and it has average height of 1000 meters. The irrigation here is rain fed and ground water is sweet. Wheat, millet and maize are the crops which yield here.

3.2.7 Sources of Contamination:

Throughout the previous couple of decades, the lake is subjected to contamination by various sources. These sources as indicated by Report on Rawal lake catchment region observing operation in June, 2004 by Pakistan environmental protection agency ministry of environment Islamabad are:

- Human settlements
- Poultry squanders
- Recreational exercises
- Agricultural activities
- Deforestation
- Erosion and sedimentation
- Eutrophication of Rawal Lake

3.3 Rawal Lake Monitoring Plan

This research have three major parts as discussed below:

a. Sampling
b. In-situ testing
c. Lab testing

3.3.1 Sampling

In order to collect samples from Rawal Lake, It is divided into four Quadrants having 300m radius from the Centre of lake. This research mainly focuses on 300m radius of influence from Centre. In 2nd step, mark 3 points on each quadrant line at regular interval of 100m each. In 3rd step, two samples of water from each three points & depths at quadrant line with depth of 0m, 3m, 6m and 9m will be collected respectively. So the research will be based on 96 samples on each visit to Rawal Lake for seven consecutive months; i.e., single visit a month.

3.3.2 In-situ Testing

Each collected sample was tested on boat right after collection without any delay because some physical parameters are changing with delay. Those parameters are as follows:

- Temperature (Hach digital Multimeter)
- Dissolve oxygen (DO meter)
- PH (Hach digital Multimeter)
- Electrical conductivity (Hach digital Multimeter)
- Turbidity (Turbidity meter)

World Health association (WHO) has published guidelines to help nations to set up quality measures with which household water supplies ought to go along. The water samples from Rawal Lake were analyzed for physical parameters including, pH, Temperature, Conductivity etc. The detailed procedures for these parameters are given in the ensuing paragraphs. To start with knowing the permissible limit of water quality parameter is considered imperative. WHO and Quality drinking water standards of Pakistan have set the guidelines for physical parameters of drinking water (MOH, 2007[1]).

Table-3.2: Standards and Guidelines for Physical Parameters

Parameter	Drinking Water Standards in Pakistan	WHO standard
Taste	Non Objectionable	Non Objectionable
Odor	Non Objectionable	Non Objectionable
Turbidity	<5 NTU	<5 NTU
pH	6.5-8.5	6.5-8.5
Dissolved Oxygen	6.5- 8.5 mg/L	6.5- 8.5 mg/L
Color (TCU)	15	15

3.3.2.1 Temperature

The temperature of water can be measured with a Hach digital Multimeter. It is an electronic device with a probe. The probe contains sensitive temperature sensors that detects temperature of water body. Temperature can also be measured by putting ordinary thermometer into water sample.

Temperature of all water samples in the Rawal Lake was measured using Hach digital Multimeter. The temperature of water in the sample bottles was measured by dipping the temperature glass electrode. Stability between electrode and sample was achieved by stirring the sample to confirm uniformity. Using Hach digital Multimeter temperature probe we recorded temperature in degree centigrade as well as in degree Fahrenheit.

Figure-3.3: Hach digital Multimeter

3.3.2.2 Dissolved Oxygen (DO)

Dissolved Oxygen are measured with an electrode meter or with field test kit. The electronic DO meter can quantify oxygen by indirect means. The electrodes measures the fractional pressure of oxygen present in water, then it transformed to oxygen concentration. The quantity of dissolved oxygen is expressed as its concentration in milligrams per liter (mg/L).

To measure DO in the Rawal Lake, Hanna Instrument HI 9143 a waterproof, microprocessor based, auto calibration meter was used. Dissolved Oxygen indicated in thousandth parts per million (ppm) or in percent air saturation. The DO of the samples was determined on the field as well as in the laboratory. A slight difference in reading was observed due to change in temperature and settling of water impurities when the DO was measured in Laboratory.

Figure-3.4 Hanna DO meter kit (HI 9143)

3.3.2.3 pH

The pH of water was measured with hand-held Hach digital Multimeter. It has an electronic device with a pH probe. The probe contains an acidic aqueous solution enclosed by a glass membrane that allows migration of H^+ ions

pH of all water samples in the Rawal Lake was measured using Hach digital Multimeter **(Figure-3.3).** The meter was standardized with appropriate buffer whose pH was known. The pH of water in the sample bottles was measured by dipping the pH glass electrode. The Balance was established between electrode and sample by stirring.

3.3.2.4 Electrical Conductivity

In this study the electrical conductivity of Rawal Lake was measured, using Hach digital Multimeter **(Figure-3.3)** having conductivity probe. The meter can also measure salinity of water. Both these readings were taken at the sampling location. The measuring probe was stabilized prior taking the reading of each selected parameter. The Hach digital Multimeter specification includes digital LCD that simultaneously displays temperature and electrical conductivity. The meter can likewise be used for a wide range of applications in the field or at the research facility. Water quality, salinity, acids, bases, and other aqueous samples can easily be analyzed for conductivity with the available conductivity probes. The meter is designed as maintenance free and is operated with alkaline batteries.

3.3.3 Laboratory Testing

The raw water of Rawal Lake was analyzed for 3 important chemical parameters. Before proceeding to analyze, knowledge of permissible limits of chemical parameters is considered essential. WHO and Quality drinking water standards of Pakistan have set the guidelines for the chemical parameters in safe drinking water. Some of the chemical parameters which were measured during the study along with the maximum permissible limits are appended in Table 3.3

Table 3.3: Standards and Guidelines for Chemical Parameters

Parameter	Drinking Water Standards in Pakistan	WHO standard for lakes/reservoirs
Total organic Carbon (Toc)	Not defined	Not defined
Phosphate-phosphorus(P-po3)	Not defined	0.05mg/L
Total Nitrogen (TN)	Not defined	10mg/L

Chemical parameters were tested are as follows:

- Total organic Carbon (TOC)
- Total Nitrogen
- Phosphate Phosphorus
- Turbidity

All of the above required parameters was analysed by simple analytical technique used in Laboratory.

3.3.3.1 Total Organic Carbon (TOC)

TOC in source waters comes from decaying Natural Organic Matter (NOM) and from synthetic sources. It is very useful to find out the correct concentration of NOM in water. During the treatment of water, it reacts with chloride which contains disinfectants. Within the last few years, TOC analysis has developed as a speedy and accurate alternative to the old and prolonged Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) tests conventionally reserved for measuring the contamination potential of source. Based on TOC concentrations, trace limits of DBPs will be regulated by environmental agencies in drinking water. The TOC of a water body is effected by various reasons, which includes vegetation, sewage and climate.

TOC Flow chart is explained in (**Figure-3.5)**

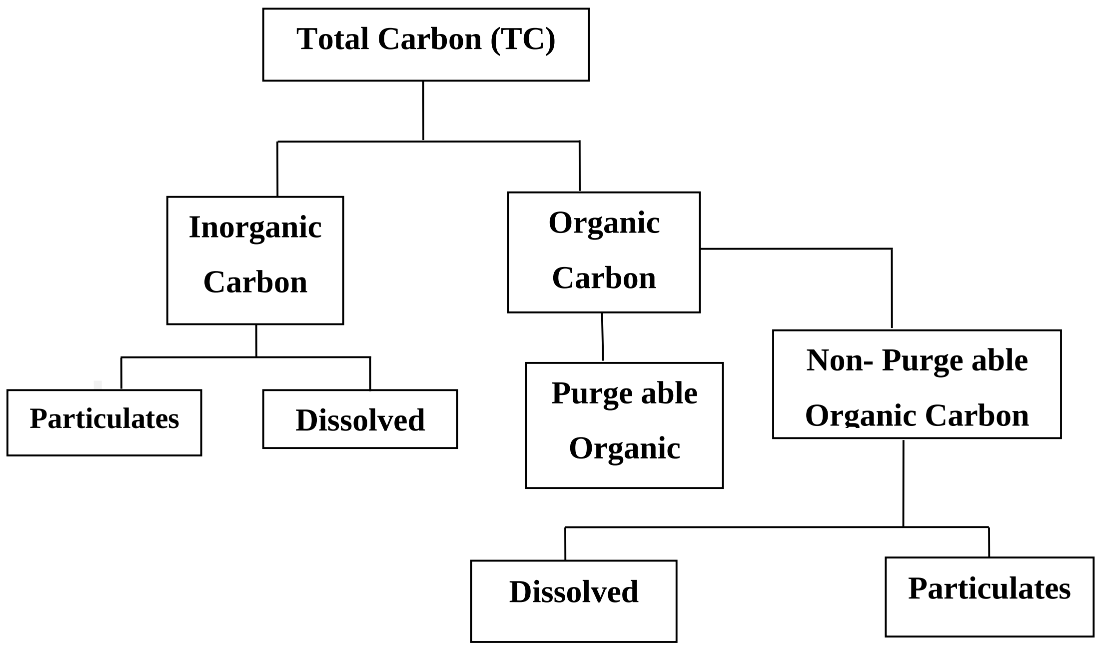

Figure-3.5: Flow chart to determine carbon composition

The analysis of the total carbon content (TC) in the Rawal Lake was performed using N/C 3000 multi analyzer through the highly precise injection of the sample aliquot into the hot zone of the furnace. With a calibration curve stored on the system, the concentrations were calculated in µg/L or mg/L. For the detection of inorganic carbon (TIC), a sample aliquot conveyed into the combined TIC and condensation vessel, where 10% phosphoric acid has already been filled in. CO_2 liberated from carbonates and hydrogen carbonates and then purged off the sample by means of the carrier gas. The differential method is used if the sample contains easily purge able organic substances, such as benzene, chloroform etc. The analysis of nitrogen performed simultaneously with the determination of carbon.

3.3.3.2 Phosphate-Phosphorus (P-PO_4)

DR 2010N HACH spectrophotometer was used to determine the phosphate in the Rawal Lake water samples. In this method 25 ml of sample water was taken in the sample bottle and one ml of Molybdovanadate reagent added and swirled to maximum. Stored program number 480 for reactive phosphorus, molybdovanadate method was entered with corresponding wavelength of 430 nm. A three to six minutes reaction time was allowed for the sample to homogenize. A blank sample with distilled water was also prepared prior to placement of the actual sample in the spectrophotometer. The prepared sample was placed in the equipment and PO_4^{-3} was recorded as mg/L of PO_4^{-3}.

Figure-3.6: Hach digital spectrophotometer (DR 2010) for measuring P-PO_4

3.3.3.3 Turbidity

Several methods are available to measure the turbidity of water. Turbidity in slow moving, deep waters was measured using a device called Secchi disk. This method is no longer in used for turbidity measurement. The other methods used to measure turbidity are Nepthelometric and Jackson methods with units NTU and JTUs respectively. This method can only be used in more turbid waters.

Turbidity of Rawal Lake water was measured by Nepthelometric method using turbidity meter (HACH 2100N). This method is based on a comparison of the intensity of light scattered under the defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. The 90-degree scatter detector receives light scattered by particles and forward scatter detectors receive light that passes through the sample.

Figure-3.7: Hach Turbiditimeter (2100N)

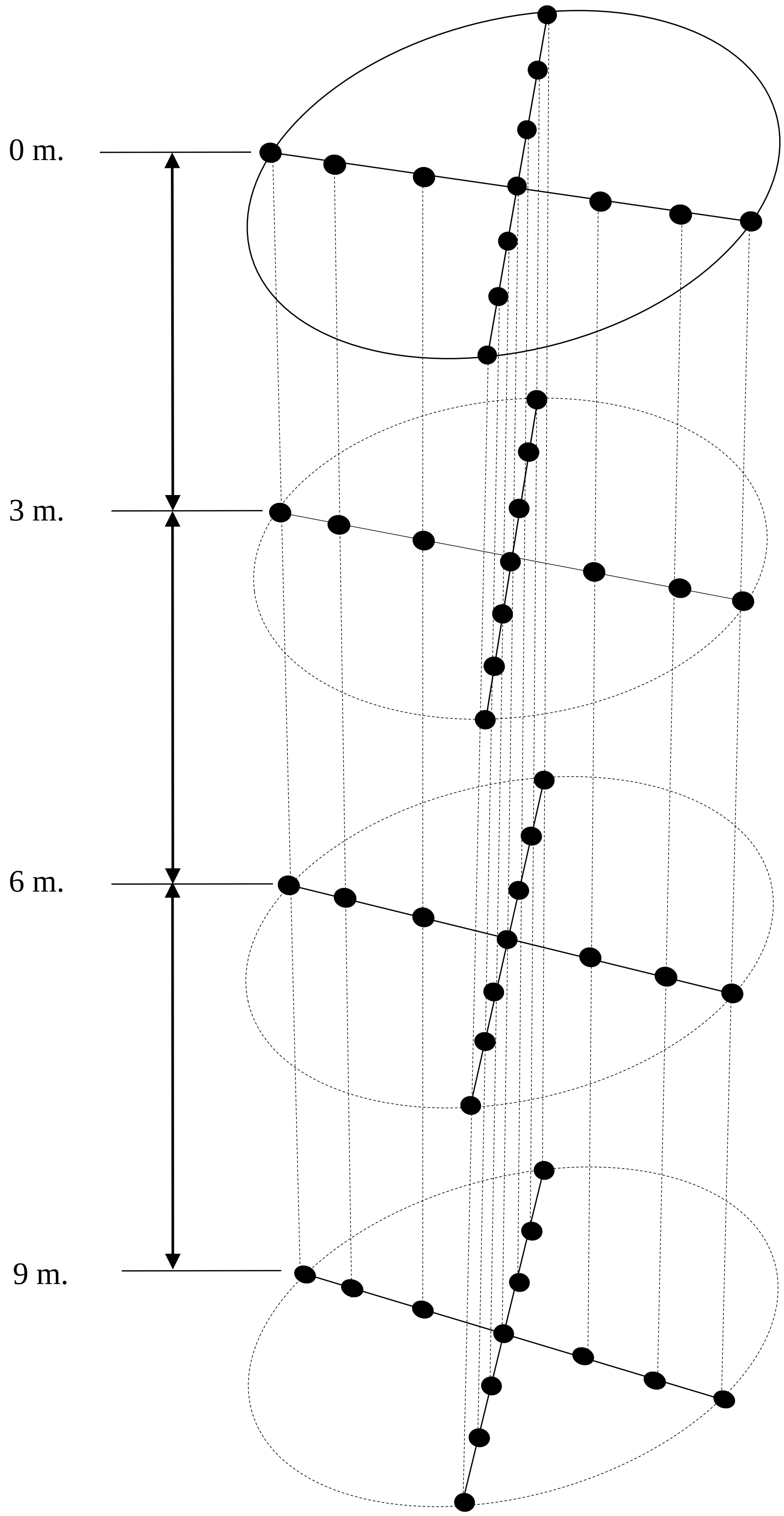

Figure-3.8: 3D model of study area.

CHAPTER 4

Results and Discussions

4.1 General

Rawal Lake is being used as a raw water source for the filtration plant which supplies water to major part of Rawalpindi cantonment areas and to some areas of Islamabad. Raw water samples were collected from March to September 2013 from a cylinder of water with 300m radius and 9m average depth. A total of 96 samples were collected from the lake out of which 24 samples were taken from 12 different points from the lake surface in X-Y dimensions and perpendicularly i.e., in Z dimension 72 samples were collected with depth interval of 3m each. The main objective of the study was to examine the variations in the water quality of Rawal Lake in X, Y and Z dimensions taking center of the lake as center of circle. The analysis of various parameters showed that most of the physical and chemical parameters were within WHO's Guidelines of potable water but residing on sharp edges of allowable limits while some parameters were found beyond permissible limits. Water quality parameters studied in the research included Temperature, pH, Dissolve Oxygen, Electric Conductivity, Turbidity, TOC, Phosphate phosphorus and Total Nitrogen. Effects of time, weather, precipitations and inflow to the lake from various sources on lake water quality have been discussed in the results. Based on the methodology discussed in the sections that follow, results of different parameters analyzed for lake water quality and their relative distribution at various sampling point in the study area are gives in Appendix A of this thesis.

4.2 Results and Analysis of Key Parameters

4.2.1 Temperature

The average temperature of the lake was recorded as 25˚C with highest to lowest values from 35˚C to 14˚C respectively. The temperature profile of all the selected points shows no major change spatially while moving along X or Y dimension (**Fig.4.1-4.2)**. However, a big decreasing trend was observed while moving from surface to depth. Because, it is impossible for sunlight to enter from surface to depth evenly (due to scattering effect of suspended particles, diffraction effect, other impurities and depth of lake) which results into stratification of the Lake. So the temperature of surface water remains higher than bottom. Throughout the study period, a sharp increase in temperature was observed from March to August and then fall in September **(Fig. 4.3-4.4)** due to seasonal shift from winter to summer and seasonal changes from Pre-monsoon to Post-monsoon. Therefore, the observed temperature of the lake from May to August favors speedy growth rate of Lake Biota. i.e., well above 25˚C to 30˚C.

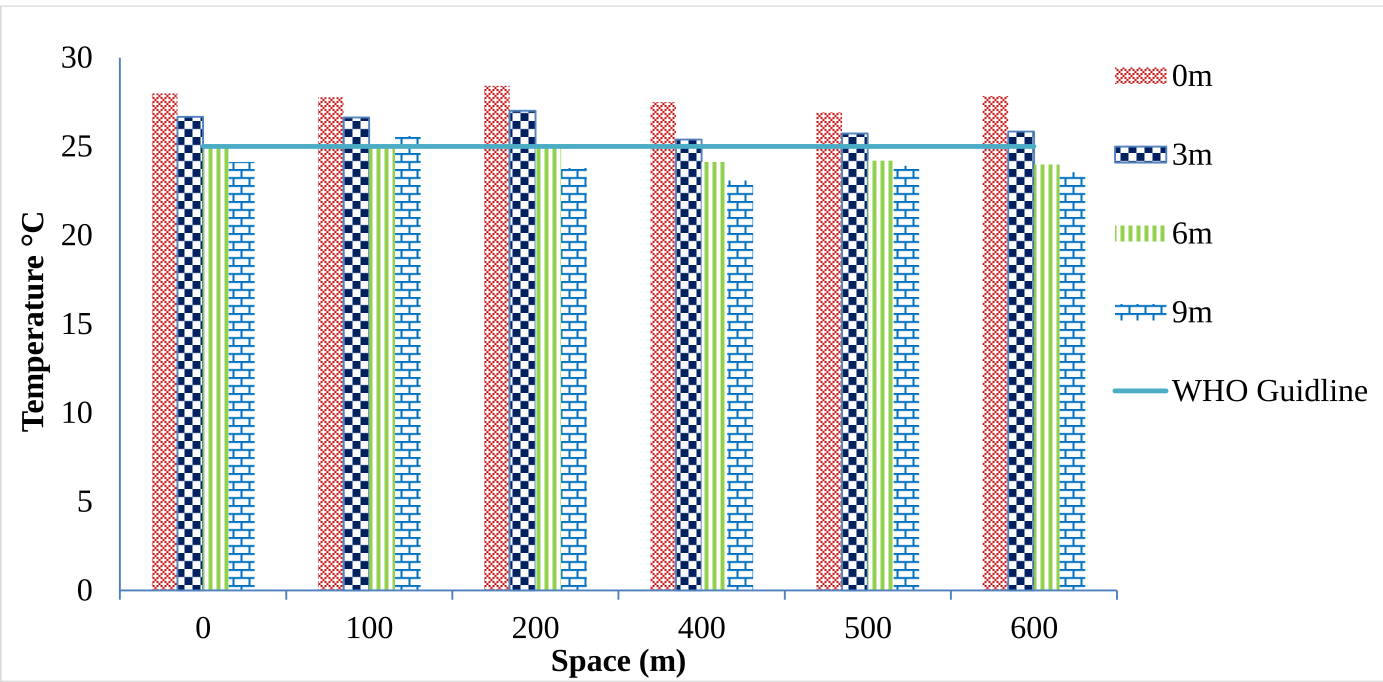

Figure-4.1: Average Spatial variations in Temperature in N-S direction vs Depth

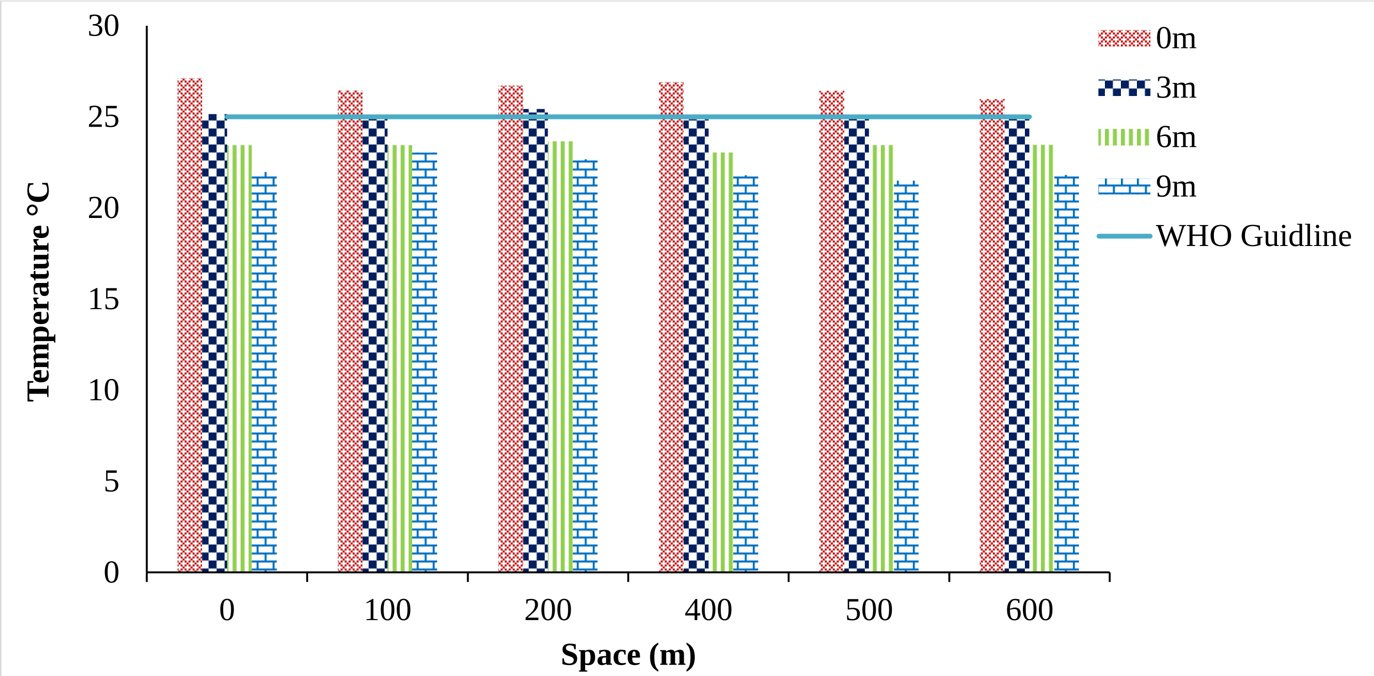

Figure-4.2: Average Spatial variations in Temperature in E-W direction vs Depth

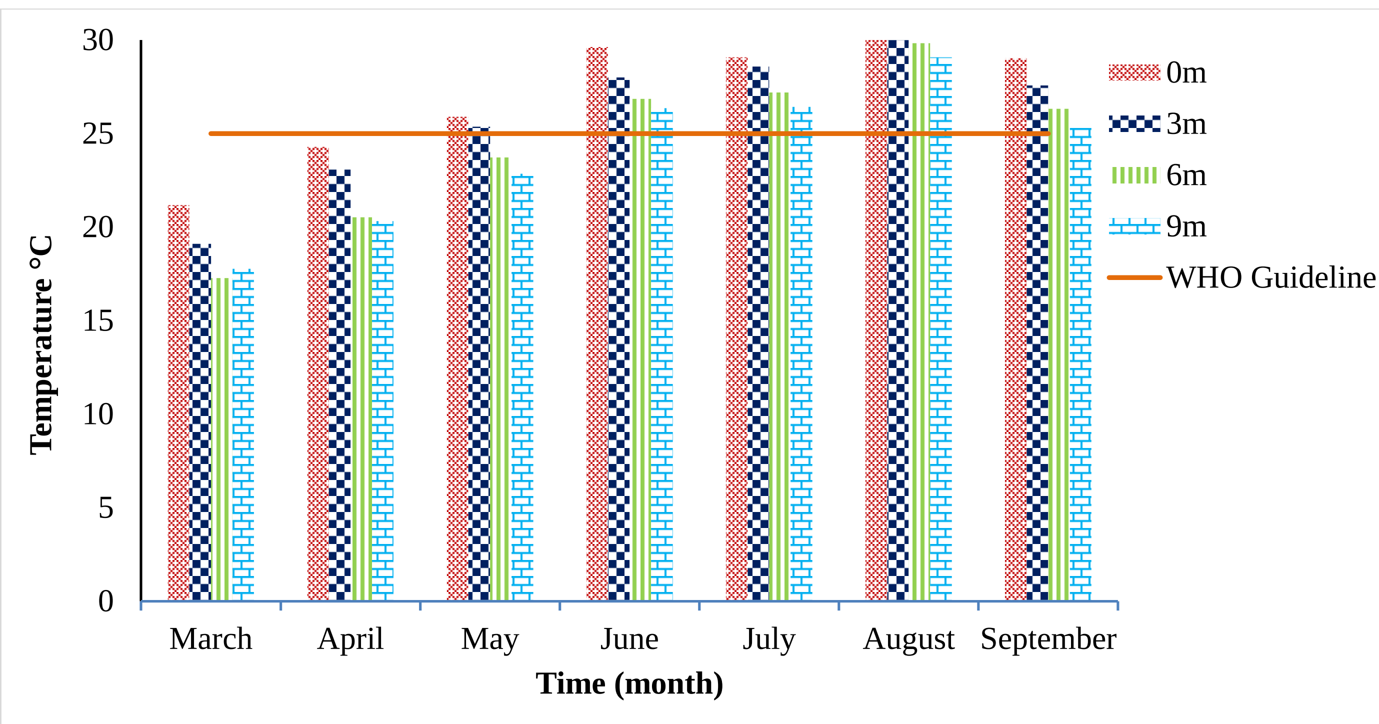

Figure-4.3: Average Temporal variations in Temperature in N-S direction vs Depth

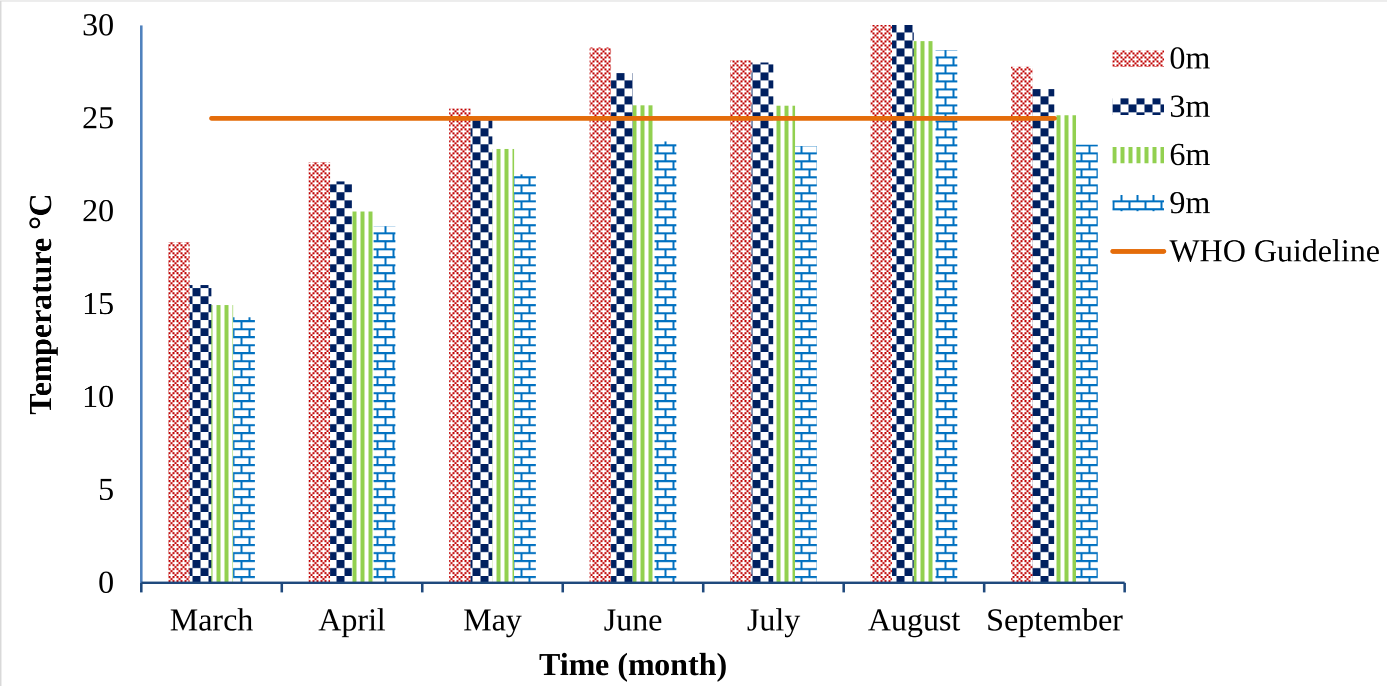

Figure-4.4: Average Temporal variations in Temperature in E-W direction vs Depth

4.2.2 Electrical Conductivity

Electrical conductivity varied from 300 to 330 µS/cm with an average around 319 µS/cm during 7 months study of Rawal lake Islamabad. However, the highest value recorded was 359 µS/cm and minimum recorded was 179 µS/cm. There was no major change observed with respect to X-Y and Z dimension **(Fig. 4.5-4.6).** However, it was also observed that conductivity varies with respect to Time i.e., Low values were recorded during March and April with an average of 300 µS/cm and then increased abruptly during August-September i.e. 340-345 µS/cm, **(Fig. 4.7-4.8).** This was due to increase in rainfall from Pre monsoon to Post monsoon period. But, this change had limited impacts on Lake Environment. The value of conductivity was well within permissible range defined by WHO and USEPA standard of 400 µS/cm for fresh drinking water. Conductivity is an easy and accurate way to measure the level of dissolved ions, but cannot indicate what type of substances are present in water body. A steady increase in conductivity over a period of years is usually indicative of pollution.

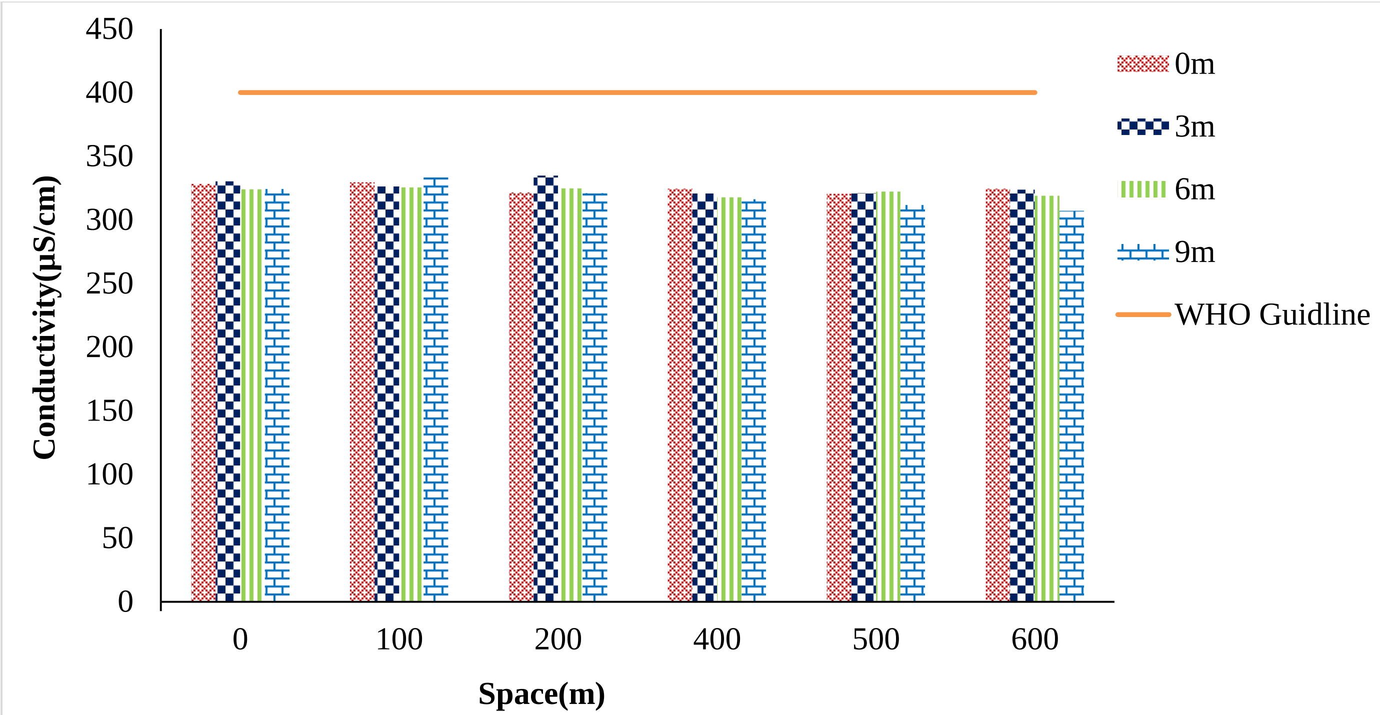

Figure-4.5: Average Spatial variations in Conductivity in N-S direction vs Depth

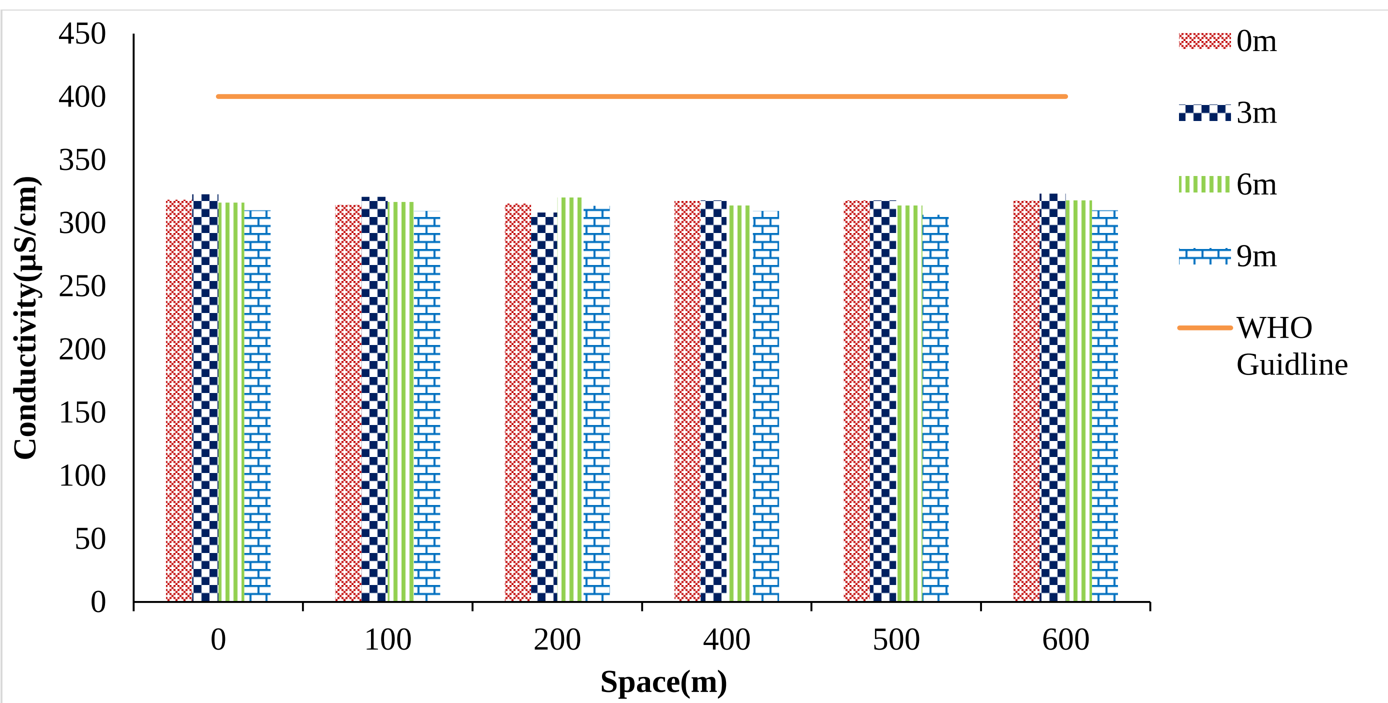

Figure-4.6: Average Spatial variations in Conductivity in E-W direction vs Depth

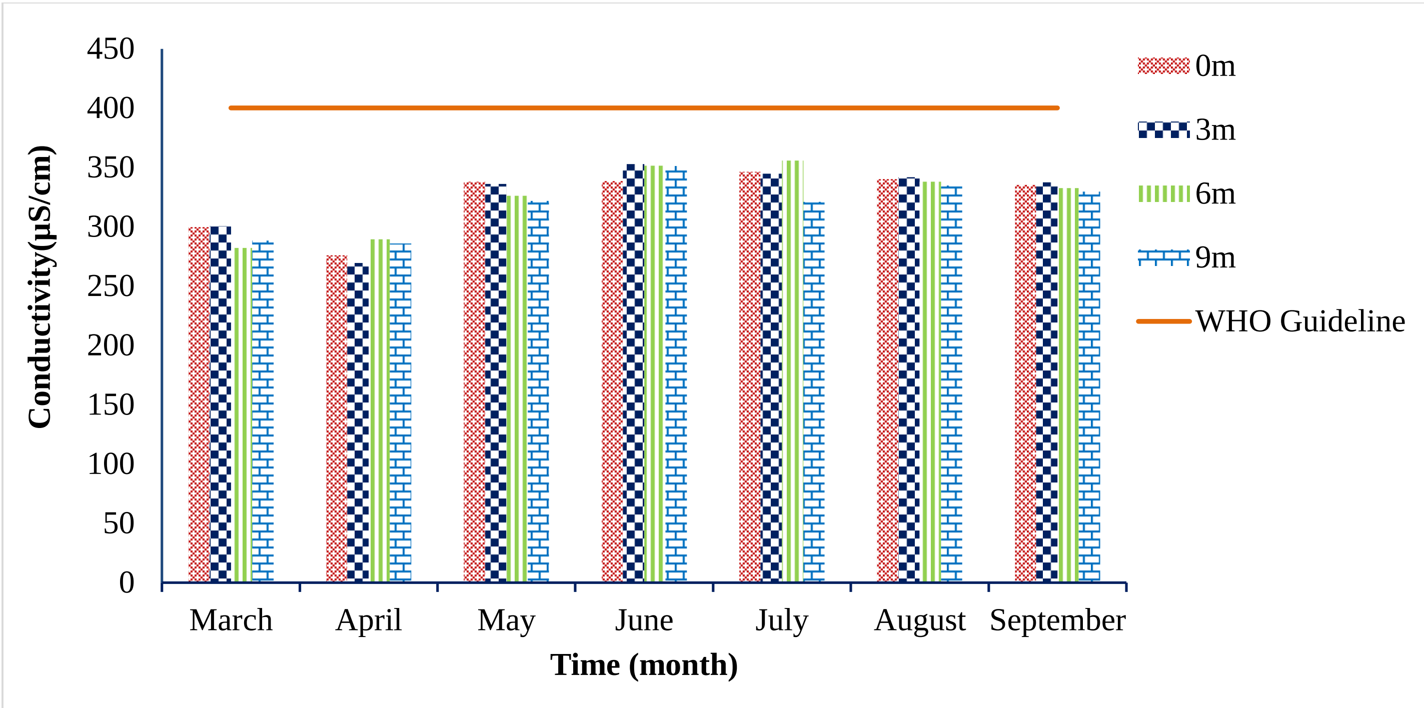

Figure-4.7: Average Temporal variations in Conductivity in N-S direction vs Depth

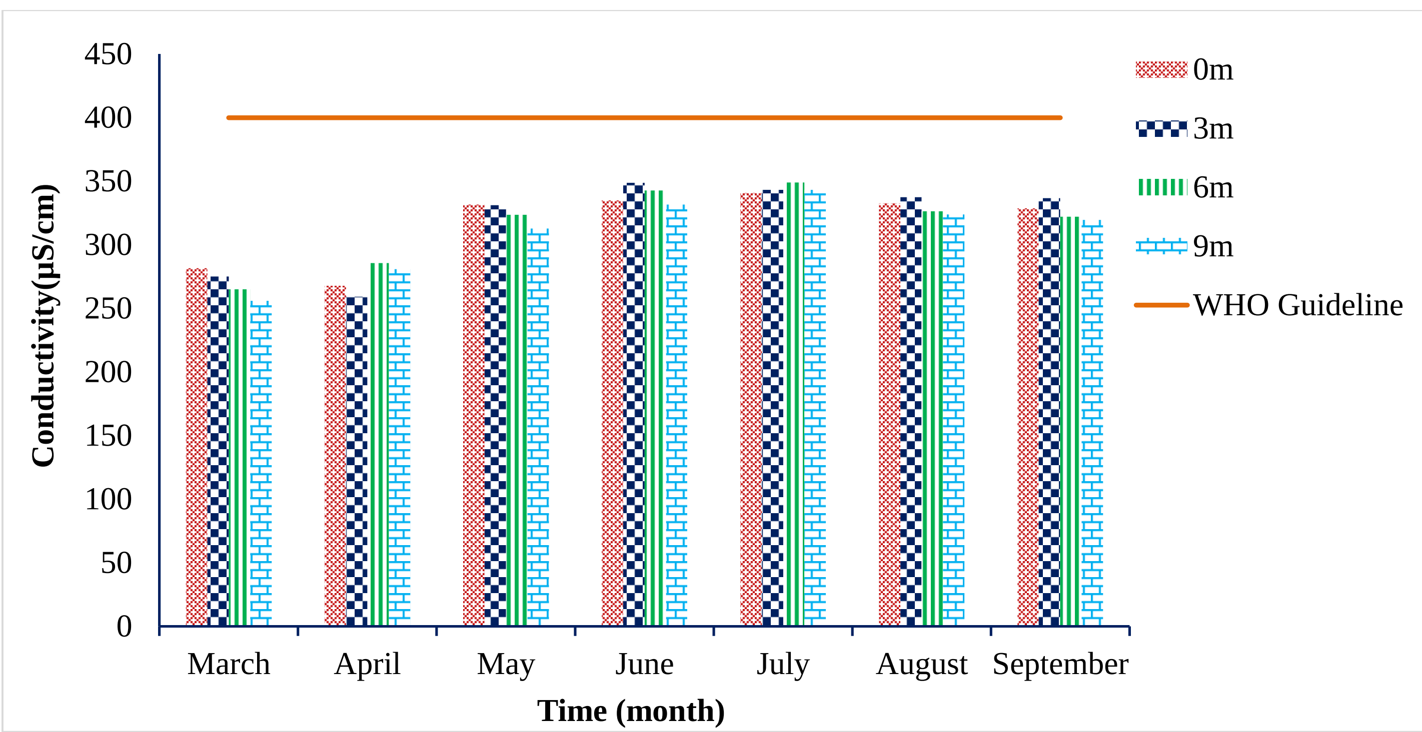

Figure-4.8: Average Temporal variations in Conductivity in E-W direction vs Depth

4.2.3 Dissolve Oxygen (DO)

The average value recorded for DO during seven months survey of Rawal Lake was 4.6 mg/L with highest to lowest value of 10.6 mg/L and 2.1 mg/L respectively. It changes with depth massively by decreasing trend from top to bottom of the Lake, because of oxygen absorbance capability of surface water from atmosphere during day light and oxygen intake by aquatic plants for nourishment and decaying at bottom of lake. This phenomenon causes oxygen stratification which results a dissolved oxygen reduced with depth. So, the problem observed here is, DO other than surface i.e., from 3m to 9m (bottom of lake) was recorded less than WHO and USEPA standards of 5 mg/L defined for drinking water lakes which was alarming for aquatic biota and for lake as well. As colder water bodies have greater amount of DO compared to warm waters, but here, rainfall, winds and natural mixing of water overcome that slight difference in temperature from March to September. So, dissolve oxygen was recorded low from May to July but higher from March to April and August to September. **(Fig. 4.11-4.12).** The question rise here in **(Fig-4.9)** that while moving North to south the surface water DO gradually increases when move towards south, because Dam is located at southern corner of lake and southern side of the lake is deepest side of the lake basin i.e. lake depth increases when moves from center to south direction which results in availability of excellent quality water with reasonable DO near Dam site.

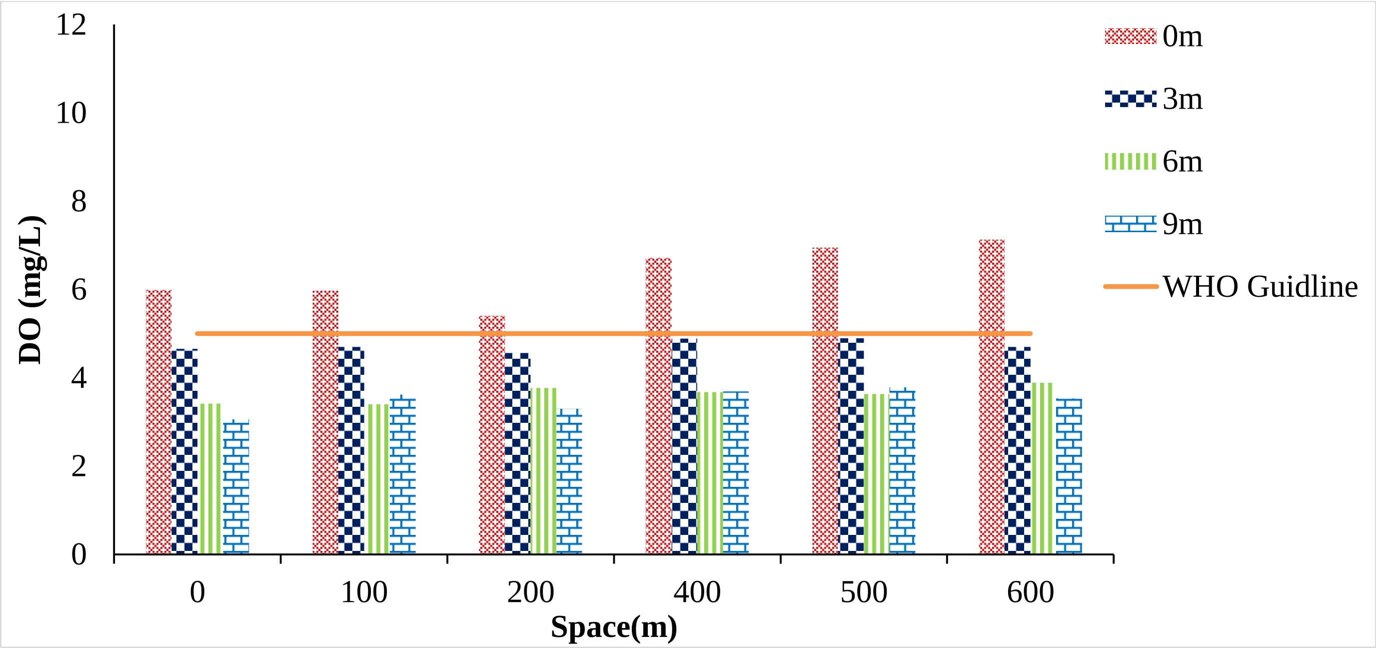

Figure-4.9: Average Spatial variations in DO in N-S direction vs Depth

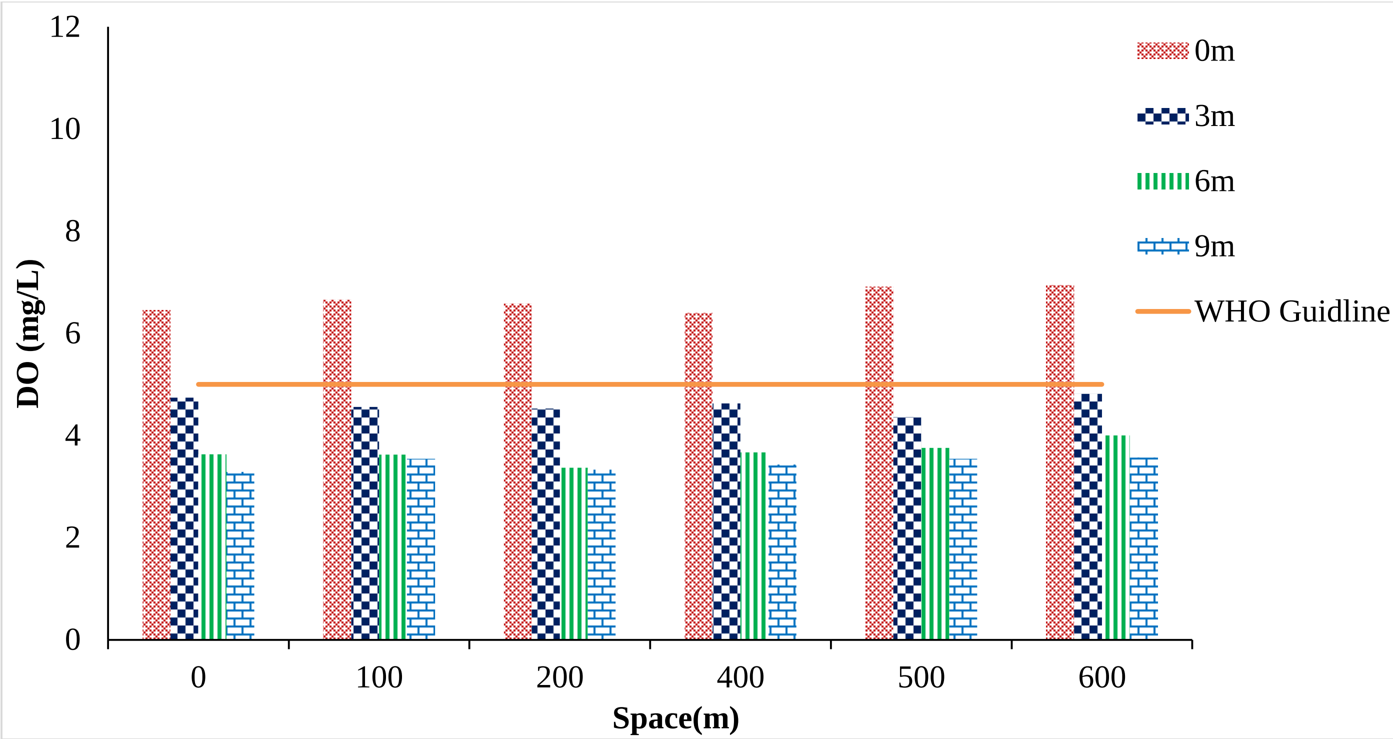

Figure-4.10: Average Spatial variations in DO in E-W direction vs Depth

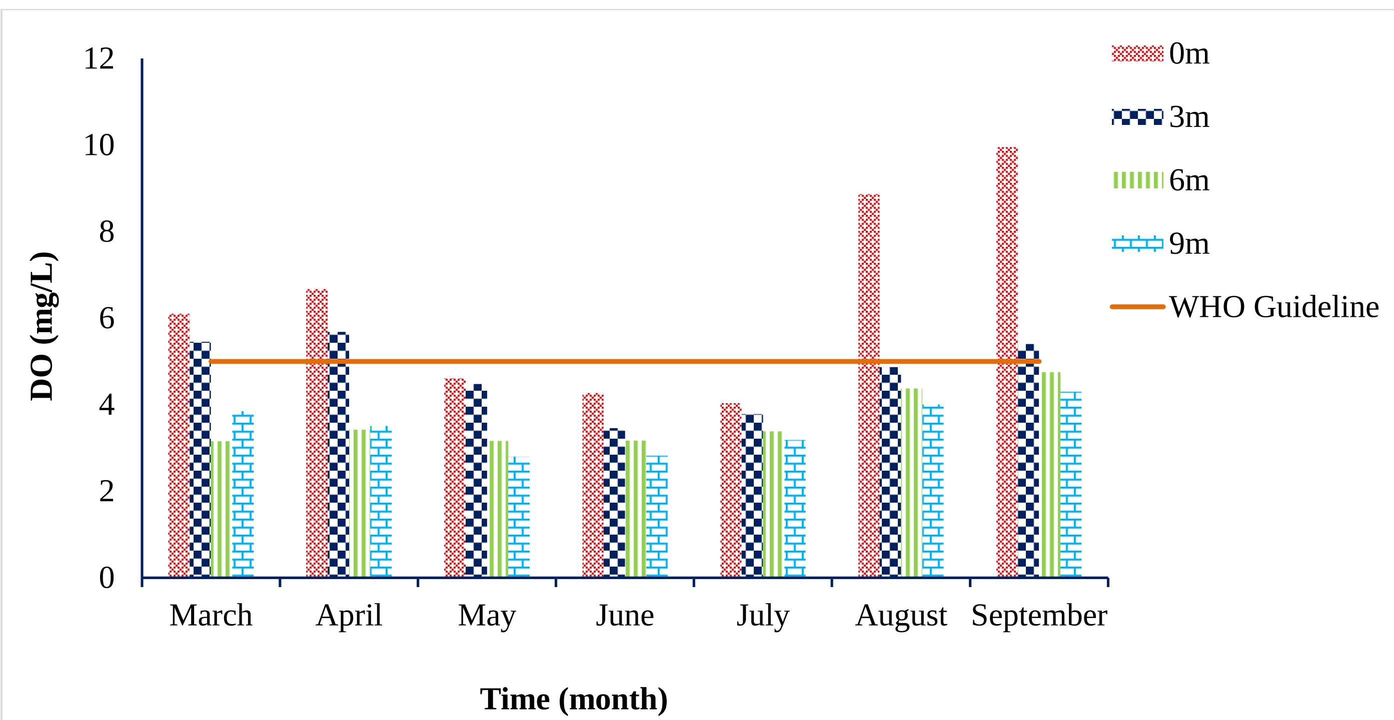

Figure-4.11: Average Temporal variations in DO in N-S direction vs Depth

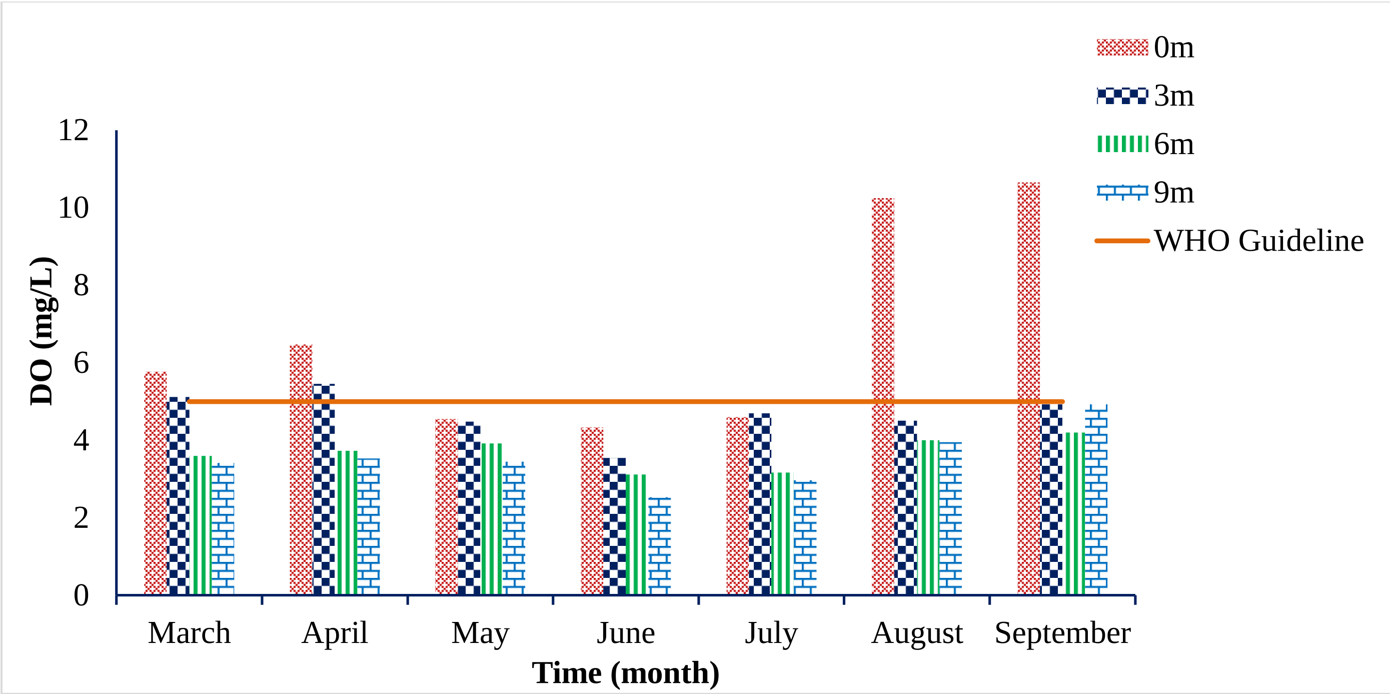

Figure-4.12: Average Temporal variations in DO in E-W direction vs Depth

4.2.4 pH

The average pH value recorded during seven months of survey was 7.7, while the highest and lowest values recorded were 8.9 and 6 respectively. This indicates moderately high alkalinity from the limestone-rich geology of the area, and provides a natural protection against acid precipitation. While moving in X-dimension its average value becomes 7.5 and its value becomes 8 while moving in Y-dimension. That slight difference was observed spatially, due to being closer to inlet point of the lake, varying depth of the lake and wind direction etc. **(Fig. 4.13- 4.14**). Overall pH behaves well in permissible limits of WHO and USEPA defined for fresh drinking water i.e., 6.5 to 8.5. It was also observed that pH was slightly low in June **(Fig. 4.15- 4.16)** as compared to all other months in which survey was carried out. Mainly this was due to dry period from May and June which raised concentration (build up) of acidic environment in the lake. It was clear that the depth of lake didn't effect lake water pH. It was almost constant throughout the lake.

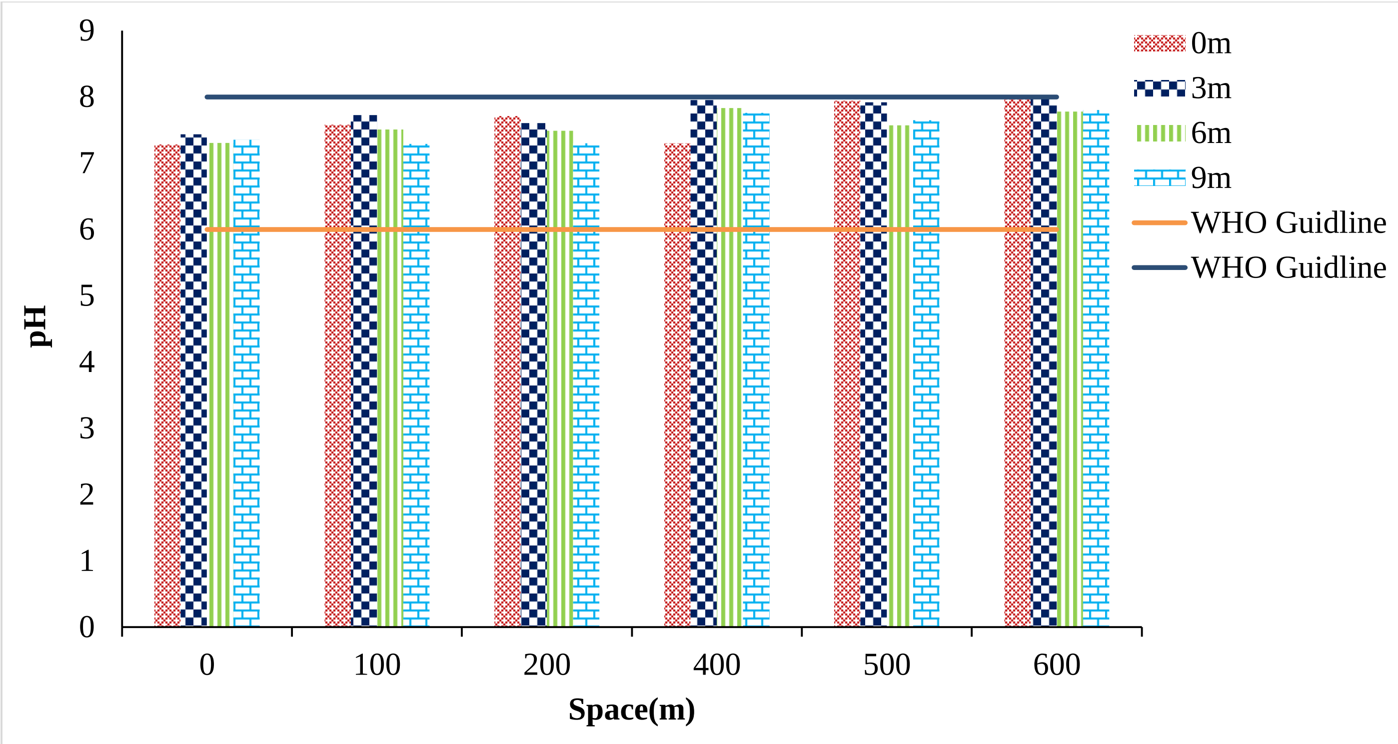

Figure-4.13: Average Spatial variations in pH in N-S direction vs Depth

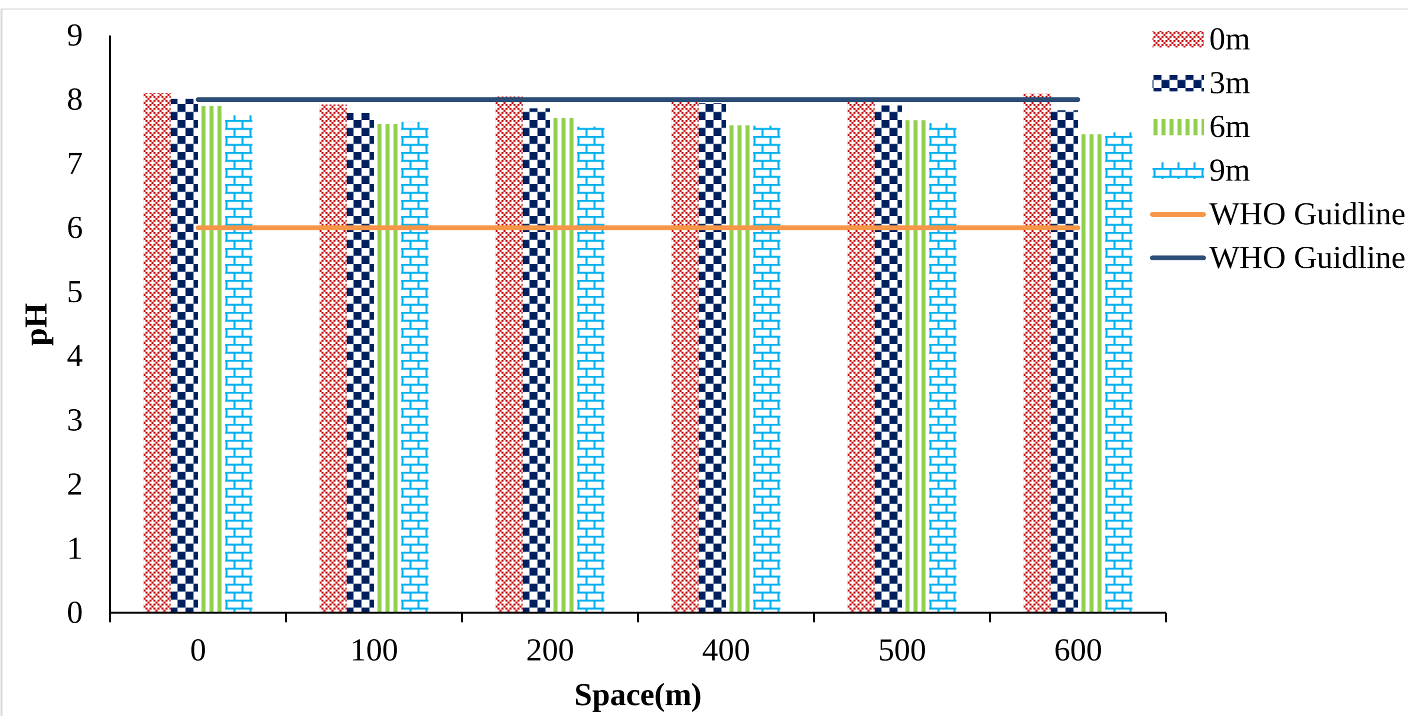

Figure-4.14: Average Spatial variations in pH in E-W direction vs Depth

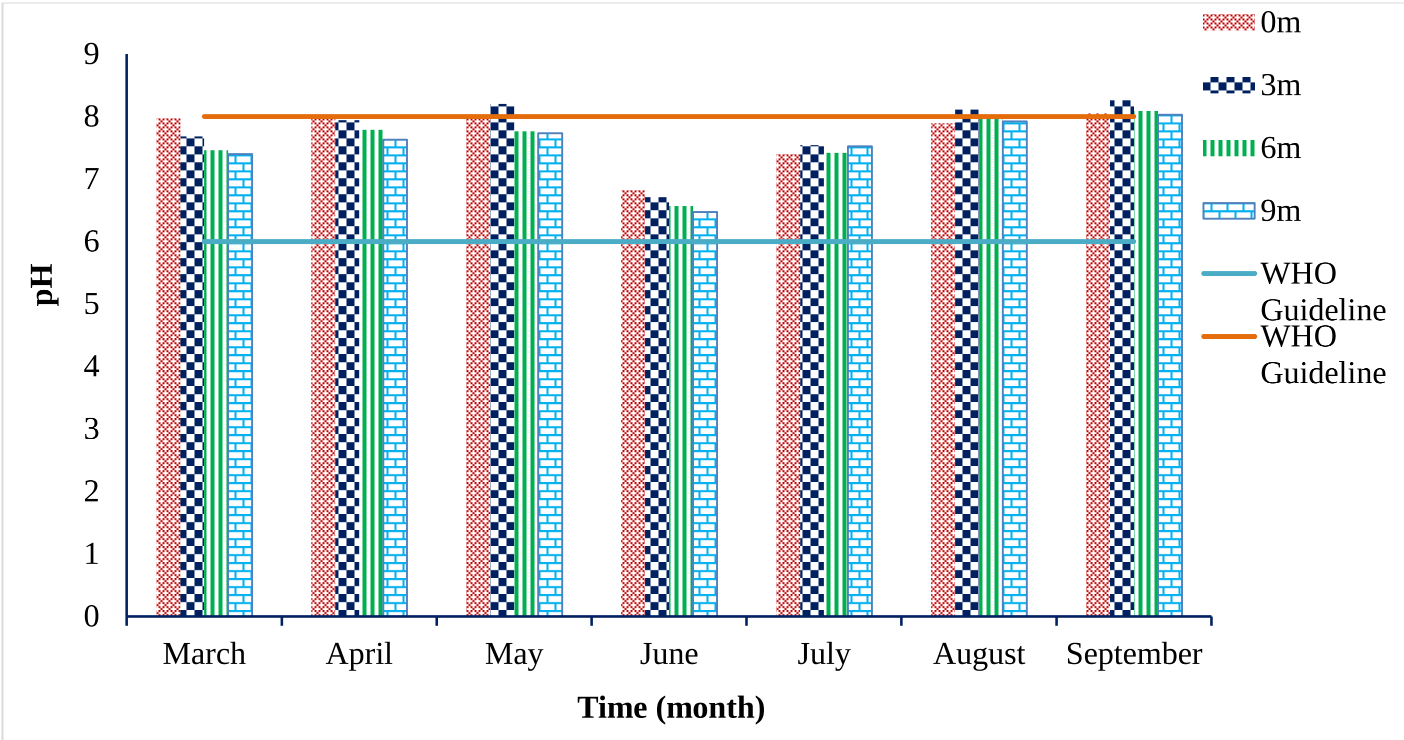

Figure-4.15: Average Temporal variations in pH in N-S direction vs Depth

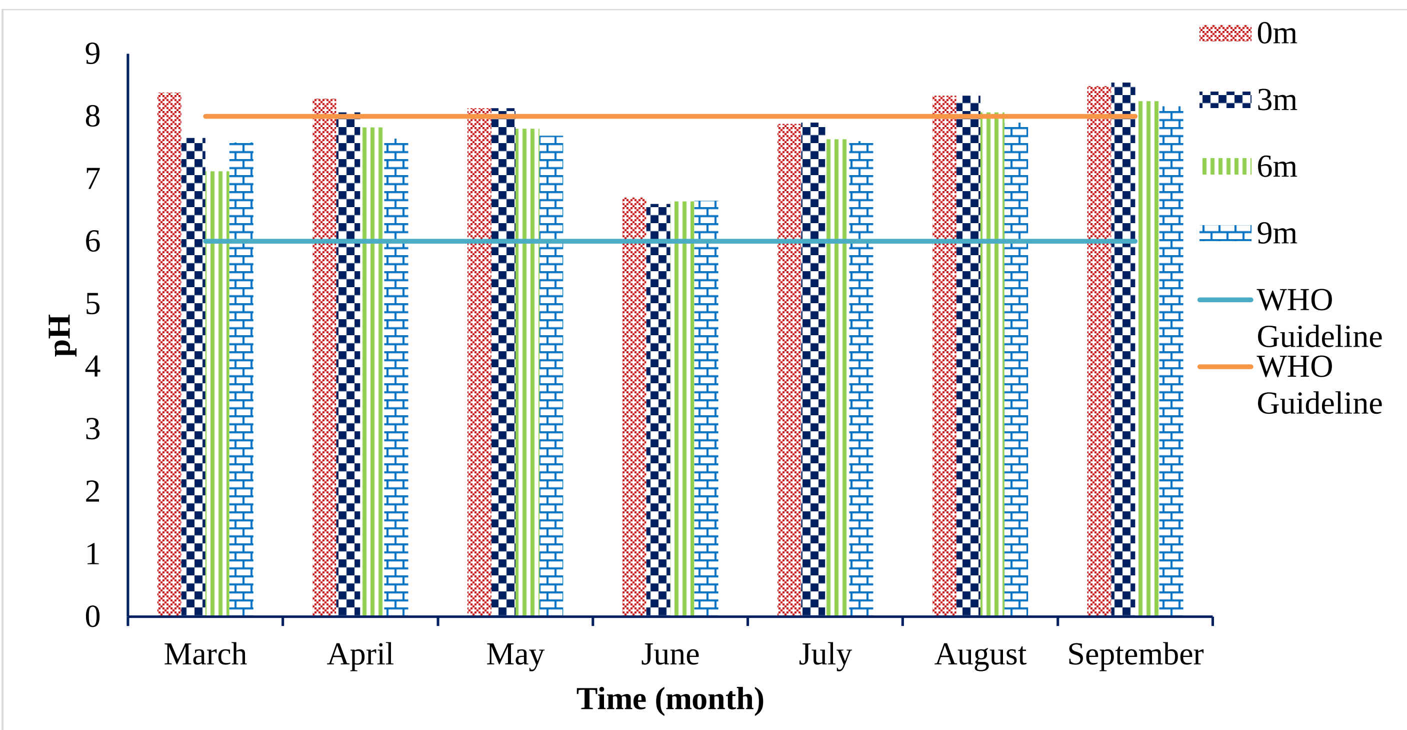

Figure-4.16: Average Temporal variations in pH in E-W direction vs Depth

4.2.5 Turbidity

Rawal Lake falls in the category of turbid lakes. The average value recoded was 9.1 NTU while the maximum and minimum recorded Turbidity were 45 and 1.7 NTU respectively. Increasing trend in turbidity was recorded when moving vertically from surface to depth. During seven months survey, surface water turbidity lies well in range but an average of 15 NTU recorded in middle and bottom of lake which crosses the standard limit of 5 NTU defined by WHO and USEPA for drinking water **(Fig.4.17-4.18).** This was not a mystery but gradual gravitational settlement of suspended particles inside turbid waters. Turbidity of Rawal Lake was low during dry spell i.e., from March to May but rapid increase was observed from June to September due to rigorous mixing during monsoon and because of polluted streams/runoff joining reservoir. **(Fig.4.19-4.20)**

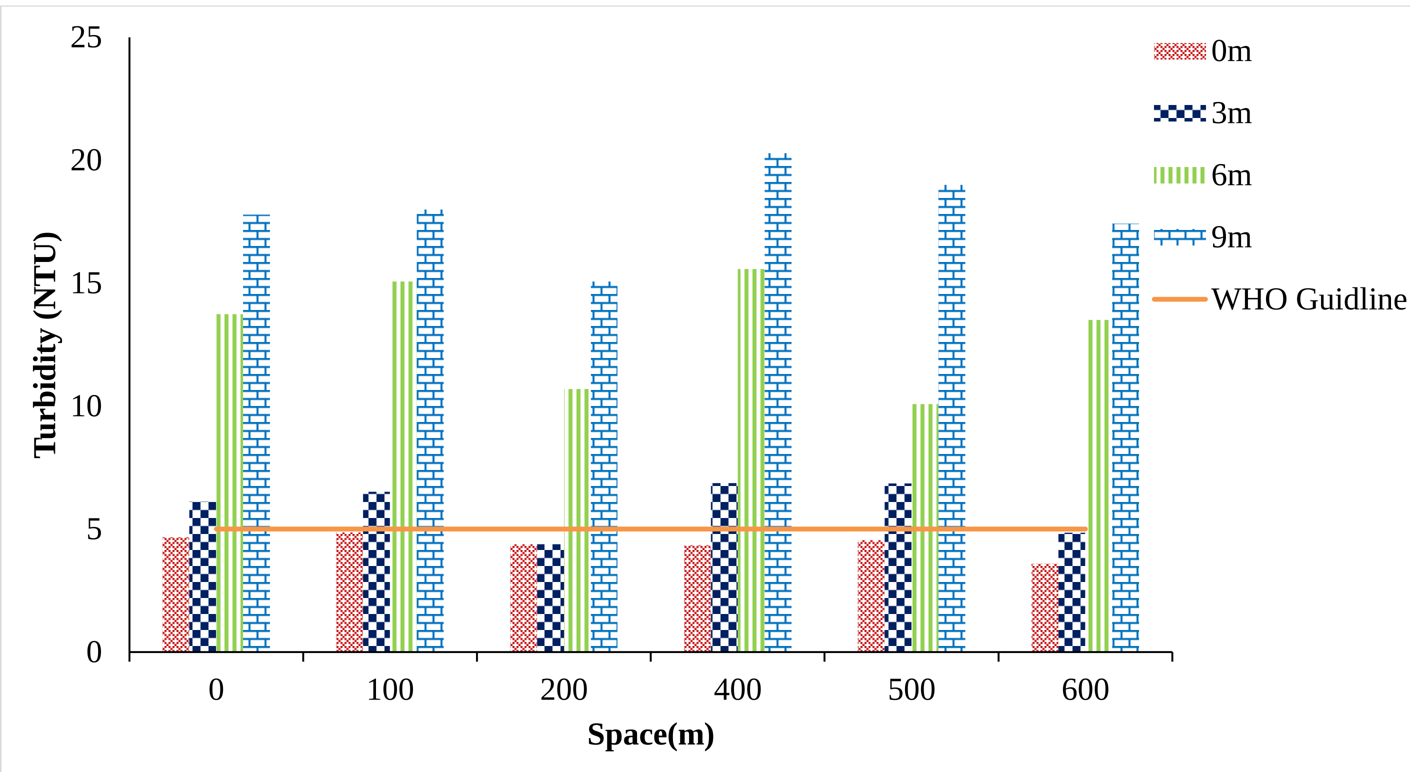

Figure-4.17: Average Spatial variations in Turbidity in N-S direction vs Depth

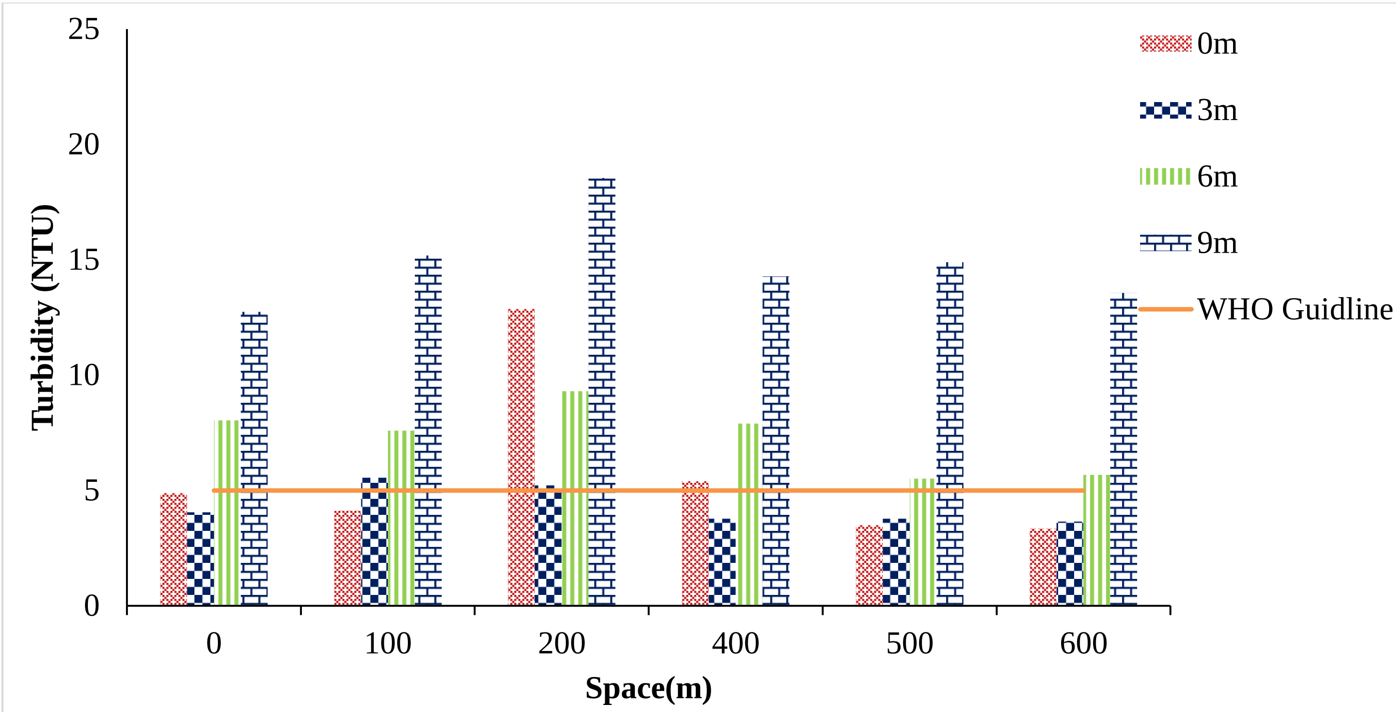

Figure-4.18: Average Spatial variations in Turbidity in E-W direction vs Depth

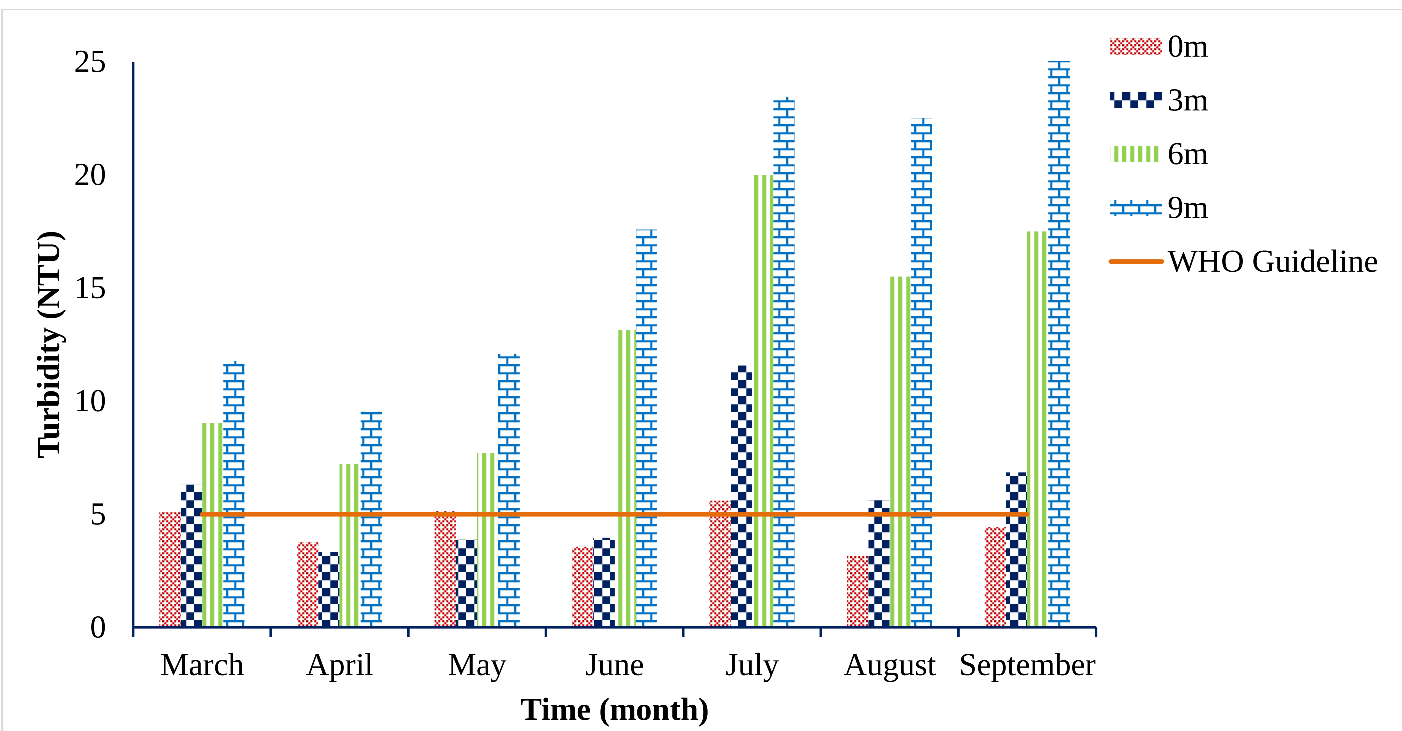

Figure-4.19: Average Temporal variations in Turbidity in N-S direction vs Depth

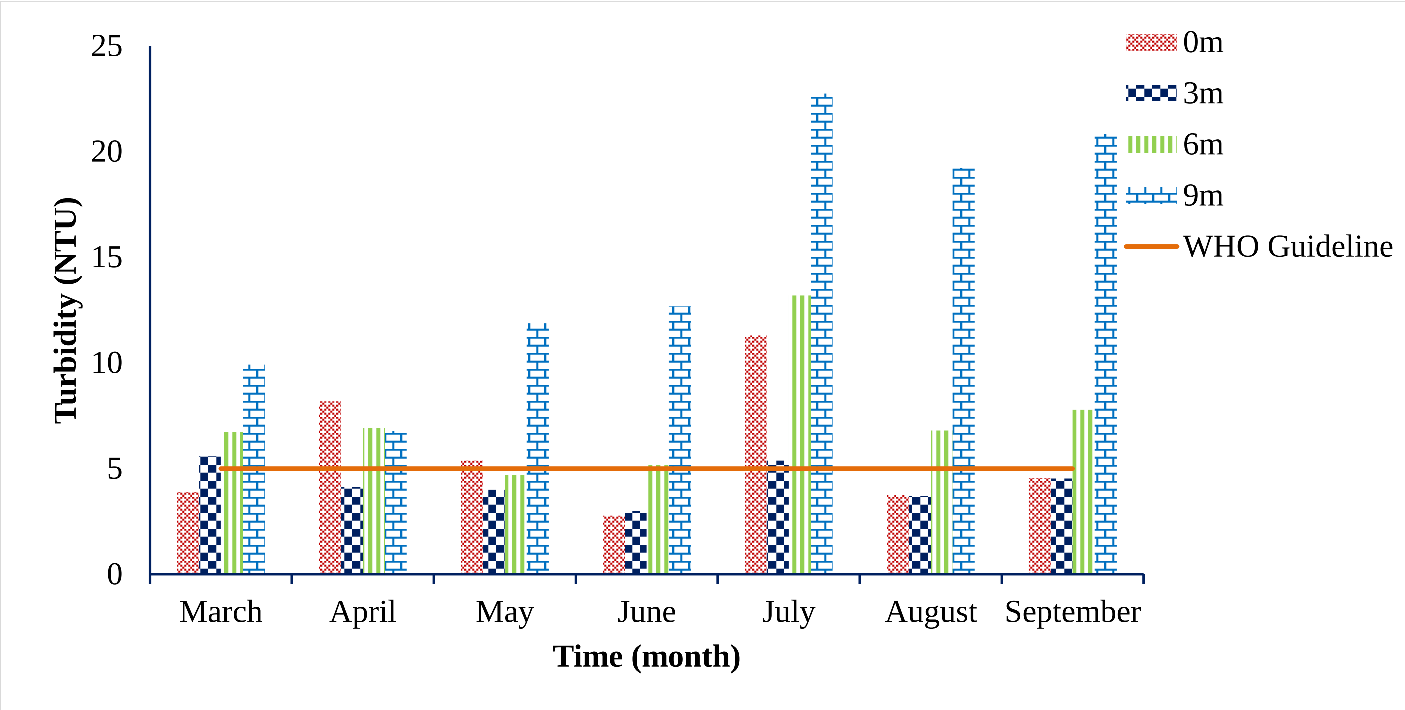

Figure-4.20: Average Temporal variations in Turbidity in E-W direction vs Depth

4.2.6 Phosphate-phosphorus

WHO and USEPA sets a permissible limit of 0.05 mg/L for fresh drinking water. The average value recorded here was 0.6 mg/L while the maximum and minimum recorded were 5.4 and 0 mg/L respectively, which was far beyond the standard limit. The amount of phosphorus present in water bodies indicates the growth rate of algae and planktons. Normally, phosphorus is directly proportional to algal concentration. The concentration of phosphorus was higher in depth of lake as compared to surface water because of presence or absence of dissolve oxygen at bottom. The possible causes of Phosphate phosphorus were animal and human waste, deforestation, poultry waste, fertilizers and other synthetic chemicals. Generally, both phosphorus and nitrogen were considered to be limiting growth factor for any fresh water reservoir, which results in Eutrophication.

It was also observed that the concentration of phosphate phosphorus was less in wet season as compared to dry season due to dilution impacts by freshwater intake. The current concentration of phosphate-phosphorus have much disastrous impacts on lake **(Fig.4.21-4.24).**

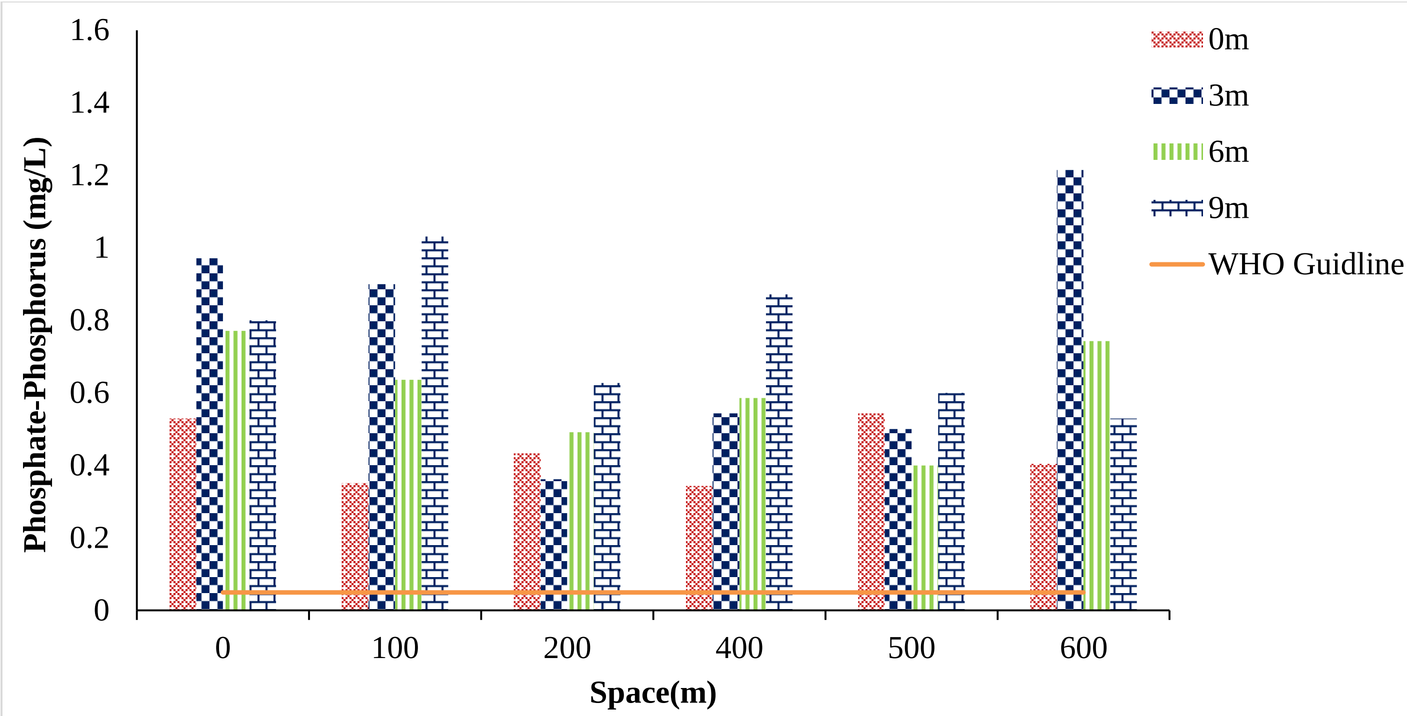

Figure-4.21: Average Spatial variations in Phosphate-Phosphorus in N-S direction vs Depth

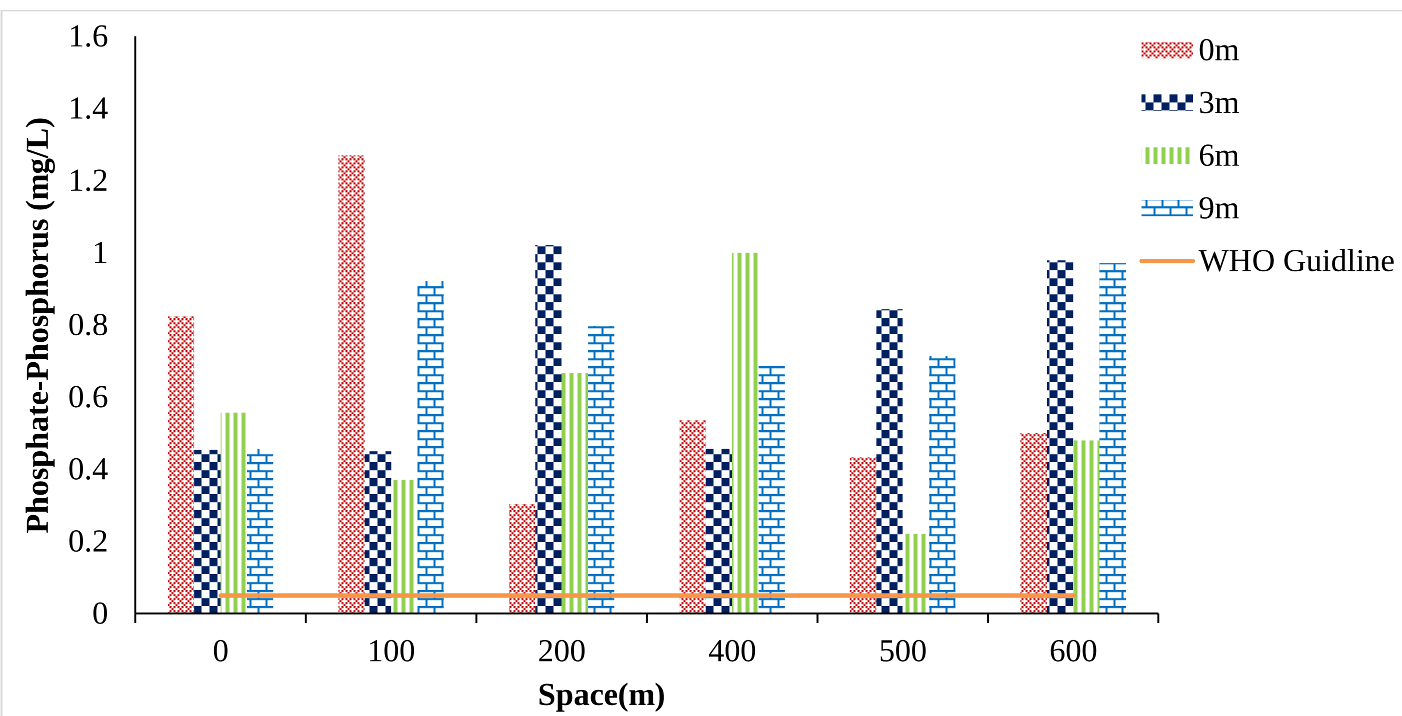

Figure-4.22: Average Spatial variations in Phosphate-Phosphorus in E-W direction vs Depth

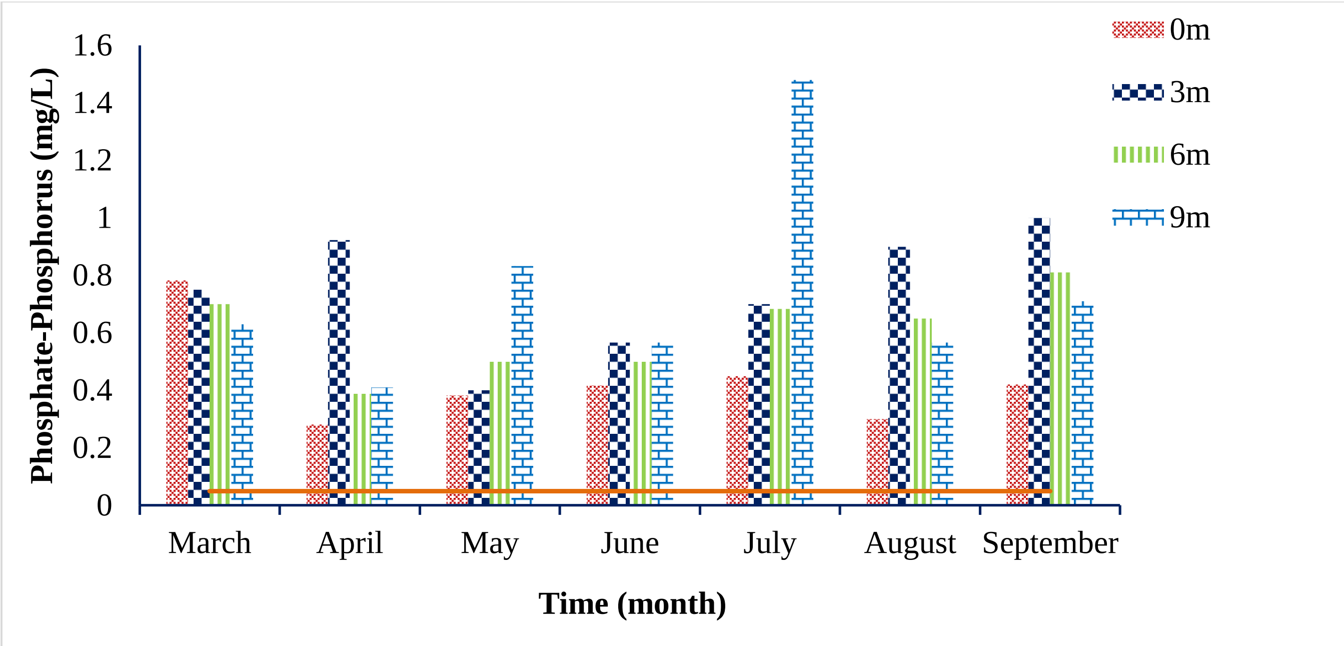

Figure-4.23: Average Temporal variations in Phosphate-Phosphorus in N-S direction vs Depth

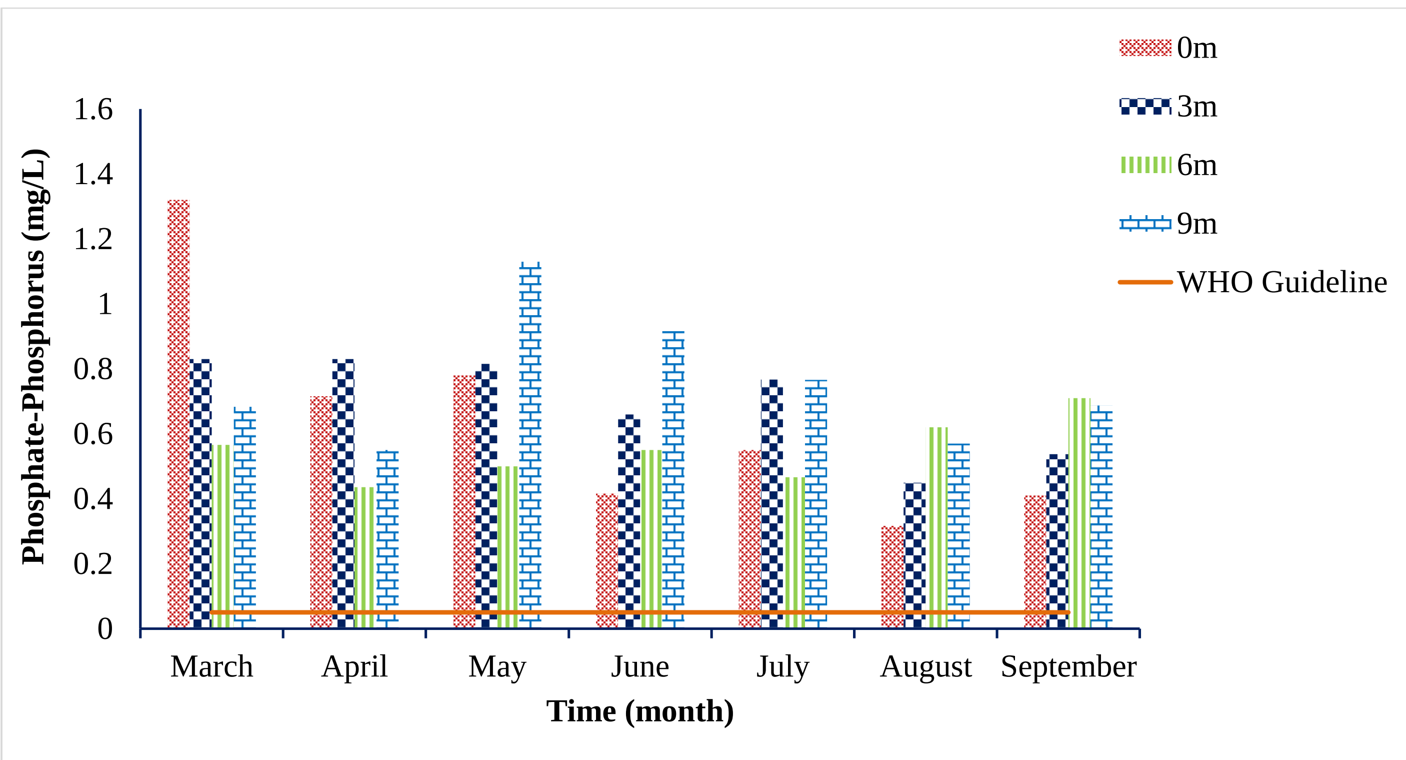

Figure-4.24: Average Temporal variations in Phosphate-Phosphorus in E-W direction vs Depth

4.2.7 Total Nitrogen

WHO and USEPA set 10mg/L standard for fresh drinking water. The average total nitrogen observed was 1.3 mg/L with a maximum and minimum values of 10.1 mg/L and 0.1 mg/L respectively during seven months survey of Rawal Lake. Overall TN value was observe well in limits. So, no major disastrous impact on Lake Environment. Nutrients plays an important role for rapid Lake growth process. So both, nitrogen and phosphorus have fundamental importance. But here total nitrogen acts as growth limiting factor for lake as compared to Phosphorus because if the ratio of nitrogen to phosphorus is greater than 10:1 then Phosphorus act as limiting factor , but here, its ratio was less than 10:1 then TN acts as a limiting factor for lake growth. Here, 2:1 or 3:1 is relation for TN to phosphorus So, TN is said to be limiting factor for lake growth. The possible causes of nitrogen were animals and human waste, poultry waste, decaying plants, fertilizers, synthetic chemicals and atmospheric nitrogen (comprises 78% of total atmospheric gases)

(Fig. 4.25-4.28)

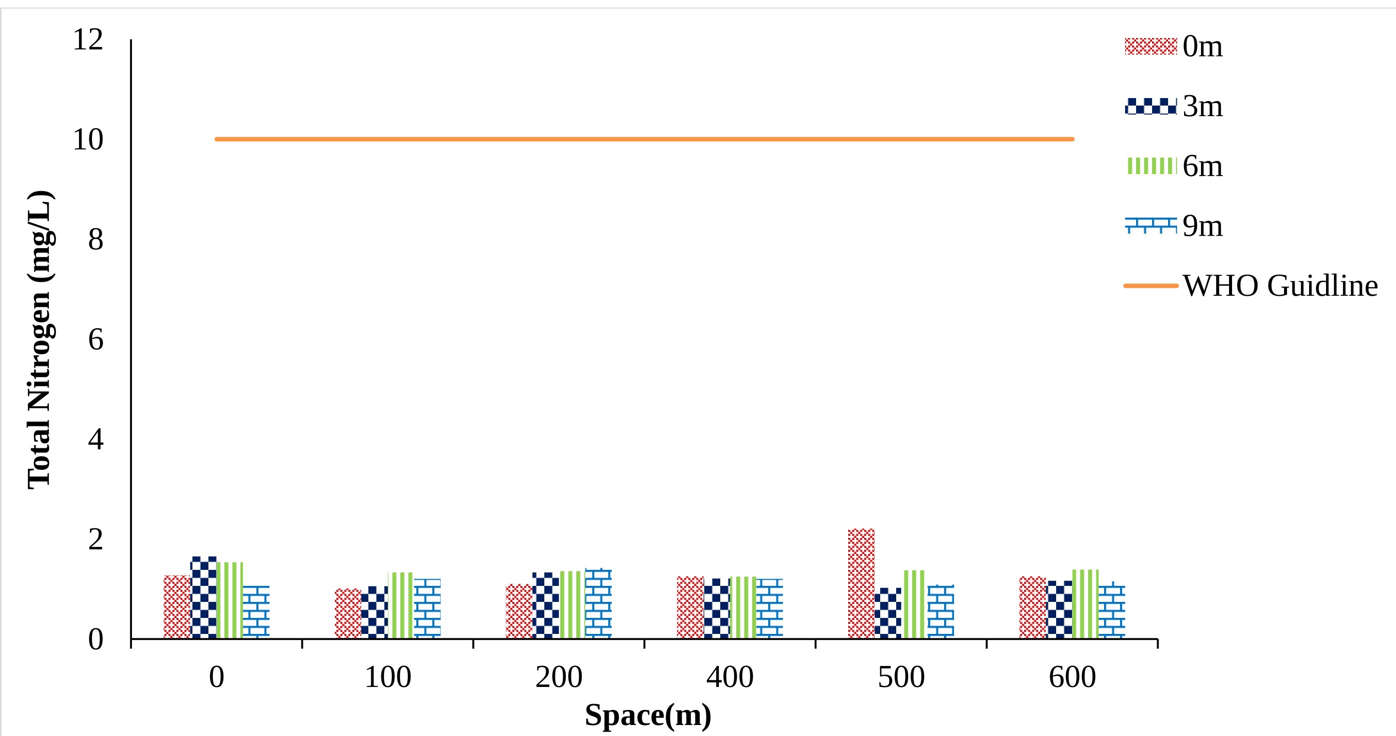

Figure-4.25: Average Spatial variations in Total Nitrogen in N-S direction vs Depth

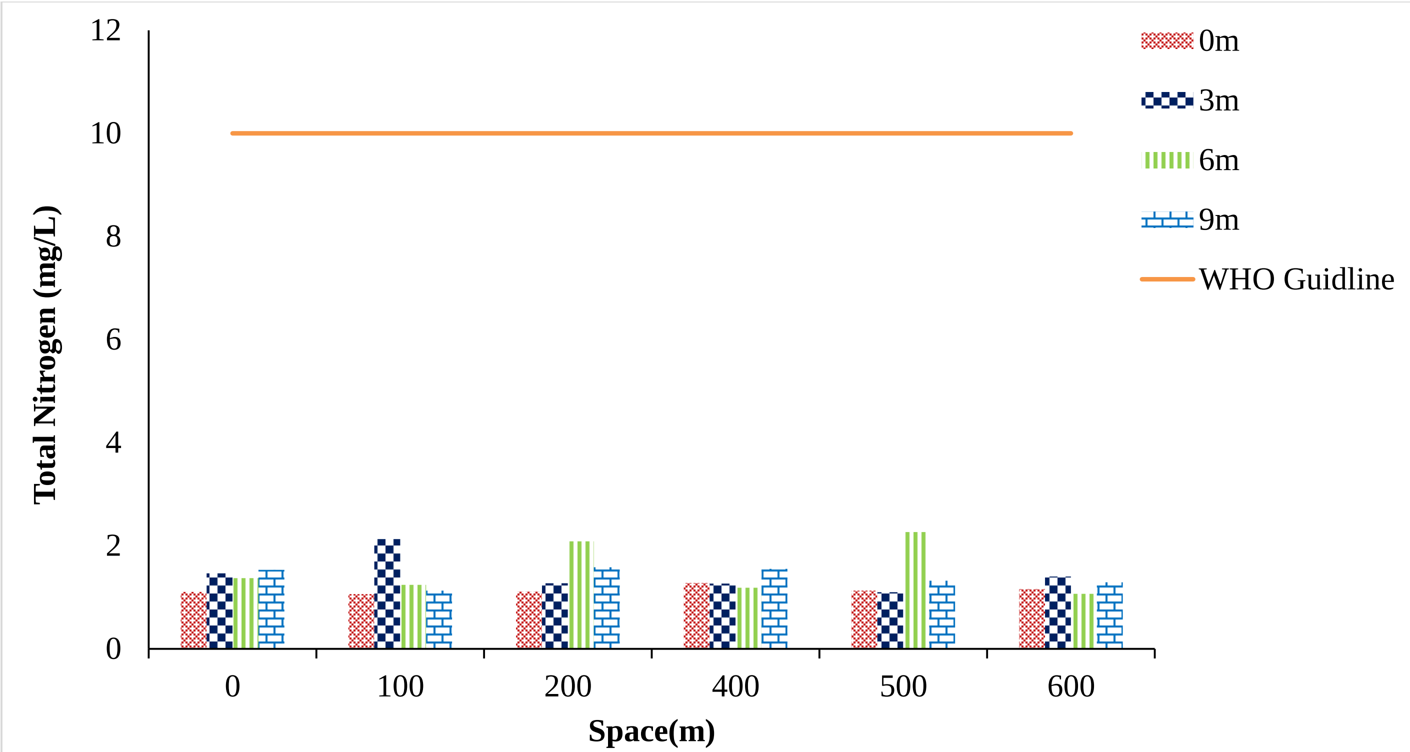

Figure-26: Average Spatial variations in Total Nitrogen in E-W direction vs Depth

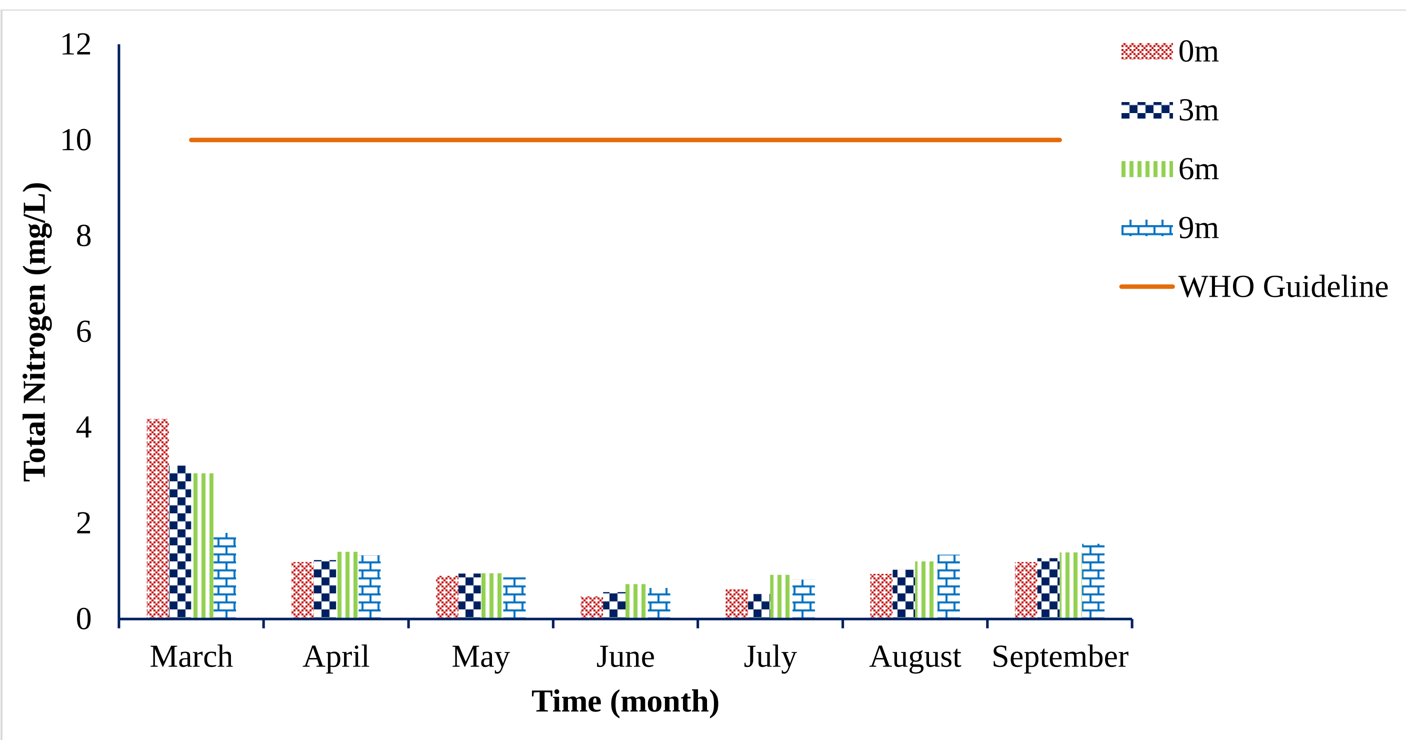

Figure-4.27: Average Temporal variations in Total Nitrogen in N-S direction vs Depth

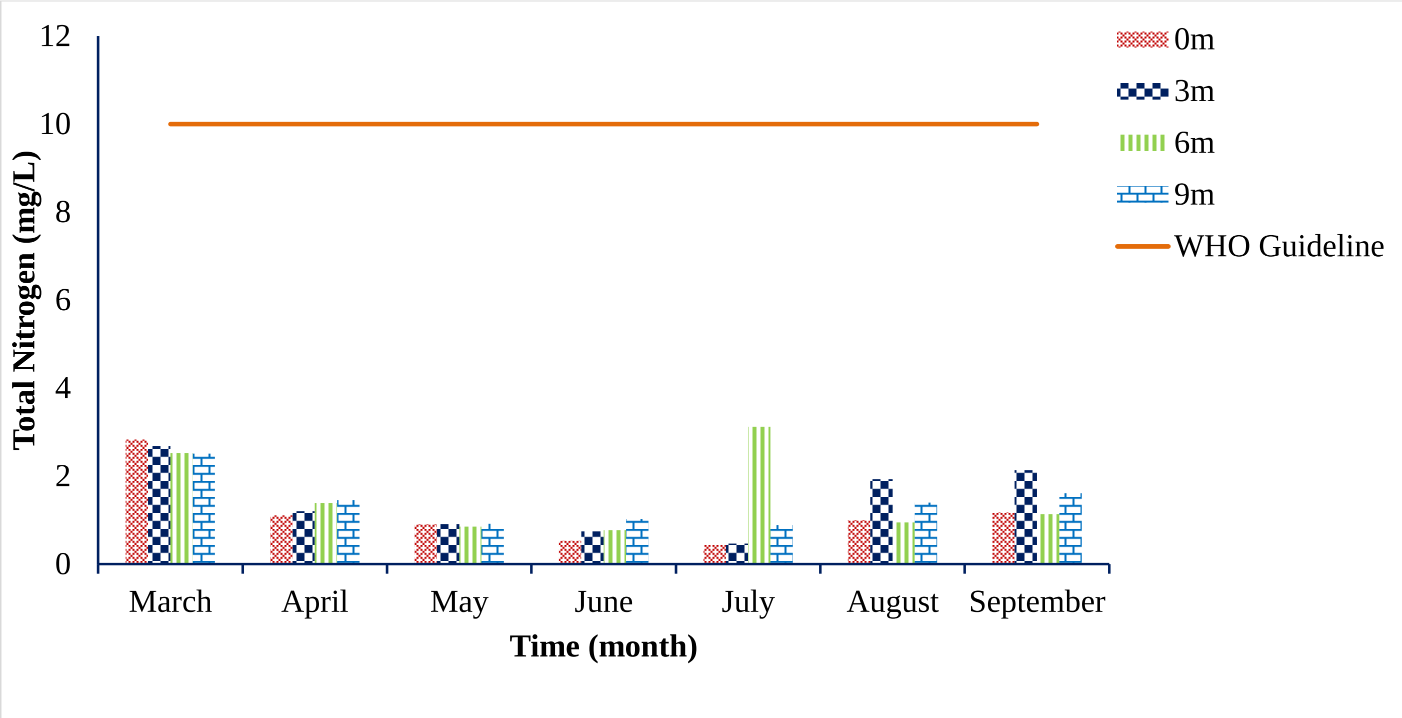

Figure-4.28: Average Temporal variations in Total Nitrogen in E-W direction vs Depth

4.2.8. Total Organic Carbon (TOC)

WHO and USEPA have not mentioned any specific standard of TOC for fresh water lakes and reservoirs. The average value recorded was 10.6 mg/L with a maximum and minimum recorded were 43.38 mg/L and 1.4 mg/L respectively during seven months survey of Rawal Lake. No major change was observed in concentration of TOC in X or Y dimension.

The concentration of TOC recorded in March was the highest then falls next four months then during monsoon it again increased after heavy rainfall inputs because of TOC increment as intake of sewage, open field farmland runoff and domestic effluents from catchment to Lake. However, no proper impact observed on TOC in Z-dimension, it was normal throughout the lake. Analysis of TOC reflects the importance of organic material necessary for aquatic growth. It effects biochemical processes, nutrient cycle and chemical transport and TOC is directly proportional to oxygen consumption in lake and vice versa. **(Fig.4.29-4.32)**

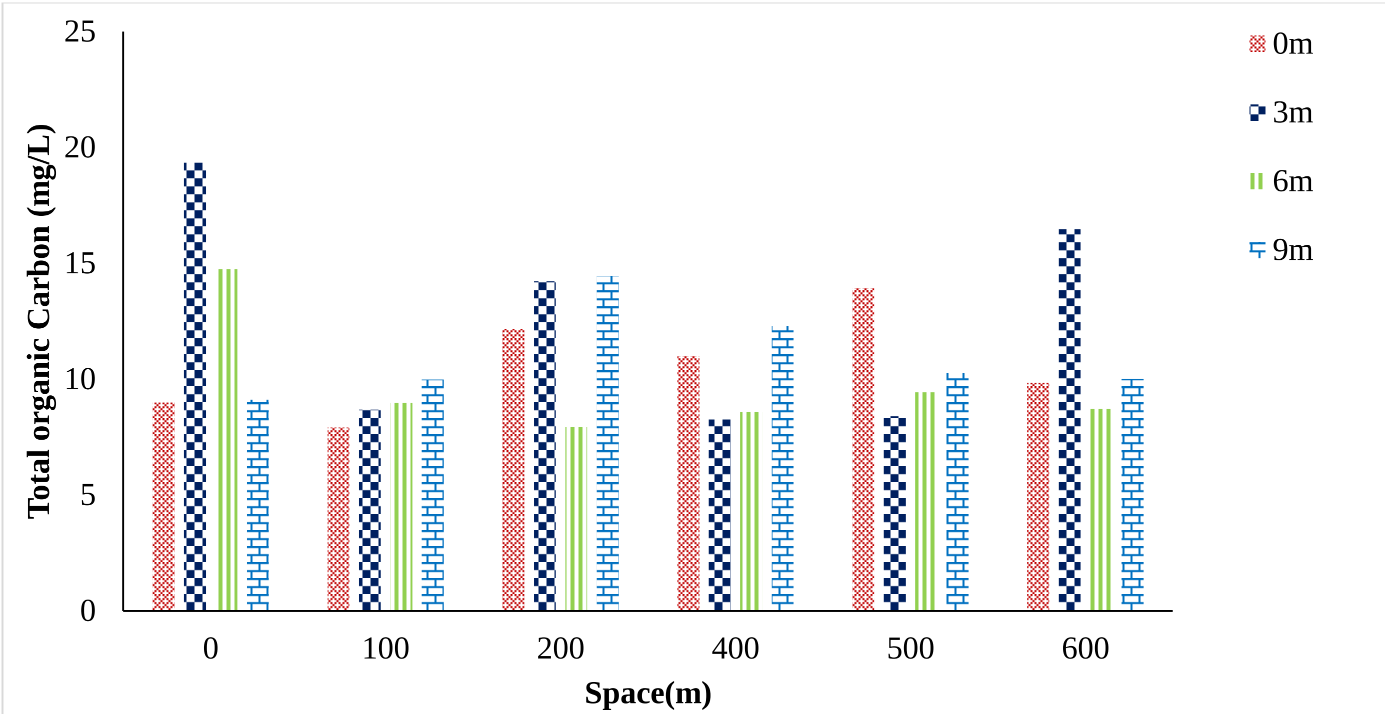

Figure-4.29: Average Spatial variations in Total Organic Carbon in N-S direction vs Depth

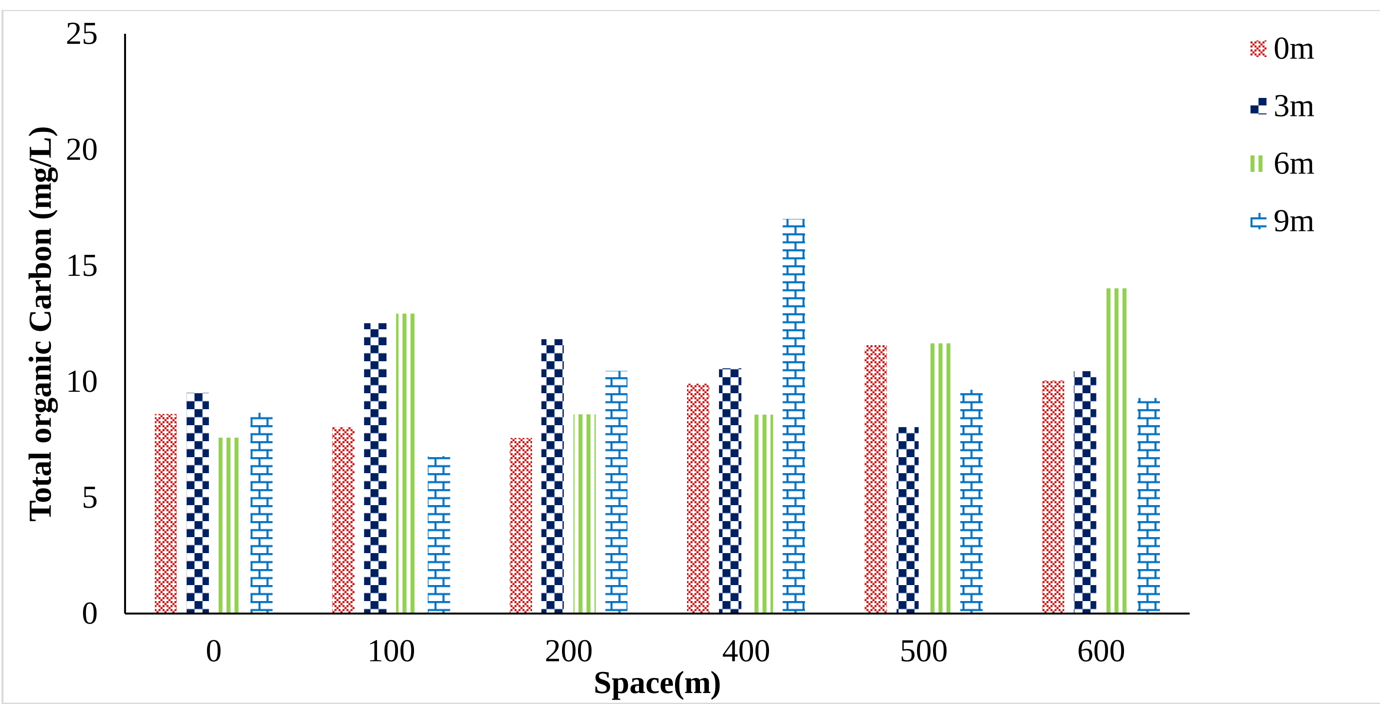

Figure-4.30: Average Spatial variations in Total Organic Carbon in E-W direction vs Depth

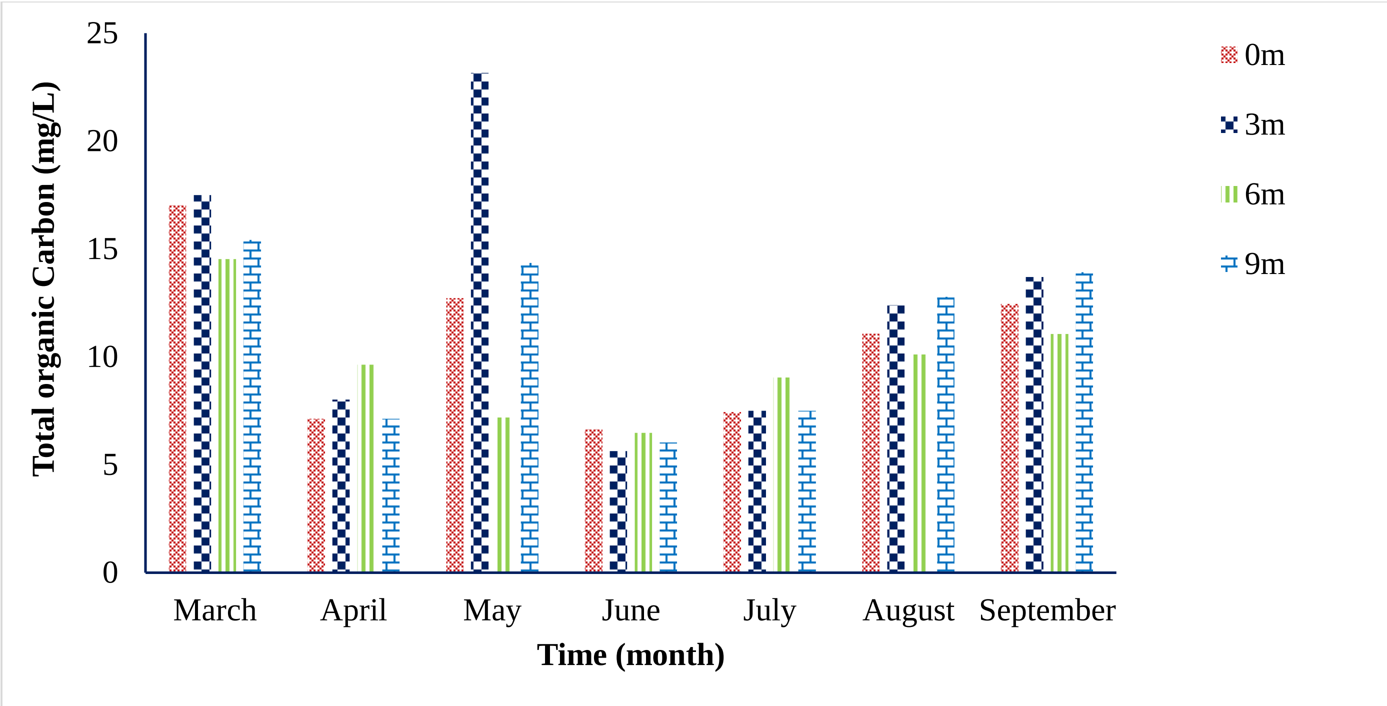

Figure-4.31: Average Temporal variations in Total Organic Carbon in N-S direction vs Depth

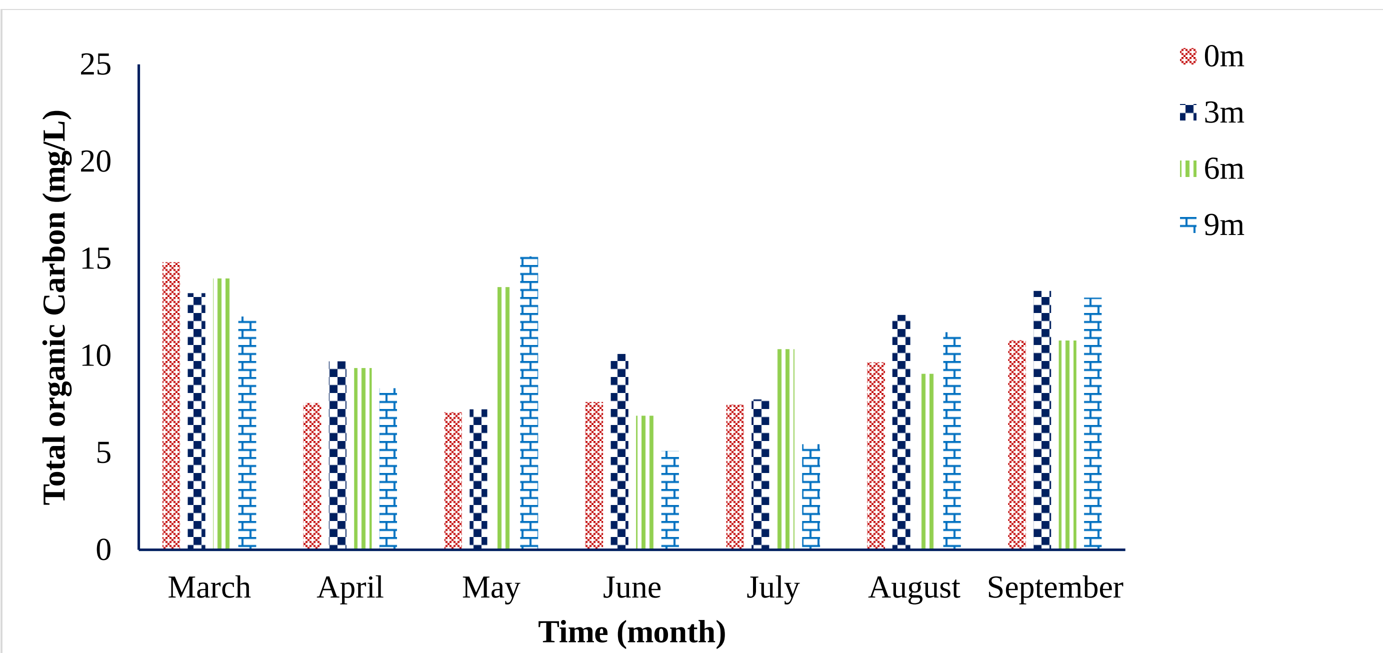

Figure-4.32: Average Temporal variations in Total Organic Carbon in E-W direction vs Depth

CHAPTER 5

Conclusions & Recommendations

The accessibility of safe and pure water supply is absolute need for public health. The domestic water supply should be clean, safe and free from contamination. As we know that Rawal Lake water is an essential source of drinking water supply to Islamabad and Rawalpindi cantonment area, following conclusions are drawn from this study.

5.1 Conclusions

- On the basis of data collected and analysis, it can be concluded that the source of Rawal Lake is highly polluted.
- During the testing of collected samples it was observed that Physico-chemical parameters of the collected samples nearly meets the drinking water guidelines of World Health Organization. However the samples must be treated before human usage.
- While sampling it was observed that intensity of physico-chemical contaminants increased while moving away from center towards the edges of Rawal Lake.
- It was observed that during wet season, conductivity, dissolved oxygen and turbidity increased as compared to dry season.
- It was also observed during taking deep samples from Western side of the lake , that water samples have very smelly odor like human waste and rotten eggs, clearly indicates accumulation of concentrated toxic gases at depth (CO_2 & H_2S) which were originate by bacterial reactions with contaminants.
- When moving from surface to depth in the lake, it clearly shows variation with temperature, due to stratification caused by suspended particles which are major carriers of pollutants, ions and other contaminants.
- Turbidity varies in ascending order from top to bottom due to gravitational settling phenomenon of suspended particles again clear evidence of thick benthic layer presence in lake depth because of a fast and active sediment transport system mechanism.

5.2 Recommendations

On the basis of analysis and results following recommendations are made to improve the water quality of Rawal Lake in future.

- To filter the pollutants, the installation of small waste water treatment plants is strongly recommended. The installation of small water treatment plant will reduce the treatment cost. Furthermore, safe Rawal Lake from the effect of sedimentation, it is strongly recommended to classify land use of Rawal catchment.
- As the catchment area of Rawal lake has forests which directly affect the water quality. The forest management in Rawal lake catchment is strongly recommended. Moreover, it is recommended to educate the people living nearby lake about the leaching of contaminants through the soil and regular septic system maintenance.
- It is strongly recommended to monitor Nitrogen and phosphate on seasonal basis and discourage the usage of pesticides and chemical fertilizers in catchment area and Pak EPA should regularly launch environmental awareness program near the Rawal Lake and the environmental protection policies should be enforced in catchment areas during recreation activities.

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APPENDIX

Appendix-1

7 months detailed survey Observations for 8 Research water Quality Parameters

Time	Direction	Space	Depth	DO (mg/L)	Temperature (^{0}C)	PH	Conductivity (µS/cm)
1	1	1	1	5.7	21	7	300
1	1	1	2	5.6	19	7.46	296
1	1	1	3	3.1	17	7.4	282
1	1	1	4	3.1	17	7.5	276
1	1	2	1	5.8	24	8.35	315
1	1	2	2	5.2	21	7.9	306
1	1	2	3	2.5	19	7.3	293
1	1	2	4	6	24	6.8	352
1	1	3	1	5.7	21	7	300
1	1	3	2	5	21	6.82	333
1	1	3	3	3.5	21	7.15	302
1	1	3	4	3.2	18	7.5	290
1	1	4	1	6.2	19.6	8.5	288
1	1	4	2	5.5	17.8	8.1	296
1	1	4	3	3	15.2	7.55	268
1	1	4	4	3.8	14.4	7.5	262
1	1	5	1	6.5	19.5	8.6	294
1	1	5	2	5.6	17.3	8.08	287
1	1	5	3	3	16	7.84	282
1	1	5	4	3.6	16.2	7.2	276
1	1	6	1	6.7	22	8.38	300
1	1	6	2	5.8	18.6	7.7	285
1	1	6	3	3.8	15.5	7.49	266
1	1	6	4	3.4	17	7.89	274
1	2	1	1	5.7	18.7	8.5	284
1	2	1	2	5.6	16.2	7.73	280
1	2	1	3	3.1	15.2	7.88	262
1	2	1	4	3	14	7.75	254
1	2	2	1	5.2	18	8.3	279
1	2	2	2	5	16.5	7.41	278
1	2	2	3	3.2	15.2	7.26	267
1	2	2	4	3.5	14	7.6	250
1	2	3	1	5	18.4	8.42	280

1	2	3	2	4.8	16.5	7.36	283
1	2	3	3	3.2	15.8	7.05	278
1	2	3	4	3	14.8	7.23	269
1	2	4	1	6.1	18.6	8.2	283
1	2	4	2	5.2	14.5	7.9	259
1	2	4	3	3.8	14	7.81	257
1	2	4	4	3.5	14	7.6	250
1	2	5	1	6.3	18.3	8.45	282
1	2	5	2	4.9	16.4	8.2	275
1	2	5	3	4.3	14.3	7.92	258
1	2	5	4	4.1	14.1	8	253
1	2	6	1	6.3	18.1	8.4	282
1	2	6	2	5.2	16	7.3	276
1	2	6	3	4	15.1	6.6	268
1	2	6	4	3.4	14.8	7.34	260
2	1	1	1	6.8	26.8	8.15	277
2	1	1	2	5.9	25.4	8.2	278
2	1	1	3	3.5	21.8	8.1	287
2	1	1	4	3.3	19.8	8.05	286
2	1	2	1	6.5	25.2	8.18	266
2	1	2	2	5.2	24.2	7.86	275
2	1	2	3	2.9	21.6	8.02	290
2	1	2	4	3.2	23.3	8.06	284
2	1	3	1	6.6	24	8.11	272
2	1	3	2	5.3	23	8.04	270
2	1	3	3	3.8	20	7.9	279
2	1	3	4	3.4	19	6	280
2	1	4	1	6.4	24.1	7.8	290
2	1	4	2	5.6	21.1	8	260
2	1	4	3	3	20.3	7.82	300
2	1	4	4	4	20.1	7.66	297
2	1	5	1	6.7	22.6	7.8	275
2	1	5	2	5.9	24	7.8	266
2	1	5	3	3.3	19.7	7.5	292
2	1	5	4	3.7	20.8	7.82	281
2	1	6	1	7	23	7.8	276
2	1	6	2	6.2	20.8	7.75	268
2	1	6	3	4	19.8	7.44	289
2	1	6	4	3.5	18.9	8.22	288
2	2	1	1	6.5	22.4	8.24	264
2	2	1	2	5.8	22.1	8.08	281

2	2	1	3	3.2	19.7	7.85	287
2	2	1	4	3.1	19.1	7.84	282
2	2	2	1	6.4	22.7	8.24	266
2	2	2	2	5.5	21.5	8	274
2	2	2	3	3.3	19.8	7.8	288
2	2	2	4	3.7	18.9	7.6	281
2	2	3	1	6.6	22.7	8.31	266
2	2	3	2	5.1	21.3	8	179
2	2	3	3	3.2	19.8	7.8	291
2	2	3	4	3.1	18.9	7.3	281
2	2	4	1	6	23.9	8.18	276
2	2	4	2	5.6	22.1	8.1	272
2	2	4	3	3.9	20.1	7.7	283
2	2	4	4	3.5	20	7.9	284
2	2	5	1	6.5	22.4	8.3	271
2	2	5	2	5.3	21.1	8.1	272
2	2	5	3	4.5	20.8	7.9	283
2	2	5	4	4.2	19.3	7.6	279
2	2	6	1	6.8	21.8	8.4	264
2	2	6	2	5.5	21.5	8.1	278
2	2	6	3	4.3	19.7	7.9	282
2	2	6	4	3.6	18.9	7.6	278
3	1	1	1	4.5	26.1	8.82	335
3	1	1	2	4.5	26	8.34	355
3	1	1	3	2.8	23.5	7.25	318
3	1	1	4	2.1	22.9	7.63	315
3	1	2	1	4.5	27.2	8.13	341
3	1	2	2	4.2	26.2	8.27	332
3	1	2	3	2.8	23.7	7.93	323
3	1	2	4	2.4	23	7.88	321
3	1	3	1	4	27.8	7.95	354
3	1	3	2	4.2	26.6	8.03	336
3	1	3	3	2.9	24.6	7.69	327
3	1	3	4	2.7	23.5	7.6	320
3	1	4	1	4.8	24.6	7.41	333
3	1	4	2	4.5	24.3	8.12	330
3	1	4	3	3.6	23.5	8	335
3	1	4	4	3.5	23.2	7.8	333
3	1	5	1	5	24.7	7.75	331
3	1	5	2	4.8	24.6	7.85	330
3	1	5	3	3.6	23	7.55	327

3	1	5	4	3.1	22.8	7.58	328
3	1	6	1	4.9	25	7.97	334
3	1	6	2	4.7	24.5	8.3	333
3	1	6	3	3.3	24	8.14	327
3	1	6	4	3	21.7	7.92	313
3	2	1	1	4	26.6	8.55	335
3	2	1	2	4.2	25.2	8.37	328
3	2	1	3	3.8	24.5	8.09	329
3	2	1	4	3.7	21.9	7.98	313
3	2	2	1	4.7	24.9	7.77	329
3	2	2	2	4.5	25.1	7.82	329
3	2	2	3	4.5	22.8	7.9	322
3	2	2	4	3.5	22.4	7.67	315
3	2	3	1	4.8	25	7.77	328
3	2	3	2	4.5	24.9	8.16	328
3	2	3	3	3.7	23.4	8.22	324
3	2	3	4	2.9	23.1	8.15	321
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3	2	5	1	4.8	25.2	7.87	331
3	2	5	2	4.7	25.6	8.14	332
3	2	5	3	3.9	22.4	8	317
3	2	5	4	3.7	21.3	7.8	305
3	2	6	1	4.7	25.2	8.44	332
3	2	6	2	4.6	25	8.13	340
3	2	6	3	4.1	24.3	7.12	331
3	2	6	4	3.5	21.2	7.11	308
4	1	1	1	3.9	29	6.3	334
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4	1	1	3	2.8	26.3	6.15	347
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4	1	2	1	4	28.8	6.3	333
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4	1	2	4	3.1	26.2	6.1	351
4	1	3	1	4.5	30.5	7.2	341
4	1	3	2	3.5	27.9	6.8	351
4	1	3	3	3.2	25.2	6.3	347
4	1	3	4	2.5	24.9	6.2	344

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4	1	4	2	3.4	28.5	6.83	354
4	1	4	3	3.3	28.9	7.06	356
4	1	4	4	2.6	28.3	7	359
4	1	5	1	4.2	29.2	6.9	339
4	1	5	2	3.55	27.7	6.8	357
4	1	5	3	3.3	27.6	6.7	359
4	1	5	4	3	27.2	6.6	361
4	1	6	1	4.3	30	7.25	341
4	1	6	2	3.2	28.7	7.4	354
4	1	6	3	3.1	26.6	7	352
4	1	6	4	3	25.3	6.8	347
4	2	1	1	3.9	29.2	6.7	336
4	2	1	2	3.5	27.6	6.6	349
4	2	1	3	3.1	25.8	6.8	340
4	2	1	4	2.6	23.9	6.6	330
4	2	2	1	3.8	28.6	6.1	333
4	2	2	2	3.4	27.3	6.3	348
4	2	2	3	3	25.6	6.35	344
4	2	2	4	2.3	24	6.3	335
4	2	3	1	4	28.4	6.49	330
4	2	3	2	3.7	27.4	6	349
4	2	3	3	3.3	25.6	6.25	344
4	2	3	4	2	24.2	6.1	336
4	2	4	1	4.9	29.3	7	340
4	2	4	2	3.6	26.7	7.1	350
4	2	4	3	3.2	25.9	6.9	344
4	2	4	4	2.8	23.2	6.8	336
4	2	5	1	4.6	28.6	6.89	334
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4	2	5	4	3	23.4	6.74	330
4	2	6	1	4.8	28.8	7	337
4	2	6	2	3.5	27.9	7.1	352
4	2	6	3	3	25.4	7.1	342
4	2	6	4	2.5	23.8	7.4	332
5	1	1	1	4.1	29.1	6.5	345
5	1	1	2	4	29.4	6.5	346
5	1	1	3	3.2	27.9	6.7	350
5	1	1	4	3	28	6.7	355
5	1	2	1	4.1	27.6	7.7	356

5	1	2	2	4	28.8	7.6	347
5	1	2	3	3	28	7.4	355
5	1	2	4	2.8	28	7.3	353
5	1	3	1	3.4	30.6	7.85	349
5	1	3	2	3.1	29.6	8	348
5	1	3	3	3	28.3	8	351
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5	2	2	1	4.8	28.4	7.85	338
5	2	2	2	4.3	27	7.9	342
5	2	2	3	3	26	7.5	350
5	2	2	4	2.5	25	7.5	344
5	2	3	1	4.7	28.5	7.8	338
5	2	3	2	4.3	29	7.9	344
5	2	3	3	2.9	26	7.7	350
5	2	3	4	2.8	24	7.73	343
5	2	4	1	4.5	27.9	7.9	335
5	2	4	2	4.2	29	7.9	343
5	2	4	3	3.3	25	7.6	349
5	2	4	4	3.4	23	7.6	343
5	2	5	1	4.8	28	7.8	345
5	2	5	2	4.5	28	7.9	342
5	2	5	3	3.3	26	7.8	349
5	2	5	4	3	23	7.8	343
5	2	6	1	4.8	27	7.9	348
5	2	6	2	4.2	28	7.9	343

5	2	6	3	3.5	26	7.7	348
5	2	6	4	3.3	23	7.5	340
6	1	1	1	8.5	35	7	355
6	1	1	2	4.5	31	7.66	344
6	1	1	3	4.1	31	7.68	344
6	1	1	4	3.5	30	7.7	348
6	1	2	1	8.1	35	7.1	350
6	1	2	2	5	32	8	340
6	1	2	3	4.5	30	7.8	340
6	1	2	4	3.8	29	7.4	340
6	1	3	1	6.6	35	7.85	320
6	1	3	2	5	32	7.65	355
6	1	3	3	4.8	29	7.57	338
6	1	3	4	4.2	27	7.8	330
6	1	4	1	10	35	8.3	340
6	1	4	2	5.2	32	8.35	335
6	1	4	3	4.2	30	8.25	333
6	1	4	4	4	29.5	8.2	335
6	1	5	1	10	35	8.4	335
6	1	5	2	5	31.5	8.5	335
6	1	5	3	4.1	30	8	339
6	1	5	4	4.5	30	8.4	330
6	1	6	1	10	35	8.7	340
6	1	6	2	4.5	32	8.5	342
6	1	6	3	4.5	29	8.5	333
6	1	6	4	4	29	8	325
6	2	1	1	10.5	35	8.3	335
6	2	1	2	5	31	8.6	338
6	2	1	3	4.5	29	8.5	325
6	2	1	4	3.8	29	8.2	325
6	2	2	1	11	35	8.5	330
6	2	2	2	4.5	31	8.4	340
6	2	2	3	4.2	29	8.1	325
6	2	2	4	4.5	30	8.3	324
6	2	3	1	10	35	8.75	335
6	2	3	2	4.5	32	8.7	340
6	2	3	3	3.5	30	8.4	330
6	2	3	4	4.5	30	8.2	325
6	2	4	1	9	35	8	330
6	2	4	2	4.5	31	8.1	338
6	2	4	3	3.8	29	7.75	325

6	2	4	4	3.5	28	7.5	320
6	2	5	1	10.5	35	8.2	333
6	2	5	2	3.6	30	8.1	330
6	2	5	3	3.5	29	7.8	325
6	2	5	4	3.2	27	7.6	320
6	2	6	1	10.5	35	8.2	333
6	2	6	2	5	31	8.1	338
6	2	6	3	4.5	29	7.8	328
6	2	6	4	4.2	28	7.6	329
7	1	1	1	8.4	28.8	7.2	352
7	1	1	2	4.8	28	7.7	341
7	1	1	3	4.4	27	7.85	340
7	1	1	4	3.7	25	7.8	344
7	1	2	1	8.8	26.5	7.3	345
7	1	2	2	5.5	26.9	8.2	335
7	1	2	3	4.8	26	7.9	330
7	1	2	4	4	25.6	7.5	332
7	1	3	1	7	30	8	315
7	1	3	2	5.8	29	7.9	350
7	1	3	3	5.2	27	7.8	330
7	1	3	4	4.6	26.5	8	328
7	1	4	1	10.5	30	8.5	336
7	1	4	2	5.7	27	8.45	329
7	1	4	3	4.6	26	8.3	329
7	1	4	4	4.3	23	8.25	328
7	1	5	1	12	28.9	8.45	329
7	1	5	2	5.7	27	8.6	331
7	1	5	3	4.5	26	8.1	337
7	1	5	4	4.8	25.3	8.4	325
7	1	6	1	13	30	8.9	335
7	1	6	2	4.9	27.6	8.7	338
7	1	6	3	5	26	8.6	330
7	1	6	4	4.4	26	8.2	320
7	2	1	1	10.6	29	8.4	334
7	2	1	2	5.6	27	8.8	336
7	2	1	3	4.7	25..5	8.7	322
7	2	1	4	4	22.9	8.4	321
7	2	2	1	10.7	27.6	8.7	326
7	2	2	2	4.7	27	8.7	334
7	2	2	3	4.2	25.8	8.4	320
7	2	2	4	4.8	27	8.6	318

7	2	3	1	11	29	8.77	330
7	2	3	2	4.8	27	8.9	334
7	2	3	3	3.8	25	8.55	324
7	2	3	4	5	23.8	8.36	320
7	2	4	1	10	27.5	8.2	323
7	2	4	2	4.9	25.8	8.3	334
7	2	4	3	4.2	24.6	7.9	320
7	2	4	4	3.9	22.4	7.8	319
7	2	5	1	10.9	27.5	8.5	330
7	2	5	2	3.9	26.8	8.35	329
7	2	5	3	3.7	25.8	7.9	321
7	2	5	4	3.6	22.4	7.9	316
7	2	6	1	10.7	26	8.3	328
7	2	6	2	5.7	25.9	8.2	335
7	2	6	3	4.6	24.8	8	326
7	2	6	4	4.5	23	7.9	324

Time	**Direction**	**Space**	**Depth**	**Turbidity (NTU)**	**Phosphorus (mg/L)**	**TN (mg/L)**	**TOC (mg/L)**
1	1	1	1	5.3	1	3.18	13.18
1	1	1	2	8.6	0.1	5.21	33.64
1	1	1	3	10	0.1	3.86	21.02
1	1	1	4	14	0.2	1.43	6.12
1	1	2	1	5.17	0.3	1.69	5.17
1	1	2	2	5.2	1.7	2.04	8.22
1	1	2	3	11.8	0.3	2.59	10.38
1	1	2	4	3.1	0.8	1.61	7.08
1	1	3	1	5.3	1	3.18	13.18
1	1	3	2	6.2	0.5	3.94	28.97
1	1	3	3	4.9	0.8	2.72	11.52
1	1	3	4	12	1.4	3	11.89
1	1	4	1	4.6	0.3	3.52	14.81
1	1	4	2	6.4	1.3	2.82	11.95
1	1	4	3	9	1.1	2.52	11.47
1	1	4	4	16	0.2	1.52	22.9
1	1	5	1	6	0.7	10.62	43.88
1	1	5	2	6.4	0.4	2.06	8.77
1	1	5	3	9.5	0.6	3.52	19.67
1	1	5	4	14	0.8	1.7	23.3
1	1	6	1	4.3	1.4	2.89	11.88

1	1	6	2	5.1	0.5	3.13	13.46
1	1	6	3	9	1.3	3.02	13.14
1	1	6	4	11.5	0.4	1.56	21.3
1	2	1	1	6.4	0.3	2.71	12.84
1	2	1	2	5.8	0.4	3.51	15.64
1	2	1	3	6	0.7	2.43	11.23
1	2	1	4	10	0.2	3.21	13.37
1	2	2	1	3.5	5.4	2.7	10.02
1	2	2	2	7.3	1	3.05	17.56
1	2	2	3	8.7	0.3	3.02	13.06
1	2	2	4	14	1	1.43	5.79
1	2	3	1	4.5	0.5	2.69	11.94
1	2	3	2	6.5	2.4	1.98	12.32
1	2	3	3	7.7	1.4	3.73	17.45
1	2	3	4	9.5	1.9	3.54	32.73
1	2	4	1	2.5	0.4	2.67	11.59
1	2	4	2	5.6	0.1	2.86	13.07
1	2	4	3	7.8	0.4	1.77	9.28
1	2	4	4	8.5	0.2	3.32	16.24
1	2	5	1	3.2	0.9	3.37	29.5
1	2	5	2	3.9	0.6	1.54	6.01
1	2	5	3	3.9	0.3	2.66	12.09
1	2	5	4	5.5	0.1	2.02	10.83
1	2	6	1	3.3	0.4	2.84	13.05
1	2	6	2	4.5	0.5	3.19	14.64
1	2	6	3	6.3	0.3	1.59	20.79
1	2	6	4	12	0.7	1.55	5.11
2	1	1	1	3.2	0.4	1.04	6.62
2	1	1	2	3.5	0.7	1.12	7.1
2	1	1	3	7.5	1	1.45	15
2	1	1	4	10	0.3	1.27	7
2	1	2	1	4.5	0.01	1.2	6.38
2	1	2	2	3.5	2.3	1.35	6.68
2	1	2	3	4.1	0.3	1.44	15.56
2	1	2	4	4.2	0.02	1.32	6.33
2	1	3	1	2.9	0.1	1.14	6.95
2	1	3	2	2.6	0.04	1.23	7.18
2	1	3	3	2.7	0.03	1.41	6.52
2	1	3	4	4	0.02	1.24	8.48
2	1	4	1	5.2	0.9	1.07	7.76
2	1	4	2	4.4	0.3	1.2	7.8

2	1	4	3	7	0.5	1.4	6.3
2	1	4	4	10	0.6	1.33	6.26
2	1	5	1	3.4	0.2	1.5	7.5
2	1	5	2	3.5	0.1	1.32	7.44
2	1	5	3	10	0.5	1.42	7.2
2	1	5	4	13	0.6	1.35	7.1
2	1	6	1	3.5	0.08	1.19	7.6
2	1	6	2	2.5	2.1	1.16	12
2	1	6	3	12	0	1.28	7.26
2	1	6	4	16	0.9	1.32	7.58
2	2	1	1	2.7	1.2	1.08	7.49
2	2	1	2	4.5	1.1	1.14	6.56
2	2	1	3	3.5	0	1.47	5.65
2	2	1	4	4.6	0.9	1.42	6.87
2	2	2	1	4.3	0	1.07	7.5
2	2	2	2	5	0.2	1.22	6.83
2	2	2	3	3.6	0	1.09	7.58
2	2	2	4	11	0	1.28	5.68
2	2	3	1	29	0.3	1.18	7.36
2	2	3	2	6	0.3	1.21	14.23
2	2	3	3	26	0.02	1.56	6.73
2	2	3	4	16	0.001	1.24	6.33
2	2	4	1	4.1	1.6	1.07	7.58
2	2	4	2	3.3	0.5	1.16	6.9
2	2	4	3	3	2.5	1.59	13.53
2	2	4	4	3	0	1.41	5.37
2	2	5	1	4	0.4	1.09	7.58
2	2	5	2	2.9	1.2	1.22	16.12
2	2	5	3	2.9	0.1	1.22	7.22
2	2	5	4	3.2	0.5	1.46	12.06
2	2	6	1	5	0.8	1.14	7.9
2	2	6	2	3	1.7	1.28	7.65
2	2	6	3	2.5	0	1.43	15.47
2	2	6	4	2.9	1.9	1.93	13.66
3	1	1	1	4.8	0.7	0.943	6.53
3	1	1	2	3.85	0	0.998	39.93
3	1	1	3	1.7	1.2	0.846	12.76
3	1	1	4	9.5	1.6	0.818	10.77
3	1	2	1	4.75	0.5	0.942	5.95
3	1	2	2	2.62	0.8	0.906	13.95
3	1	2	3	12.5	0	0.829	5.53

3	1	2	4	14	2.3	0.92	12.51
3	1	3	1	7	0	0.946	36.77
3	1	3	2	2.1	0	0.914	31.55
3	1	3	3	7.3	0.7	1.22	7.7
3	1	3	4	11	0.3	0.881	40.25
3	1	4	1	5.3	0.6	0.889	5.69
3	1	4	2	3.8	0.4	0.808	6.26
3	1	4	3	7	0.6	0.982	6.07
3	1	4	4	15	0.1	0.901	5.65
3	1	5	1	3.5	0.4	0.852	6.03
3	1	5	2	5.8	0.7	0.882	6.03
3	1	5	3	10	0.4	0.957	5.78
3	1	5	4	11	0.5	0.848	6.33
3	1	6	1	5.5	0.1	0.837	15.33
3	1	6	2	5.1	0.5	0.867	41.24
3	1	6	3	7.7	0.1	0.882	5.38
3	1	6	4	12	0.2	0.826	10.63
3	2	1	1	9	1.4	0.825	5.7
3	2	1	2	2.7	0.3	0.892	5.98
3	2	1	3	3.09	0.9	0.847	5.34
3	2	1	4	10.5	1	0.961	5.52
3	2	2	1	5	0.7	1	5.9
3	2	2	2	6.8	0.2	0.951	6.12
3	2	2	3	4	0.5	0.86	36.87
3	2	2	4	14	1.9	0.9	6.46
3	2	3	1	3.3	0.6	0.921	5.74
3	2	3	2	2.35	0.7	0.892	13.9
3	2	3	3	5.4	0	0.78	5.8
3	2	3	4	8.3	0.7	0.806	6.41
3	2	4	1	5.2	0.5	0.98	6.8
3	2	4	2	2.8	0.7	0.907	5.68
3	2	4	3	5.7	1.1	0.877	5.86
3	2	4	4	9	1.4	0.988	42.76
3	2	5	1	5	0.4	0.812	6.37
3	2	5	2	4.4	1	0.916	5.51
3	2	5	3	6	0	0.859	12.97
3	2	5	4	16.5	0.4	0.943	17.19
3	2	6	1	4.75	1.1	0.904	12.04
3	2	6	2	4.96	2	0.913	6.25
3	2	6	3	4.2	0.5	0.886	14.35
3	2	6	4	13	1.4	0.93	12.4

4	1	1	1	3.3	0	0.494	8.64
4	1	1	2	4.3	1.2	0.616	5.89
4	1	1	3	15	0.2	0.691	6.01
4	1	1	4	20	1.5	0.502	5.99
4	1	2	1	4	0.2	0.376	6
4	1	2	2	3.9	0.3	0.608	4.94
4	1	2	3	12	1.5	0.571	6.14
4	1	2	4	15	1	0.437	6.37
4	1	3	1	3.2	0.8	0.1	2.76
4	1	3	2	2.7	0	0.107	3.35
4	1	3	3	12	0.5	0.855	1.44
4	1	3	4	16	0.5	0.686	5.88
4	1	4	1	3.4	0.2	0.648	6.73
4	1	4	2	3.5	0	0.71	5.23
4	1	4	3	19	0	0.866	6.24
4	1	4	4	25	0	0.9	5.51
4	1	5	1	4	1.1	0.621	7.65
4	1	5	2	7	0.9	0.722	6.92
4	1	5	3	16	0.2	0.641	10.45
4	1	5	4	20	0.4	0.712	6.41
4	1	6	1	3.5	0.2	0.6	8.06
4	1	6	2	2.4	1	0.6	7.5
4	1	6	3	4.85	0.6	0.754	8.62
4	1	6	4	9.5	0	0.645	5.99
4	2	1	1	2.8	1	0.362	6.02
4	2	1	2	3.1	0	0.695	5.39
4	2	1	3	3.3	0.2	0.639	5.66
4	2	1	4	7.1	0.4	0.812	5.04
4	2	2	1	2.9	1.1	0.659	6.85
4	2	2	2	3.5	0.1	0.681	11.4
4	2	2	3	7	0.2	0.76	6.25
4	2	2	4	18	1.5	0.829	6.16
4	2	3	1	2	0.2	0.542	5.99
4	2	3	2	3.3	0.7	0.639	5.66
4	2	3	3	6.2	0.9	0.663	6.42
4	2	3	4	18	0.7	1.48	2.69
4	2	4	1	2.8	0.1	0.536	9.73
4	2	4	2	3.1	0.6	0.865	22.51
4	2	4	3	5.2	1	0.804	8.5
4	2	4	4	18	1.5	1.15	6.54
4	2	5	1	2.9	0.1	0.556	9.12

4	2	5	2	2.5	1.3	0.61	6.1
4	2	5	3	3.5	0.1	1.03	9.2
4	2	5	4	8	1.3	0.85	4.44
4	2	6	1	3.3	0	0.551	7.92
4	2	6	2	2.5	1.3	0.924	9.49
4	2	6	3	5.8	0.9	0.71	5.35
4	2	6	4	7	0.1	1.04	5.65
5	1	1	1	4.5	0.7	0.65	8.33
5	1	1	2	5.4	0.9	0.96	7.44
5	1	1	3	20	0.6	1.13	23.89
5	1	1	4	22	1.2	0.486	2.85
5	1	2	1	5.6	0.5	0.386	11.69
5	1	2	2	8.4	0.7	0.318	7.36
5	1	2	3	16.5	0.6	0.765	4.83
5	1	2	4	16.2	0.9	0.412	9.34
5	1	3	1	6	0.6	0.43	7.56
5	1	3	2	11	0.7	0.35	8.45
5	1	3	3	13.5	0.7	0.75	8.25
5	1	3	4	15.5	1.3	0.82	10.55
5	1	4	1	6	0.1	0.546	4.71
5	1	4	2	19	0.9	0.73	6.72
5	1	4	3	24	1.1	0.83	7.77
5	1	4	4	29	3.3	0.914	5.14
5	1	5	1	8	0.3	0.498	4.66
5	1	5	2	16	0.7	0.369	7.89
5	1	5	3	19	0.6	0.772	4.56
5	1	5	4	29	1.2	1.24	11.73
5	1	6	1	3.5	0.5	1.19	7.66
5	1	6	2	9.6	0.3	0.364	7.18
5	1	6	3	27	0.5	1.25	4.97
5	1	6	4	29	1	1.06	5.39
5	2	1	1	6	0.6	0.373	9.97
5	2	1	2	6	0.7	0.75	6.66
5	2	1	3	25	0.4	1.01	4.49
5	2	1	4	28	0.2	0.829	4.84
5	2	2	1	5.3	0.6	0.418	5.18
5	2	2	2	6.4	0.8	0.335	10.41
5	2	2	3	8	0.3	0.677	4.63
5	2	2	4	29	0.4	0.486	2.85
5	2	3	1	45	0.3	0.519	4.53

5	2	3	2	5.4	1.4	0.35	9.18
5	2	3	3	5.5	0.5	7.6	4.72
5	2	3	4	25	1	1.3	4.28
5	2	4	1	4.5	0.3	0.55	6.85
5	2	4	2	5	0.8	0.548	4.78
5	2	4	3	16	0.8	0.817	4.64
5	2	4	4	17	0.7	0.69	7.85
5	2	5	1	4	0.7	0.373	9.38
5	2	5	2	6	0.2	0.531	4.59
5	2	5	3	10.2	0.2	7.63	20.22
5	2	5	4	24	1.5	1.27	4.4
5	2	6	1	3	0.8	0.415	9.37
5	2	6	2	3.5	0.7	0.331	11.49
5	2	6	3	14.5	0.6	0.968	23.36
5	2	6	4	13.5	0.8	0.77	8.43
6	1	1	1	5.6	0.4	1.23	9.13
6	1	1	2	8.2	1.9	1.24	19.13
6	1	1	3	20	1.1	1.27	11.61
6	1	1	4	23	0.3	1.3	14.5
6	1	2	1	4	0.4	1.01	9.62
6	1	2	2	10	0.2	0.974	9.38
6	1	2	3	18	0.8	1.53	9.66
6	1	2	4	25	1	1.77	13.81
6	1	3	1	2.3	0.2	0.811	8.44
6	1	3	2	2.8	0.6	1.15	9.83
6	1	3	3	16.5	0.3	1.08	9.83
6	1	3	4	22	0.4	1.62	11.86
6	1	4	1	2.1	0.1	0.956	17.58
6	1	4	2	5	0.4	0.932	9.49
6	1	4	3	20	0.3	1.02	10.52
6	1	4	4	22	0.9	1.24	19.13
6	1	5	1	3	0.5	0.618	13.22
6	1	5	2	3.5	0.3	0.882	9.66
6	1	5	3	2.8	0.2	1.12	8.69
6	1	5	4	22	0.3	0.853	8.11
6	1	6	1	1.9	0.2	1	8.5
6	1	6	2	4.3	2	1.03	16.9
6	1	6	3	16	1.2	1.21	10.34
6	1	6	4	21	0.5	1.28	9.31
6	2	1	1	3.3	0.6	1.11	8.36
6	2	1	2	2.8	0.3	1.47	12.58

6	2	1	3	7.6	0.8	1.44	9.55
6	2	1	4	13.8	0.2	1.58	11.48
6	2	2	1	3.6	0.5	0.755	10.22
6	2	2	2	4.5	0.4	4.33	16.66
6	2	2	3	10	0.6	0.974	8.76
6	2	2	4	9.5	0.8	1.4	9.58
6	2	3	1	2.3	0.1	0.804	8.17
6	2	3	2	5.6	0.8	1.84	13.25
6	2	3	3	6	0.9	0.022	8.85
6	2	3	4	26	0.6	1.23	9.22
6	2	4	1	9.1	0.4	1.52	12.51
6	2	4	2	3.2	0.2	1.19	10.11
6	2	4	3	8.7	0.5	1.18	8.48
6	2	4	4	21	0.4	1.57	19.08
6	2	5	1	2.5	0.2	0.768	9.14
6	2	5	2	3	0.7	1.32	8.99
6	2	5	3	5.7	0.4	1.12	9.38
6	2	5	4	23	0.5	1.29	8.63
6	2	6	1	1.7	0.1	1.07	9.6
6	2	6	2	3.1	0.3	1.43	11
6	2	6	3	2.8	0.5	0.929	9.32
6	2	6	4	22	0.9	1.33	9.2
7	1	1	1	6	0.5	1.42	10.53
7	1	1	2	9	2	1.44	22.21
7	1	1	3	22	1.2	1.55	12.89
7	1	1	4	26	0.5	1.67	16.56
7	1	2	1	6	0.55	1.52	10.6
7	1	2	2	12	0.3	1.22	10.33
7	1	2	3	21	0.95	1.62	10.75
7	1	2	4	28	1.2	1.98	14.51
7	1	3	1	4	0.33	1.11	9.55
7	1	3	2	3.3	0.7	1.65	10.22
7	1	3	3	18	0.41	1.48	10.25
7	1	3	4	25	0.47	1.72	12.32
7	1	4	1	3.8	0.2	1.2	19.65
7	1	4	2	6	0.5	1.3	10.35
7	1	4	3	23	0.5	1.13	11.63
7	1	4	4	25	1	1.65	21.42
7	1	5	1	4	0.6	0.78	14.56
7	1	5	2	5.8	0.4	0.98	12.1
7	1	5	3	3.3	0.3	1.22	9.64

7	1	5	4	24	0.4	0.95	8.88
7	1	6	1	2.9	0.35	1.11	9.89
7	1	6	2	5	2.1	1.05	17.05
7	1	6	3	18	1.5	1.35	11.25
7	1	6	4	23	0.7	1.42	9.88
7	2	1	1	4	0.67	1.26	9.87
7	2	1	2	3.5	0.38	1.8	13.83
7	2	1	3	7.8	0.9	1.75	11.18
7	2	1	4	15.2	0.3	1.9	13.5
7	2	2	1	4.2	0.59	0.83	10.56
7	2	2	2	5.3	0.45	4.35	18.62
7	2	2	3	11.8	0.7	1.3	13.41
7	2	2	4	10.8	0.85	1.6	11.01
7	2	3	1	4	0.12	1.13	9.25
7	2	3	2	7.3	0.85	1.99	14.23
7	2	3	3	8.33	0.95	0.23	10.18
7	2	3	4	27	0.67	1.5	11.56
7	2	4	1	9.88	0.45	1.62	14.32
7	2	4	2	3.44	0.3	1.32	11.03
7	2	4	3	8.9	0.7	1.25	9.78
7	2	4	4	23.5	0.6	1.75	21.25
7	2	5	1	2.88	0.33	0.95	10.28
7	2	5	2	3.66	0.9	1.56	9.59
7	2	5	3	6.33	0.45	1.35	10.52
7	2	5	4	24	0.7	1.42	9.99
7	2	6	1	2.3	0.3	1.2	10.49
7	2	6	2	4	0.35	1.75	12.65
7	2	6	3	3.6	0.56	0.98	9.58
7	2	6	4	24.5	1	1.5	10.6

Appendix-2

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STATISTICAL ANALYSIS:

ANALYSIS OF VARIENCE (ANOVA)

Means of Conductivity for Time*Direction*Depth

Time	Direction	Depth	Mean	Time	Direction	Depth	Mean
1	1	1	299.50	4	2	1	335.00
1	1	2	300.50	4	2	2	348.83
1	1	3	282.17	4	2	3	342.83
1	1	4	288.33	4	2	4	333.17
1	2	1	281.67	5	1	1	346.17
1	2	2	275.17	5	1	2	344.83
1	2	3	265.00	5	1	3	335.83
1	2	4	256.00	5	1	4	321.00
2	1	1	276.00	5	2	1	340.67
2	1	2	269.50	5	2	2	343.33
2	1	3	289.50	5	2	3	349.00
2	1	4	286.00	5	2	4	343.17
2	2	1	267.83	6	1	1	340.00
2	2	2	259.33	6	1	2	341.83
2	2	3	285.67	6	1	3	337.83
2	2	4	280.83	6	1	4	334.67
3	1	1	338.00	6	2	1	332.67
3	1	2	336.00	6	2	2	337.33
3	1	3	326.17	6	2	3	326.33
3	1	4	321.67	6	2	4	323.83
3	2	1	331.67	7	1	1	335.33
3	2	2	331.17	7	1	2	337.33
3	2	3	323.50	7	1	3	332.67
3	2	4	312.83	7	1	4	329.50
4	1	1	338.50	7	2	1	328.50
4	1	2	352.67	7	2	2	333.67
4	1	3	351.33	7	2	3	322.17
4	1	4	351.17	7	2	4	319.67

Observations per Mean 6
Standard Error of a Mean 3.9382
Std Error (Diff of 2 Means) 5.5694

Means of Conductivity for Direction*Space*Depth

Direction	Space	Depth	Mean	Direction	Space	Depth	Mean
1	1	1	328.29	2	1	1	318.29
1	1	2	330.29	2	1	2	322.57
1	1	3	324.00	2	1	3	316.14
1	1	4	324.14	2	1	4	310.14
1	2	1	329.43	2	2	1	314.43
1	2	2	326.14	2	2	2	320.71
1	2	3	325.43	2	2	3	316.57
1	2	4	333.29	2	2	4	309.57
1	3	1	321.57	2	3	1	315.29
1	3	2	334.71	2	3	2	308.14
1	3	3	324.86	2	3	3	320.14
1	3	4	321.00	2	3	4	313.57
1	4	1	324.57	2	4	1	317.43
1	4	2	320.71	2	4	2	318.00
1	4	3	317.71	2	4	3	313.71
1	4	4	316.29	2	4	4	309.57
1	5	1	320.43	2	5	1	318.00
1	5	2	321.00	2	5	2	317.86
1	5	3	322.29	2	5	3	313.71
1	5	4	311.57	2	5	4	306.57
1	6	1	324.43	2	6	1	317.71
1	6	2	323.71	2	6	2	323.14
1	6	3	319.00	2	6	3	317.86
1	6	4	307.14	2	6	4	310.14

Observations per Mean 7
Standard Error of a Mean 3.6460
Std Error (Diff of 2 Means) 5.1563

Means of DO for Time*Direction*Depth

Time	Direction	Depth	Mean	Time	Direction	Depth	Mean
1	1	1	6.100	4	2	1	4.333
1	1	2	5.450	4	2	2	3.550
1	1	3	3.150	4	2	3	3.117
1	1	4	3.850	4	2	4	2.533
1	2	1	5.767	5	1	1	4.033
1	2	2	5.117	5	1	2	3.783
1	2	3	3.600	5	1	3	3.383
1	2	4	3.417	5	1	4	3.183
2	1	1	6.667	5	2	1	4.600
2	1	2	5.683	5	2	2	4.167
2	1	3	3.417	5	2	3	3.167
2	1	4	3.517	5	2	4	2.967

2	2	1	6.467	6	1	1	8.867
2	2	2	5.467	6	1	2	4.867
2	2	3	3.733	6	1	3	4.367
2	2	4	3.533	6	1	4	4.000
3	1	1	4.617	6	2	1	10.250
3	1	2	4.483	6	2	2	4.517
3	1	3	3.167	6	2	3	4.000
3	1	4	2.800	6	2	4	3.950
3	2	1	4.550	7	1	1	9.950
3	2	2	4.483	7	1	2	5.400
3	2	3	3.917	7	1	3	4.750
3	2	4	3.450	7	1	4	4.300
4	1	1	4.267	7	2	1	10.650
4	1	2	3.458	7	2	2	4.933
4	1	3	3.167	7	2	3	4.200
4	1	4	2.817	7	2	4	4.300

```
Observations per Mean              6
Standard Error of a Mean      0.1938
Std Error (Diff of 2 Means)   0.2741
```

Means of DO for Direction*Space*Depth

Direction	**Space**	**Depth**	**Mean**	**Direction**	**Space**	**Depth**	**Mean**
1	1	1	5.9857	2	1	1	6.4571
1	1	2	4.6571	2	1	2	4.7429
1	1	3	3.4143	2	1	3	3.6286
1	1	4	3.0571	2	1	4	3.2857
1	2	1	5.9714	2	2	1	6.6571
1	2	2	4.7000	2	2	2	4.5571
1	2	3	3.4000	2	2	3	3.6286
1	2	4	3.6143	2	2	4	3.5429
1	3	1	5.4000	2	3	1	6.5857
1	3	2	4.5571	2	3	2	4.5286
1	3	3	3.7714	2	3	3	3.3714
1	3	4	3.3000	2	3	4	3.3286
1	4	1	6.7143	2	4	1	6.4000
1	4	2	4.8857	2	4	2	4.6286
1	4	3	3.6714	2	4	3	3.6714
1	4	4	3.6857	2	4	4	3.4286
1	5	1	6.9429	2	5	1	6.9143
1	5	2	4.8929	2	5	2	4.3571
1	5	3	3.6286	2	5	3	3.7571
1	5	4	3.7857	2	5	4	3.5429
1	6	1	7.1286	2	6	1	6.9429
1	6	2	4.7000	2	6	2	4.8143
1	6	3	3.8857	2	6	3	4.0000

1	6	4	3.5286	2	6	4	3.5714

Observations per Mean 7
Standard Error of a Mean 0.1795
Std Error (Diff of 2 Means) 0.2538

Means of PH for Time*Direction*Depth

Time	Direction	Depth	Mean	Time	Direction	Depth	Mean
1	1	1	7.9717	4	2	1	6.6967
1	1	2	7.6767	4	2	2	6.6083
1	1	3	7.4550	4	2	3	6.6383
1	1	4	7.3983	4	2	4	6.6567
1	2	1	8.3783	5	1	1	7.4083
1	2	2	7.6500	5	1	2	7.5433
1	2	3	7.4200	5	1	3	7.4250
1	2	4	7.5867	5	1	4	7.5167
2	1	1	7.9733	5	2	1	7.8750
2	1	2	7.9417	5	2	2	7.9000
2	1	3	7.7967	5	2	3	7.6333
2	1	4	7.6350	5	2	4	7.6050
2	2	1	8.2783	6	1	1	7.8917
2	2	2	8.0633	6	1	2	8.1100
2	2	3	7.8250	6	1	3	7.9667
2	2	4	7.6400	6	1	4	7.9167
3	1	1	8.0050	6	2	1	8.3250
3	1	2	8.1517	6	2	2	8.3333
3	1	3	7.7600	6	2	3	8.0583
3	1	4	7.7350	6	2	4	7.9000
3	2	1	8.1300	7	1	1	8.0583
3	2	2	8.1317	7	1	2	8.2583
3	2	3	7.8083	7	1	3	8.0917
3	2	4	7.6850	7	1	4	8.0250
4	1	1	6.8250	7	2	1	8.4783
4	1	2	6.7133	7	2	2	8.5417
4	1	3	6.5683	7	2	3	8.2417
4	1	4	6.4667	7	2	4	8.1600

Observations per Mean 6
Standard Error of a Mean 0.1093
Std Error (Diff of 2 Means) 0.1546

Means of PH for Direction*Space*Depth

Direction	Space	Depth	Mean	Direction	Space	Depth	Mean
1	1	1	7.2814	2	1	1	8.0986
1	1	2	7.4371	2	1	2	8.0114
1	1	3	7.3043	2	1	3	7.9029
1	1	4	7.3543	2	1	4	7.7529
1	2	1	7.5800	2	2	1	7.9229
1	2	2	7.7257	2	2	2	7.7900
1	2	3	7.5071	2	2	3	7.6157
1	2	4	7.2914	2	2	4	7.6529
1	3	1	7.7086	2	3	1	8.0443
1	3	2	7.6057	2	3	2	7.8600
1	3	3	7.4871	2	3	3	7.7100
1	3	4	7.3000	2	3	4	7.5814
1	4	1	7.8871	2	4	1	7.9800
1	4	2	7.9500	2	4	2	7.9386
1	4	3	7.8329	2	4	3	7.5971
1	4	4	7.7586	2	4	4	7.5143
1	5	1	7.9429	2	5	1	8.0014
1	5	2	7.9186	2	5	2	7.9057
1	5	3	7.5700	2	5	3	7.6786
1	5	4	7.6571	2	5	4	7.6343
1	6	1	8.0000	2	6	1	8.0914
1	6	2	7.9871	2	6	2	7.8329
1	6	3	7.7814	2	6	3	7.4600
1	6	4	7.8043	2	6	4	7.4929

```
Observations per Mean              7
Standard Error of a Mean      0.1012
Std Error (Diff of 2 Means)   0.1431
```

Means of Phosphate-Phosphorus for Time*Direction*Depth

Time	Direction	Depth	Mean	Time	Direction	Depth	Mean
1	1	1	0.7833	4	2	1	0.4167
1	1	2	0.7500	4	2	2	0.6667
1	1	3	0.7000	4	2	3	0.5500
1	1	4	0.6333	4	2	4	0.9167
1	2	1	1.3167	5	1	1	0.4500
1	2	2	0.8333	5	1	2	0.7000
1	2	3	0.5667	5	1	3	0.6833
1	2	4	0.6833	5	1	4	1.4833
2	1	1	0.2817	5	2	1	0.5500
2	1	2	0.9233	5	2	2	0.7667
2	1	3	0.3883	5	2	3	0.4667
2	1	4	0.4067	5	2	4	0.7667

2	2	1	0.7167	6	1	1	0.3000
2	2	2	0.8333	6	1	2	0.9000
2	2	3	0.4367	6	1	3	0.6500
2	2	4	0.5502	6	1	4	0.5667
3	1	1	0.3833	6	2	1	0.3167
3	1	2	0.4000	6	2	2	0.4500
3	1	3	0.5000	6	2	3	0.6167
3	1	4	0.8333	6	2	4	0.5667
3	2	1	0.7833	7	1	1	0.4217
3	2	2	0.8167	7	1	2	1.0000
3	2	3	0.5000	7	1	3	0.8100
3	2	4	1.1333	7	1	4	0.7117
4	1	1	0.4167	7	2	1	0.4100
4	1	2	0.5667	7	2	2	0.5383
4	1	3	0.5000	7	2	3	0.7100
4	1	4	0.5667	7	2	4	0.6867

```
Observations per Mean            6
Standard Error of a Mean    0.2139
Std Error (Diff of 2 Means) 0.3025
```

Means of Phosphate-Phosphorus for Direction*Space*Depth

Direction	Space	Depth	Mean	Direction	Space	Depth	Mean
1	1	1	0.5286	2	1	1	0.8243
1	1	2	0.9714	2	1	2	0.4543
1	1	3	0.7714	2	1	3	0.5571
1	1	4	0.8000	2	1	4	0.4571
1	2	1	0.3514	2	2	1	1.2700
1	2	2	0.9000	2	2	2	0.4500
1	2	3	0.6357	2	2	3	0.3714
1	2	4	1.0314	2	2	4	0.9214
1	3	1	0.4329	2	3	1	0.3029
1	3	2	0.3629	2	3	2	1.0214
1	3	3	0.4914	2	3	3	0.6671
1	3	4	0.6271	2	3	4	0.7959
1	4	1	0.3429	2	4	1	0.5357
1	4	2	0.5429	2	4	2	0.4571
1	4	3	0.5857	2	4	3	1.0000
1	4	4	0.8714	2	4	4	0.6857
1	5	1	0.5429	2	5	1	0.4329
1	5	2	0.5000	2	5	2	0.8429
1	5	3	0.4000	2	5	3	0.2214
1	5	4	0.6000	2	5	4	0.7143
1	6	1	0.4043	2	6	1	0.5000
1	6	2	1.2143	2	6	2	0.9786
1	6	3	0.7429	2	6	3	0.4800

1	6	4	0.5286	2	6	4	0.9714

Observations per Mean 7
Standard Error of a Mean 0.1980
Std Error (Diff of 2 Means) 0.2801

Means of Temperature for Time*Direction*Depth

Time	Direction	Depth	Mean	Time	Direction	Depth	Mean
1	1	1	21.183	4	2	1	28.817
1	1	2	19.117	4	2	2	27.433
1	1	3	17.283	4	2	3	25.700
1	1	4	17.767	4	2	4	23.750
1	2	1	18.350	5	1	1	29.083
1	2	2	16.017	5	1	2	28.583
1	2	3	14.933	5	1	3	27.200
1	2	4	14.283	5	1	4	26.417
2	1	1	24.283	5	2	1	28.117
2	1	2	23.083	5	2	2	28.000
2	1	3	20.533	5	2	3	25.667
2	1	4	20.317	5	2	4	23.500
2	2	1	22.650	6	1	1	35.000
2	2	2	21.600	6	1	2	31.750
2	2	3	19.983	6	1	3	29.833
2	2	4	19.183	6	1	4	29.083
3	1	1	25.900	6	2	1	35.000
3	1	2	25.367	6	2	2	31.000
3	1	3	23.717	6	2	3	29.167
3	1	4	22.850	6	2	4	28.667
3	2	1	25.517	7	1	1	29.033
3	2	2	25.133	7	1	2	27.583
3	2	3	23.350	7	1	3	26.333
3	2	4	21.983	7	1	4	25.233
4	1	1	29.617	7	2	1	27.767
4	1	2	28.000	7	2	2	26.583
4	1	3	26.850	7	2	3	25.167
4	1	4	26.350	7	2	4	23.583

Observations per Mean 6
Standard Error of a Mean 0.3235
Std Error (Diff of 2 Means) 0.4575

Means of Temperature for Direction*Space*Depth

Direction	Space	Depth	Mean	Direction	Space	Depth	Mean
1	1	1	27.971	2	1	1	27.114
1	1	2	26.671	2	1	2	25.157

1	1	3	24.929	2	1	3	23.457
1	1	4	24.129	2	1	4	21.971
1	2	1	27.757	2	2	1	26.457
1	2	2	26.629	2	2	2	25.057
1	2	3	24.971	2	2	3	23.457
1	2	4	25.586	2	2	4	23.043
1	3	1	28.414	2	3	1	26.714
1	3	2	27.014	2	3	2	25.443
1	3	3	25.014	2	3	3	23.657
1	3	4	23.786	2	3	4	22.686
1	4	1	27.486	2	4	1	26.914
1	4	2	25.386	2	4	2	24.871
1	4	3	24.129	2	4	3	23.043
1	4	4	23.071	2	4	4	21.800
1	5	1	26.914	2	5	1	26.429
1	5	2	25.729	2	5	2	25.086
1	5	3	24.186	2	5	3	23.457
1	5	4	23.900	2	5	4	21.500
1	6	1	27.829	2	6	1	25.986
1	6	2	25.843	2	6	2	25.043
1	6	3	23.986	2	6	3	23.471
1	6	4	23.543	2	6	4	21.814

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Observations per Mean             7
Standard Error of a Mean     0.2995
Std Error (Diff of 2 Means) 0.4235
```

Means of Turbidity for Time*Direction*Depth

Time	Direction	Depth	Mean	Time	Direction	Depth	Mean
1	1	1	5.112	4	2	1	2.783
1	1	2	6.317	4	2	2	3.000
1	1	3	9.033	4	2	3	5.167
1	1	4	11.767	4	2	4	12.683
1	2	1	3.900	5	1	1	5.600
1	2	2	5.600	5	1	2	11.567
1	2	3	6.733	5	1	3	20.000
1	2	4	9.917	5	1	4	23.450
2	1	1	3.783	5	2	1	11.300
2	1	2	3.333	5	2	2	5.383
2	1	3	7.217	5	2	3	13.200
2	1	4	9.533	5	2	4	22.750
2	2	1	8.183	6	1	1	3.150
2	2	2	4.117	6	1	2	5.633
2	2	3	6.917	6	1	3	15.550
2	2	4	6.783	6	1	4	22.500
3	1	1	5.142	6	2	1	3.750

3	1	2	3.878	6	2	2	3.700
3	1	3	7.700	6	2	3	6.800
3	1	4	12.083	6	2	4	19.217
3	2	1	5.375	7	1	1	4.450
3	2	2	4.002	7	1	2	6.850
3	2	3	4.732	7	1	3	17.550
3	2	4	11.883	7	1	4	25.167
4	1	1	3.567	7	2	1	4.543
4	1	2	3.967	7	2	2	4.533
4	1	3	13.142	7	2	3	7.793
4	1	4	17.583	7	2	4	20.833

Observations per Mean 6
Standard Error of a Mean 1.5999
Std Error (Diff of 2 Means) 2.2626

Means of Turbidity for Direction*Space*Depth

Direction	Space	Depth	Mean	Direction	Space	Depth	Mean
1	1	1	4.671	2	1	1	4.886
1	1	2	6.121	2	1	2	4.057
1	1	3	13.743	2	1	3	8.041
1	1	4	17.786	2	1	4	12.743
1	2	1	4.860	2	2	1	4.114
1	2	2	6.517	2	2	2	5.543
1	2	3	13.700	2	2	3	7.586
1	2	4	15.071	2	2	4	15.186
1	3	1	4.386	2	3	1	12.871
1	3	2	4.386	2	3	2	5.207
1	3	3	10.700	2	3	3	9.304
1	3	4	15.071	2	3	4	18.543
1	4	1	4.343	2	4	1	5.440
1	4	2	6.871	2	4	2	3.777
1	4	3	15.571	2	4	3	7.900
1	4	4	20.286	2	4	4	14.286
1	5	1	4.557	2	5	1	3.497
1	5	2	6.857	2	5	2	3.766
1	5	3	10.086	2	5	3	5.504
1	5	4	19.000	2	5	4	14.886
1	6	1	3.586	2	6	1	3.336
1	6	2	4.857	2	6	2	3.651
1	6	3	13.507	2	6	3	5.671
1	6	4	17.429	2	6	4	13.557

Observations per Mean 7
Standard Error of a Mean 1.4812
Std Error (Diff of 2 Means) 2.0948

Means of TN for Time*Direction*Depth

Time	Direction	Depth	Mean	Time	Direction	Depth	Mean
1	1	1	4.1800	4	2	1	0.5343
1	1	2	3.2000	4	2	2	0.7357
1	1	3	3.0383	4	2	3	0.7677
1	1	4	1.8033	4	2	4	1.0268
1	2	1	2.8300	5	1	1	0.6167
1	2	2	2.6883	5	1	2	0.5152
1	2	3	2.5333	5	1	3	0.9162
1	2	4	2.5117	5	1	4	0.8220
2	1	1	1.1900	5	2	1	0.4413
2	1	2	1.2300	5	2	2	0.4742
2	1	3	1.4000	5	2	3	3.1170
2	1	4	1.3050	5	2	4	0.8908
2	2	1	1.1050	6	1	1	0.9375
2	2	2	1.2050	6	1	2	1.0347
2	2	3	1.3933	6	1	3	1.2050
2	2	4	1.4567	6	1	4	1.3438
3	1	1	0.9015	6	2	1	1.0045
3	1	2	0.8958	6	2	2	1.9300
3	1	3	0.9527	6	2	3	0.9442
3	1	4	0.8657	6	2	4	1.4000
3	2	1	0.9070	7	1	1	1.1900
3	2	2	0.9118	7	1	2	1.2733
3	2	3	0.8515	7	1	3	1.3917
3	2	4	0.9213	7	1	4	1.5650
4	1	1	0.4732	7	2	1	1.1650
4	1	2	0.5605	7	2	2	2.1283
4	1	3	0.7297	7	2	3	1.1433
4	1	4	0.6470	7	2	4	1.6117

Observations per Mean 6
Standard Error of a Mean 0.2796
Std Error (Diff of 2 Means) 0.3954

Means of TN for Direction*Space*Depth

Direction	Space	Depth	Mean	Direction	Space	Depth	Mean
1	1	1	1.2796	2	1	1	1.1029
1	1	2	1.6549	2	1	2	1.4653
1	1	3	1.5424	2	1	3	1.3694
1	1	4	1.0680	2	1	4	1.5303
1	2	1	1.0177	2	2	1	1.0617
1	2	2	1.0594	2	2	2	2.1310
1	2	3	1.3350	2	2	3	1.2401
1	2	4	1.2070	2	2	4	1.1321

1	3	1	1.1024	2	3	1	1.1123
1	3	2	1.3344	2	3	2	1.2716
1	3	3	1.3593	2	3	3	2.0836
1	3	4	1.4239	2	3	4	1.5851
1	4	1	1.2613	2	4	1	1.2780
1	4	2	1.2143	2	4	2	1.2643
1	4	3	1.2497	2	4	3	1.1840
1	4	4	1.2079	2	4	4	1.5540
1	5	1	2.2127	2	5	1	1.1313
1	5	2	1.0307	2	5	2	1.0996
1	5	3	1.3786	2	5	3	2.2670
1	5	4	1.0933	2	5	4	1.3219
1	6	1	1.2596	2	6	1	1.1600
1	6	2	1.1716	2	6	2	1.4026
1	6	3	1.3923	2	6	3	1.0704
1	6	4	1.1587	2	6	4	1.2929

Observations per Mean	7
Standard Error of a Mean	0.2588
Std Error (Diff of 2 Means)	0.3661

Means of TOC for Time*Direction*Depth

Time	Direction	Depth	Mean	Time	Direction	Depth	Mean
1	1	1	17.017	4	2	1	7.605
1	1	2	17.502	4	2	2	10.092
1	1	3	14.533	4	2	3	6.897
1	1	4	15.432	4	2	4	5.087
1	2	1	14.823	5	1	1	7.435
1	2	2	13.207	5	1	2	7.507
1	2	3	13.983	5	1	3	9.045
1	2	4	14.012	5	1	4	7.500
2	1	1	7.135	5	2	1	7.483
2	1	2	8.033	5	2	2	7.753
2	1	3	9.640	5	2	3	10.343
2	1	4	7.125	5	2	4	5.442
2	2	1	7.568	6	1	1	11.082
2	2	2	9.715	6	1	2	12.398
2	2	3	9.363	6	1	3	10.108
2	2	4	8.328	6	1	4	12.787
3	1	1	12.717	6	2	1	9.667
3	1	2	23.160	6	2	2	12.098
3	1	3	7.203	6	2	3	9.057
3	1	4	14.357	6	2	4	11.198
3	2	1	7.092	7	1	1	12.463
3	2	2	7.240	7	1	2	13.710
3	2	3	13.532	7	1	3	11.068

3	2	4	15.123	7	1	4	13.928
4	1	1	6.640	7	2	1	10.795
4	1	2	5.638	7	2	2	13.325
4	1	3	6.483	7	2	3	10.775
4	1	4	6.025	7	2	4	12.985

Observations per Mean 6
Standard Error of a Mean 2.1288
Std Error (Diff of 2 Means) 3.0105

Means of TOC for Direction*Space*Depth

Direction	Space	Depth	Mean	Direction	Space	Depth	Mean
1	1	1	8.994	2	1	1	8.607
1	1	2	19.334	2	1	2	9.520
1	1	3	14.740	2	1	3	7.586
1	1	4	9.113	2	1	4	8.660
1	2	1	7.916	2	2	1	8.033
1	2	2	8.694	2	2	2	12.514
1	2	3	8.979	2	2	3	12.937
1	2	4	9.993	2	2	4	6.790
1	3	1	12.173	2	3	1	7.569
1	3	2	14.221	2	3	2	11.824
1	3	3	7.930	2	3	3	8.593
1	3	4	14.461	2	3	4	10.460
1	4	1	10.990	2	4	1	9.911
1	4	2	8.257	2	4	2	10.583
1	4	3	8.571	2	4	3	8.581
1	4	4	12.287	2	4	4	17.013
1	5	1	13.929	2	5	1	11.570
1	5	2	8.401	2	5	2	8.046
1	5	3	9.427	2	5	3	11.657
1	5	4	10.266	2	5	4	9.649
1	6	1	9.846	2	6	1	10.053
1	6	2	16.476	2	6	2	10.453
1	6	3	8.709	2	6	3	14.031
1	6	4	10.011	2	6	4	9.293

Observations per Mean 7
Standard Error of a Mean 1.9709
Std Error (Diff of 2 Means) 2.7872

Appendix-3

Coordinates used for water sampling at Rawal Lake

Space (m)	North	East	West	South
100	N 33°42'12.52" E73° 7'33.15"	N 33°42'9.35" E73° 7'38.03"	N 33°42'9.39" E73° 7'30.09"	N 33°42'6.27" E73° 7'34.85"
200	N 33°42'15.68" E73°7'32.21"	N 33°42'9.56" E73° 7'41.80"	N 33°42'9.35" E73° 7'26.18"	N33°42'3.12" E73° 7'35.59"
300	N 33°42'18.76" E73° 7'31.42"	N33°42'9.56" E73° 7'45.84"	N 33°42'9.32" E73° 7'22.28"	33°42'0.05"N E 73° 7'36.40"

Appendix-4

Random Research Pics: