A report on

MULTIVARIATE STATISTICAL ANALYSIS OF PHYSICO-CHEMICAL WATER QUALITY PARAMETRS OF DAL LAKE

Submitted in the partial fulfillment of the requirements for the award of degree of

MASTER OF TECHNOLOGY
(Environmental Engineering)

by

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2013-2015

ACKNOWLEDGEMENTS

Any accomplishment requires the efforts of many people and this work is no exception. I appreciate the contribution and support which various individuals have provided for the successful completion of this study. It may not be possible to mention all by name but the following were singled out for their exceptional help.

First and foremost, I would like to express my deepest gratitude to my project supervisor ***Prof. S.K. Singh****, Department of Environmental Engineering, Delhi Technological University, for his valuable guidance, support, motivation and encouragement during the project work, without which the completion of the work would have been impossible.*

I am highly obliged and pay my gratitude to the ***Jammu And Kashmir Lakes And Waterways Development Authority (JKLWDA)****, Srinagar, J&K; for providing me the required data without which this work would have been impossible.*

I would like to thank my family members for supporting and helping me at every step of life. Their sincere blessings and wishes have enabled me to complete my work successfully. I am also thankful to all my friends and family for their unconditional support and motivation during this work. Above all thanks to the God, for the blessings that has been bestowed upon me in all my endeavors.

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CERTIFICATE

This is to certify that Mr. SHAH MANAAN, M. Tech. student in the Department of Environmental Engineering has submitted a project report on "Multivariate Statistical Analysis of Physico-Chemical Water Quality Parameters of Dal Lake" in partial fulfillment of the requirement for award of degree of Master of Technology in Environmental Engineering,

It is a record of the student's research work prepared under my supervision and guidance.

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Declaration of Originality

I hereby undertake that I am the sole author of this report. I undertake that this report neither infringes upon anyone's copyright nor violates any proprietary rights to the best of my knowledge. Any ideas, techniques, quotations, or any other material form of work of other people included in this report, published or otherwise, are fully acknowledged in accordance with the standard referencing practices.

I declare that this is the true copy of my/our report, including all revisions, as approved by my advisor and supervisor, and that this report has not been submitted for any other degree to any other University or Institution.

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Abstract

Dal Lake is one of the foremost Himalayan lakes of the Kashmir Valley. Being an urban lake, it is the economic backbone of Srinagar city's tourist commerce, which beacons travellers from all over. Unfortunately the lake is a victim of proliferating anthropogenic pollution and is subjected to a steadily expanding rate of eutrophication and siltation.

Considering the significance of this world acclaimed water body by way of Kashmiri human resource advancement and economic development, the main objectives of this study was long term assessment of water quality of the Dal Lake by using multivariate statistical tools in addition to developing a Water Quality Index which can be used by the regional monitoring body i.e. Jammu And Kashmir Lakes And Waterways Development Authority to convey the water quality status for the development of lake water quality. The period of water quality assessment was 5 years from September 2010 to August 2015.

Significant spatio-temporal variability in most parameters indicated substantial spatio-temporal variations. From the principal component analysis it can be construed that the lake water quality is mainly influenced by waste water discharge and agricultural run-off in the form of proliferation of nutrients like nitrate-nitrogen, ammonium-nitrogen, phosphates and chlorides. From the spatial cluster analysis it is clear that the Central Site Nigeen, Outlet Sites of Habak and Outlet Site of Hazratbal are the most polluted sites of Dal Lake and need immediate remediation strategies.

The spatial WQI, asserts the high pollution levels of water quality at the Central Site Nigeen, Outlet Sites of Habak and Outlet Site of Hazratbal, also indicating soaring annual trends of spatial lake water deterioration. The spatial annual average development of overall WQI puts the status of the Dal Lake in the “Very Poor” category of water quality. The calculated temporal WQI, identifies Summer as the season which suffers most from the lake water pollution, having the highest WQI among all seasons, and also reflects the generally increasing annual trends of seasonal lake water deterioration. The average seasonal/temporal overall WQI of Dal Lake again puts the status of Dal Lake in the “Very Poor” category of water quality.

Overall, this study may contribute towards the advancement of knowledge and development of conservation strategies for the Dal Lake.

Keywords: Dal Lake; principal component analysis; cluster analysis; water quality,WQI

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CHAPTER 1
INTRODUCTION

1.1 General background:

More than seventy percent of the surface of earth is covered with water in the form of streams, lakes, rivers, and oceans. Water is most essential topographical agent that adjusts the surface morphology of the planet on an exceptionally great scale. Any aperture of extensive size in the surface of the earth that is loaded with water might be characterized as a lake. Unequivocally a lake is an assemblage of stagnant, semi stagnant or new water, most lakes are impermanent in character. Lakes demonstrate an immense diversity in form. In size lakes may run from a couple square kilometers to a few hundred thousand square kilometers in territory. Likewise in shape lakes appear as round, semi round, half-moon shape, rectangular and triangular. Lakes assume an imperative part in the economy of an area or nation and are of colossal scholarly, societal and financial significance. They go about as characteristic water supplies and store a substantial amount of water, which can be utilized for drinking, modern, water system, stylish and different purposes including hydel power generation.

Dal Lake, a warm monomictic lake, situated at an elevation of 1587m above the mean sea level and at 34°07′N latitude and 74°52′E longitude with a catchment area of 316 square kilometers, is one of a progression of freshwater lakes of Kashmir valley. Dal Lake is a multi-basined, bull bow kind of lake, with shallow saucer-molded bowls framed by the changing course of stream Jhelum. The principle source of water for the lake is Telbal Nallah in the Dachigam territory, various springs emerging from the base of lake and outwash from encompassing mountains. The surge of lake happens through a weir-n-bolt framework. The greatest depth is 6.5m, while the normal/average depth is under 3m. The pH estimations of the lake fall inside the alkaline range as of not long ago.

Figure 1.1: Map Of Dal Lake

Atmosphere of Kashmir is montane valley atmosphere with a professed icy season from October to March (mean temperature 7.5 degree Celsius) and warm summers mean temperature 19.8 degree Celsius. The month of January is the coldest (temperature of minus two degree Celsius to three degree Celsius), while the hottest is July (thirty four degree Celsius to thirty five degree Celsius). The main proportion of the precipitation is received as snow (December-February). The waters of Dal Lake bolster a changeless drifting populace of somewhere in the range of 7000 individuals, with entire towns having essentially been illicitly made in the lake. The lake underpins an enormous drifting business sector, cultivation industry, an imperative fishery and a blasting traveler industry. Weeds are collected for dairy cattle feed. The lake additionally goes about as a sump for a lot of the waste items from Srinagar. Violations of water from structures and by swelling of floating gardens and installation of lake bed materials and removing weeds on current solid land masses and obviously by transformation of floating gardens in to lasting land masses by way of accumulative weight and mass by planting of materials withdrawn from the lake. Solid waste management in the lake remains a great predicament for the following explanations that in wider terms Dal Lake is a city in itself in the interior of the city with following factors. About 2.5 lac people (source:JKLWDA) living in the surrounding areas discharge wastes which one way or the other reaches into the lake The population living in the interior of the lake discharges their solid wastes into the lake. Resident population going to the lake, commuters and tourists also discharge their solid wastes straight into the lake.

Dearth of cognizance amid the resident common people particularly among the general public living in the riparian zones and within the lake , who recourse to laundry activities on lake shores and discharge their solid waste materials straight to into the lake notwithstanding having access to dustbins. During rainfall, runoff waters collect dust, debris and adsorbed nutrients which due to permeable land surface find way to the lake.

Dal Lake, imperiled to a progressively intensifying rate of eutrophication and siltation, has been evaluated to exhaustively be wiped out in the subsequent fifty years. Siltation has expanded essentially since various streams and rivulets which joined the lake on its western edge were dammed or filled amid the development of a roundabout street around the old city in later past. The volume of nutrients achieves a top amid the mid-year months, when more than 1700 houseboats and many inns bolster an additional 500,000 individuals for every season (Source:http//:www.kashmirtourist.com). Jammu and Kashmir is one of the delightful parts of this planet with rich water assets. Dal Lake is world renowned water body which should be saved. The Government of Jammu and Kashmir has authorized an agency to spare this water body from contamination called Jammu and Kashmir Lakes and Waterways Development Authority (JKLWDA). This lake has truly been the focal point of Kashmiri progress and has assumed a noteworthy part in the economy of the state through its fascination of visitors and additionally its usage as a wellspring of sustenance and water. Considering the significance of this world acclaimed water body for Kashmiri human advancement and economy, it is proper to direct this study on Dal Lake.

1.2 Objectives of the Study:

1. To study the water quality of Dal Lake.
2. To analyze the spatio-temporal variations in the physico-chemical parameters of the lake.
3. To conduct a multivariate statistical analyses of the lake utilising techniques such as Principal Component Aanalysis and Cluster Analysis to identify the natural, anthropological and seasonal processes in the lake.
4. To utilise a simple and reasonable way to display and illuminate the deterioration of water quality of Dal Lake by developing a Water Quality Index of the lake. This tool can be used as an optimum way to interface and deal with the press, the public and help in policy making.

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1.3 Limitations of Study:

Even though this study was conducted with utmost care, the following are its main restrictions:

-The records were not exactly as immaculate as desired.

-There were challenges to acquire certain information, particularly from the local assets.

-The general nature of water analysis in this examination relies upon selected physical and chemical parameters. Biological parameters are excluded.

1.4 Research Methodology:

1.4.1 Research Steps:

The targets of the study have been accomplished by actualizing the following steps:

1. Data assortment for this study is based on regular fieldwork conducted by the Jammu and Kashmir Lakes and Waterways Development Authority (JKLWDA) and other related institutions for lake water samples collected from predetermined locations.

2. A general statistical study of the physico-chemical parameters of the lake's water quality has been conducted to determine the interrelationship among them and also to know the water quality configurations in the basin.

3. Data scaling/standardization is important in multivariate analysis. In this study Principal Component Analysis/Factor Analysis and hierarchical cluster analysis (HCA) will be applied.

4. The Principal Component Analysis is conducted after fragmenting the data into the four distinct seasons operating in the study area i.e. Spring (March-April-May), Summer (June-July-August), Autumn (September-October-November) and Winter (December-January-February). It will account each factor of the total variance in the hydrochemistry of the study in the context of the four seasons.

5. The HCA results in dendograms which are a depiction of the spatio-temporal lake water associations in the area.

6. Water quality index of the lake is determined. Water quality index is a means to condense extensive water quality data into a communicable format for relaying it to authorities, management and the public in simple terms.

1.5 Outline of research:

This research consists of five chapters as follows:

Chapter One: Introduction

This part has an overall prelude to the matter of the exploration, general foundation of study zone, issue articulation, and legitimization of research, research objective, and research material.

Chapter Two: Literature Review

This section incorporates the meaning of lakes and lake water quality and variables influencing water quality, multivariate techniques, the part of multivariate in examination of water quality, the meaning of water quality index ,water quality index application, advantages and disadvantages , how to compute a physiochemical water quality index water quality. This chapter includes the definition of lakes and factors affecting lake water quality, multivariate methods, the role of multivariate in analysis of water quality, the explanation of water quality index, water quality index uses, needs, advantages and disadvantages.

Chapter Three: Methodology

This part clears up the procedure and strategies which are utilized amid the planning of the exploration that will be connected through information accumulation, preparing and methods used to accomplish the targets of the examination. Analysis like principal component analysis, cluster analysis, and WQI are explained in general.

Chapter Four: Results and Discussions

This part incorporates the results includes maps, tables, figures and summaries that describe the factors affecting water quality, clusters of sampling locations and seasons, water quality index.

Chapter Five: Conclusions & Recommendations

This part elucidates the drawn conclusions and recommendations for the study in question.

CHAPTER 2
LITERATURE REVIEW

2.1 Lake

A lake is a territory of irregular size loaded with water, confined in a bowl that is peripherally surrounded by land, aside from any waterways or other outlets that function to replenish or deplete the lake. Lakes are extant on land and are not a splinter of the ocean, and hence are detached from lagoons, and are congruently greater and more abysmal than ponds, however there are no formal or precise definitions. Lakes can be distinguished with rivers, which are ordinarily flowing. Most lakes are nourished and exhausted by rivers and streams.

2.1.1 Classification of Lakes

Two classifiers can be employed to sort a lake i.e. the depth that regulates the water stratification and the water circulation patterns and the trophic state that describes its productivity. According to its depth or stratification, lake is categorized as:

- Shallow lake or pond where stratification does normally not occur.

- Dimictic lake which has two seasonal periods of overturn.

- Cold monomictic lake whose water temperature is never above 4°C, generally found in Polar Regions.

- Warm monomictic lake having water temperature always above 4°C, found in warm, temperate or subtropical regions.

- Polymictic lake: more or less continuous in circulation, located in high altitude or equatorial zones.

- Oligomictic lake: rarely or very slowly mixed. This is the case of many tropical lakes.

- Meromictic lake: permanently stratified due to chemical differences in water surface and bottom water.

The classification based on Lake Trophy gives the following categories:

- oligotrophic lake (or new lake)

- mesotrophic lake (middle aged lake)

- eutrophic lake (old lake)

Oligotrophic lakes are unblemished, cold lakes with to some extent acidic to somewhat alkaline water. Level of nutrients is meager and scarce macrophytes or plants develop. The phosphorus concentration in the water is usually less than 1µg/l and there are little or no algae present.

Eutrophic lakes exhibit elevated nutrient levels, turbid water, and increased algae and macrophyte plant populations. Phosphorus level is normally higher than 10µg/l. the water pH is usually alkaline. The age and shape are two factors we must consider when managing a lake. The existing zones or regions should be well managed in order to maintain an ecological balance in the lake.

2.1.2 The aging process in a lake - eutrophication process

Lakes are dynamic and complex ecosystems. They are subject to a natural aging process known as eutrophication. This process consists of the change from an original oligotrophic state to a eutrophic state including fluctuations in physic-chemical and biological features of the lake. Eutrophication is caused by the increase of nutrients, especially nitrogen and phosphorus, in the ecosystem leading to an increase of primary production (photosynthesis) and an accumulation of organic matter in the lake. In addition, silt from the drainage basins will accumulate over time, which makes the lake shallower and warmer. Under natural conditions, the rate of this process is very slow and it takes hundreds or thousands of years. When human activities contribute, however, the process accelerates and we refer to it as a cultural eutrophication.

Cultural eutrophication is the anthropogenic expediting of Lake Eutrophication by way of loading excess nutrients into the lake water body. Surveys showed that fifty three percent of lakes in Asia are eutrophic; fifty two percent in Europe; forty nine percent in North America; forty two percent in South America; and twenty six percent in Africa

2.1.3 Effects of Eutrophication

Eutrophication affects greatly the dissolved oxygen concentration in water. At the surface, oxygen concentration may always be higher since it is continuously produced by photosynthesis and also provided by air-water interaction. When receding water depth, its production is curtailed. In fact, photosynthesis occurs only in presence of sunlight and for a eutrophic lake, the water turbidity prevents the light to enter deeper into water column. gIn addition, the super production of algae due to nutrient abundance is associated with algal death. The dead algae sink into the bottom and are degraded there. The degradation process demands oxygen which emphasizes the diminution of oxygen concentration at that depth. Regarding the variation of dissolved oxygen within depth, oligotrophic lakes shows little variation and oxygen can always be. However, in eutrophic lakes, dissolved oxygen concentration diminishes considerably with depth and may become zero at a certain depth (Gilbert M. Masters, 1991).

In addition to those impacts, other consequences can be also observed depending on the eutrophication level in the water, for example:

- Apparition of noxious algae (blue, green toxic algae), scum, odor and colour.

- Excessive macrophyte growth causing loss of open water.

- Damage of habitat for fish and fish nutriment due to the low dissolved oxygen content

-Generation of "Toxic" gases (such as ammonia) in water (more loss of fish habitat).

Knowledge of the lake's trophic state is vital on the grounds that it gives a reference indicate see changes in a lake's water quality and see how these progressions may grow.

2.2 Multivariate Procedures in Water Quality Analysis:

2.2.1 Role of Multivariate Techniques in Examination of Water Quality Data:

Multivariate statistical exploration propositions an objective technique to approximate the perceived strengths of the particular progressions that encompass concurrent shift of many water quality factors (Peterson et al 2001).

Use of multivariate statistical techniques in elevated mountain lake recorded information has provided various key inferences about the significance of environ-metric methods in Lake Water quality review (Simonov et al 2010).

Study suggests that the multivariate statistical procedures aids in recognizing the association amongst the parameters that is hard to detect initially. The Pearson correlation coefficient makes simple the intricacies of physio-chemical information and show the extent of dependence of one variable on the other (Khan et al2012).

2.2.2 Multivariate Techniques:

The multivariate statistical techniques such as cluster analysis and principal component analyses have been expansively used as unprejudiced approaches in examination of water quality information for extracting significant information (Singh et al. 2004).

Factor analysis method is quite advantageous in the investigation of statistics corresponding to great amount of variables, analysis via this technique produce easily understood effects, and this technique has been used fruitfully in hydrochemistry for several years (Praus, 2005).

Utilisation of several multivariate statistical methods, such as cluster analysis, principal component analysis etc, aids in the clarification of intricate data matrix aimed at an improved comprehension of water quality and environmental standing of the area under observation. These methodologies permit documentation of the potential sources that effect water structures and proposes a cherished instrument for dependable organization of water assets in addition to fast resolution to pollution complications (Kazi et al2009).

The drawbacks of multivariate statistical methods comprise (1) subjectivity in terms of interpretation for controlling the sources and processes (Liu et al. 2003), (2) undependability in water quality data which might not give suitable results, (3) presence of same parameters in different PCs which might modify the interpretations, and (4) difficulty in identification of appropriate number of clusters.

2.2.3 Principal Component Analysis:

An exceptionally effective procedure to shrink the dimensionality of a data set encompassing a massive number of interrelated parameters, at the same time holding as much as possible the variability extant in data is the Principal Component Analysis (PCA). (Singh et al 2004). As per (Shrestha S and Kazama F.,2007) the main goal of principal component analysis is to mitigate the contribution of insignificant variables to streamline even more of the data configuration coming from PCA.

2.2.4 Cluster Analysis:

The Cluster Analysis is an explorative examination that attempts to distinguish arrangements inside the information structure. Cluster Analysis is additionally called division examination or scientific categorization examination. Particularly it mainly tries to recognize identical accumulation of cases, i.e., perceptions, members, respondents. It is employed to distinguish gatherings of cases if the gathering is not beforehand known. As it is explorative it makes every refinement amongst reliant and free factors.

Cluster analysis is a multivariate technique whose principal goal is to bring together objects based on the similar features they hold. Cluster analysis categorizes entities, so that each entity is alike to the others in the cluster with regards to a preset assortment standard. Resulting clusters of entities ought to disclose high inner (within-cluster) homogeneity and high outer (between clusters) heterogeneity.

Hierarchical Agglomerative Clustering is a of the more common approaches, which offers instinctive likeness associations between any one sample and the entire information set, and is usually demonstrated by a dendrogram.

(Shrestha S and Kazama F., 2007) identified Cluster Analysis as “an efficient means to recognize groups of samples that have similar chemical and physical characteristics” (Shaban et al.,2010).

2.3 Water Quality Index:

A Water Quality Index (WQI) is a methodological tool engaged to condense water quality data for relaying it to administration and the community in an easy to understand form.

Horton (1965) considered a basic way of working out the water quality index from a selection of ratings and weightings of the numerous variables such as sewage treatment, DO, pH, coliforms, chlorides, alkalinity, specific conductivity, etc. He computed the index through an arithmetic weighted mean.

Nives (1999), WQI as a mathematical tool devised to convert enormous amount of water quality data into a singular number which is reflective of the water quality level while removing the idiosyncratic valuations of water quality and leanings of individual water quality experts.

WQI shares similarity with many other index systems and corresponds to a assemblage of water quality parameters on a common scale and conglomerates them into a single number in agreement with a preferred technique of computations (Mohsen 2007).

A few of the indices have subsequently been assimilated into water quality indices and used by environmental organizations such as the National Sanitation Foundation (NSF) (Ahamed et al 2004) .

Unlike water quantity, which can be expressed in precise terms, water quality is a multi-parameter attribute. The usefulness of a WQI depends on the combination of data about water-quality parameters at different times and in different places and translating this information into a single number that characterizes the time period and the spatial unit under consideration. (Terrado et al.2010).

2.3.1 Water Quality Index Uses:

The goal of an index is not to designate discretely a waste product's quantity or fluctuations in a specific variable. Combining an intricate entity into a singular figure is the prime objective in construction of a WQI, as it is solidly impacted by a huge quantity of ecological multivariates. Hence, a precise description of the objectives to be managed by the application of such an index is a must. The devising of a WQI can be streamlined if it reflects only the variables which are considered significant for a definite water body. Hence it can be utilised as a cheap and interpretable water use benefit index as a instrument for checking aquatic related leanings in the Great Barrier Reef region (Smajgl et al 2010).

Several physico-chemical individualities can be utilised to determine water quality or the extent of water contamination. Consequently, it is difficult inn to distinctly express water quality both on a spatial or chronological level and through independently examining the performance of all parameters (Cordoba et al 2010).

2.3.2 Water Quality Index advantages and disadvantages:

2.3.2.1 Advantages:

1. Numerous scientists have incorporated water quality parameters into the format of indices, known in technical terminology as water quality indices (WQIs) For observation of water quality and to make conclusions on qualitative and quantitative assessment grounded on actual data has poised a contest for environmental engineers on all levels of the progression, from data accumulation, retention and computation till analysis and inference of the results (Lermontov et al 2009).

2. One of the benefits of indices lies in the fact that it enables communication with the laymen in a succinct manner (Lermontov et al 2009).

3. WQI's are regarded as more reliable than individual parameters. They also assimilate numerous variables into a sole figure, coalescing varied units of measurement (Lermontov et al 2009).

4. In doing so, WQI develops as an easy statement implement for conveying technical data from specialists to the broad-spectrum audience (Terrado et al 2010).

5. Appeal of utilising WQI lies in its suppleness meant for picking variables as well as the option of adjusting the purposes to be attained by every parameter as per a specific application of the water body (Terrado et al 2010).

2.3.2.2 Disadvantages:

1. The difficulty with this methodology is the prospect that certain parameters have an inordinate impact on concluding results, generating a prejudiced index (Lermontov et al 2009).

2. The indicator comprise of various physico-chemical parameters. Corresponding to each parameter, index involved a quality-value function (usually linear) which described the likeness between the variable and its quality level. Functions were demarcated via direct measurements of the quantity of a species or the assessment of a physical parameter acquired through analysis of water samplings, these functions are not general: they are not applicable in all topographical areas. Therefore, it is unlikely to use the index for direct appraisals of water quality between regions or countries (Cordoba et al 2010). Water Quality Indices are mainly valuable for relative determinations and for general inquiries. (Saeedi et al 2010).

3. Preferred usage of WQI is unintended for an outright evaluation of the extent of contamination or the prevailing water quality. (Mishra et al 2008). Hence, the index could never be regarded as an absolute assessable appraisal of the competence of groundwater to be used as a trustworthy basis of drinking water but should be actualised as a goal-specific water supervision instrument. (Saeedi et al 2010).

4. Major difficulty related with variable assortment is subjectivity. (Terrado et al 2010).

2.4 Parameters Used In The Study:

The parameters used in this study are those physiochemical parameters which are being monitored by the Jammu and Kashmir Lakes and Waterways Development Authority and the data of which is collected and maintained on a regular basis.

pH

pH of a solution is the magnitude of the concentration of hydrogen ions (H+) and it identifies the negative logarithm of hydrogen ions concentration. It expresses the strength of the acid or the alkaline form of a solution. pH of water regulates the solubility and biological obtainability of chemical species such as nutrients and heavy metals.

Conductivity

Conductivity is a measure of the ionic activity of a solution in terms of its capacity to transmit current. In a water sample, the electric current is conducted by the ions present in it, hence as the concentration of ions increases, the conductivity also amplifies. This parameter relates then to the amount of dissolved solids (as it includes ions) in the water: the higher the total dissolved solids in the solution, the higher the ion concentration and conductivity.

Chemical Oxygen Demand

The chemical oxygen demand can be used to measure the whole amount of organic compounds in water. It is established on the point that every organic matter can be oxidized under the effect of potassium dichromate under acidic condition.

Total Alkalinity

Total alkalinity is the measurement of all bases in the water and can be thought of as the buffering capacity of water, or its ability to resist change in pH. The most common and important base is carbonate. Total alkalinity is expressed as milligrams per liter (mg/L) or parts per million (ppm) of calcium carbonate ($CaCO_3$).

Chloride:

Water contaminated with chloride creates a higher water density and will settle at the deepest part of the water body where current velocities are low such as lakes. This can lead to a chemical stratification which can impede turnover and mixing, preventing the dissolved oxygen within the upper layers of the water from reaching the bottom layers and nutrients within the bottom layers from reaching the top layers. This leads to the bottom layer of the water body becoming void of oxygen and unable to support aquatic life. The concentration of chloride found in surface water correlates with the proportion of impervious surfaces in the watershed. Chloride remains in the watershed until it is flushed downstream.

Calcium and Magnesium:

Calcium is naturally present in water. It may dissolve from rocks such as limestone, marble, calcite, dolomite, gypsum, fluorite and apatite. Calcium is a determinant of water hardness, because it can be found in water as Ca^{2+} ions. Magnesium is the other determinant.

Ortho-phosphate

Biologically available phosphorus is found in lakes, waterways and wastewater in the form of ortho-phosphates. Phosphate increase is the most common cause of undesirable growth of aquatic weeds and algae. The discharge of reclaimed wastewater and watershed drainage will increase a lake's phosphate level. Lawn and landscape fertilizer runoff are another major source of phosphate in lakes and their use should be avoided near the water.

Total Phosphate

Total phosphates measure all the forms of phosphorus, both dissolved and particulate. Ponds and lakes are categorized by their total phosphorus level and high phosphorus waters are considered polluted or “eutrophic”. Control of undesirable blue green algae can often be obtained at phosphorus levels below 0.02 mg/L.

Dissolved Oxygen

Dissolved oxygen (DO) is the most critical indicator of a lake’s health and water quality. DO levels in natural waters are dependent on the physical, chemical and biochemical activities prevailing in the water body. Oxygen is added to aquatic ecosystems by aquatic plants and algae through the process of photosynthesis; and by diffusion at the water’s surface and atmosphere interface. Animal and plant respiration and decomposition are major causes of oxygen depletion. Oxygen is required for fast oxidation of organic wastes including bottom muck. When the oxygen is used up in the bottom of the lake, anaerobic bacteria continue to breakdown organic materials, creating toxic hydrogen sulfide gas in the process. For a healthy game-fish population, oxygen levels in the 6-10 mg/L range are necessary. Respiration stress in most fish occurs when oxygen levels are reduced to 3-4 mg/L.

Nitrate Nitrogen

Nitrate (NO_3) is a common inorganic form of nitrogen. Chemically, it is an anion with a single negative charge, consisting of one atom of nitrogen and three atoms of oxygen. Because it is an anion, it is soluble in water. Plants normally use nitrate as their source of the nitrogen needed by all living things, and so nitrate is considered a nutrient for plants. Excessive concentrations of nitrate in lakes and streams greater than about 5 milligrams per liter (measured as nitrogen), depending on the water body, can cause excessive growth of algae and other plants, leading to accelerated eutrophication or 'aging' of lakes, and occasional loss of dissolved oxygen. Animals and humans cannot use inorganic forms of nitrogen, so nitrate is not a nutrient for us. Nitrate can get into water directly as the result of runoff of fertilizers containing nitrate. Some nitrate enters water from the atmosphere, which carries nitrogen-containing compounds derived from automobiles and other sources. Nitrate can also be formed in water bodies through the oxidation of other, more reduced forms of nitrogen, including nitrite, ammonia, and organic nitrogen compounds such as amino acids.

Ammonical Nitrogen

Ammonia nitrogen (N) is present in variable concentrations in many surface and ground water supplies. A product of microbiological activity, ammonia when found in natural water is regarded as indicative of sanitary pollution. Ammonia and organic nitrogen can enter water through sewage effluent and runoff from land where manure has been applied or stored Ammonia is rapidly oxidized by certain bacteria, in natural water systems, to nitrite and nitrate--a process that requires the presence of dissolved oxygen. Ammonia, being a source of nitrogen is also a nutrient for algae and other forms of plant life and thus contribute to overloading of natural systems and cause pollution. .

Sulphate

Although sulphate is an essential nutrient for tissue growth in plants and animals, at higher concentrations sulphate can contribute to detrimental conditions in aquatic habitat. At higher concentrations, sulphate can encourage the release of metals from streambed sediments, thereby increasing stream alkalinity, which can adversely affect aquatic organisms that have low tolerance level for high pH. Sources of sulphate in urban lake areas can be derived from natural processes and anthropogenic activities.

CHAPTER 3
METHODOLOGY

So as to achieve the intentions of the research we endeavored to achieve a comprehensive assessment of the water quality of Dal Lake, by applying multivariate techniques. The ensuing steps below display plainly the measures used to obtain the research intentions.

3.1 Data Collection and processing:

Water quality information cum data was obtained from the Jammu and Kashmir Lakes and Waterways Development Authority (JKLWDA). The month wise collected data for the lake from the i.e. the period between September-2010 to August 2015 was obtained.

The data so acquired data is for the following parameters: Electrical conductivity (EC), Calcium, Magnesium, Chloride, Ortho Phosphate, Total Phosphate, nitrate-nitrogen, ammonical nitrogen, pH, Dissolved oxygen (DO), Sulphate, Total Alkalinity and Chemical Oxygen Demand (COD).

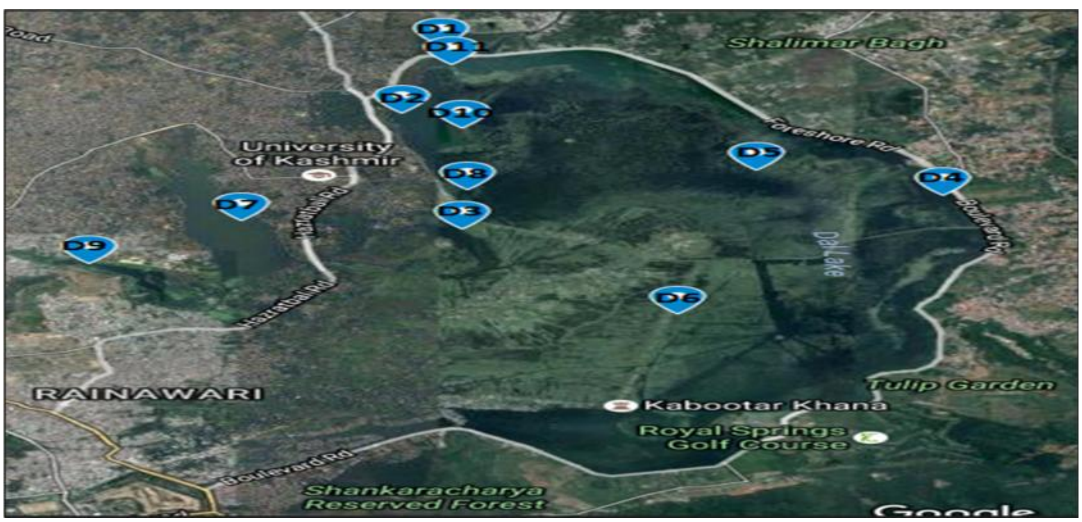


Figure 3.1: Map showing sampling locations

Sampling was generally done monthly from 11 locations/sites as per the standard guidelines.

Table 3.1: Sampling Locations/Sites

Site	Description
D1	Inside Lake near the entry of Telbal Nallah
D2	Dhobi Ghat area
D3	Central site near Sonilank
D4	Near Nishat Pipe line bund (Culvert 1)
D5	Central site near Char Chinari
D6	Near Kabootar Khana
D7	Central site Nigeen
D8	Saderabal Area
D9	Pokhribal area
D10	Outlet site of Hazratbal STP
D11	Outlet site of Habak STP

3.2 Analysis of data for trends

The acquired data is studied for the purpose of discerning a trend and pattern in relation to the operating seasons of the lake i.e. Spring (March-April-May), Summer (June-July-August), Autumn (September-October-November) and Winter (December-January-February). For this purpose we computed the 5 year (2010-11 to 2014-15) average of the data for all sampling sites and overall 5 year season wise average data of the lake for all the prevailing seasons. This helps to distinguish consistent and precise longitudinal cum seasonal behavioural trends of the monitored physico-chemical data and minimises the possibility of deviation from the original trend.

3.3 Data Standardisation

Various examiners have reported the significance of standardizing variables for multivariate analysis. Else, variables recorded at dissimilar measures do not add correspondingly for the exploration. For instance, in boundary detection, a parameter that varies from 0 to 100 will overshadow a parameter that varies from 0 to 1. Expending these parameters devoid of standardization in consequence gives the parameter with the greater range a load of 100 in the analysis. Altering the data to equivalent measures can avert this difficulty. Characteristic data standardization measures level the range. The data was therefore scaled to their corresponding z-scores by employing Equation(1) below, in order to achieve the purposes of normal distribution as well as homogeneity

$$\mathbf{z} = \frac{\mathbf{x}-\boldsymbol{\mu}}{\boldsymbol{\mu}} \qquad \ldots (1)$$

Where x = Data and

μ = Mean

3.4 Principal Component Analysis

Principal component analysis (PCA) is considered among the utmost appreciated outcomes from applied linear algebra. PCA is applied copiously in all procedures of examination - from medical sciences to engineering for it is an unassuming, non-parametric method of pulling out pertinent material from confusing information sets.

PCA was conducted on the available data using Statistical Package For Social Sciences (SPSS) version 20, after breaking up acquired/available data into four sets season wise i.e. Spring(March-April-May), Summer(June-July-August), Autumn(September-

October-November), and Winter(December-January-February). The total number of factors spawned from a characteristic factor analysis point out the overall number of likely causes of variation in the data. Principal Components are hierarchical in order of importance. The first factor or component has the maximum eigenvector figure and signifies the greatest cause of variation in the data. The last factor is the minimum important process causative to the chemical variation. The number of factors is determined using a scree plot. Scree plot shows the eigenvalues related with a component or factor in descending order versus the number of the component or factor. Scree plots are employed in principal components analysis and factor analysis to graphically appraise which components or factors elucidate ultimate variability in the data. Factor loadings on the factor loadings tables are construed as correlation coefficients between the variables and the factors.

3.5 Cluster Analysis

Cluster Analysis remains a unsupervised learning statistical methodology. The aforementioned is an explorative technique that tries to designate data by discrete ‘groups’ with same characteristics. Implication of ‘groups’ may diverge by data. To be more precise, it attempts to categorize identical groups of cases, i.e., observations, partakers, locations etc. Cluster analysis is used to organise groups of cases of which alignment is not known beforehand. Since the aforementioned is unsupervised it does not make any difference between response and explanatory parameters. Many cluster analysis methods that SPSS version 20 provides resources to entertain binary, nominal, ordinal, and scale (interval or ratio) data.

Hierarchical cluster analysis (HCA) using Statistical Package For Social Sciences (SPSS) version 20, was implemented to the data after breaking up the data, season wise and also location wise with regards to the sampling locations. Hierarchical cluster analysis is one of the more popular procedures of cluster analysis. It splits datasets into grading based on similarity or dissimilarities in the field. Here HCA, groups seasons and sampling locations into clusters. The method as in used for clustering is Wards Linkage based on a minimum variance criteria which finds the pair of clusters that leads to least escalation in total inside cluster variance after incorporation. The measured distance is Squared Euclidean Distance which is the space between two items, x and y and is equal to the sum of the squared variances between the values for the items.

$$\textbf{Squared Euclidean Distance} = \Sigma (x_i - y_i)^2 \qquad \dots (2)$$

3.6 The Water Quality Index:

In this study we have utilised Weighed Arithmetic Water Quality Index Method. It favors quality of water as per the level of purity by means of the most ordinarily measured water quality variables. It has been extensively used by numerous scientists and the computation of WQI was made by using the following equation:

$$WQI = \Sigma Q_i W_i / \Sigma W_i^2 \qquad \dots (3)$$

The quality rating scale (Q_i) for each parameter is computed by using this expression:

$$Q_i = 100[(V_i - V_o / S_i - V_o)] \qquad \dots (4)$$

Where,

V_i = estimated concentration of i^{th} parameter in the analyzed water

V_o = the ideal value of this parameter in pure water

V_o = 0 (except pH = 7.0 and Dissolved Oxygen=14.6)

Si is the recommended standard value of i^{th} parameter

The unit weight (Wi) for each water quality parameter is calculated is calculated by using the following formula:

$$W_i = K/S_i \qquad \dots (5)$$

Where,

K = proportionality constant which can also be calculated by using the following equation

$$K = 1/\Sigma(1/S_i) \quad \dots (6)$$

Table 3.2: Water Quality Index (WQI) and status of water quality (Chatterji and Raziuddin 2002)

Sr.No	Water Quality Index	Water Quality Status
1	0-25	Excellent water quality
2	26-50	Good water quality
3	51-75	Poor water quality
4	76-100	Very Poor water quality
5	>100	Unsuitable for drinking

Here we utilized those parameters for which the JKLWDA has most successfully maintained data over the last 5 years from 2010-11 to 2014-15 i.e. the period between September-2010 to August 2015. WQI was computed corresponding to all selected sampling locations of Dal Lake from the year 2010-11 to 2014-2015 in addition to the overall lake WQI for all the four seasons for every year falling in the timeline (2010-11 to 2014-15) under consideration.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Results of Lake Water Monitoring

The data obtained from JKLWDA was processed and a 5 year average from September 2010 to August 2015. (2010-11 to 2014-15) was computed in order to define consistent and precise behavioural patterns of the physico-chemical monitored data.

Table 4.1.1: 5 Year Average (2010-11 to 2014-15) Of Various Parameters at Sampling Sites Of Dal Lake

	pH	conductivity	D.O	total alkalinity	chloride	calcium	magnesium	sulphate
Site		**µS/cm**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
D1	7.934182	253.06	7.41	180.61	13.40	39.66	4.35	8.90
D2	7.750182	268.54	5.50	205.10	17.99	40.89	4.60	11.13
D3	7.99203	224.81	6.02	165.17	10.91	35.03	3.78	8.41
D4	8.018253	216.12	6.47	162.14	13.25	35.42	3.80	8.61
D5	8.043082	223.92	6.03	165.42	12.11	34.64	3.71	8.56
D6	8.057564	224.68	6.22	171.56	13.72	35.13	3.79	9.22
D7	7.930345	325.53	4.67	232.42	19.32	38.22	4.70	12.41
D8	8.010465	294.84	5.79	209.13	17.11	37.92	4.19	11.32
D9	7.94701	270.55	5.80	203.76	16.54	38.63	4.43	11.81
D10	7.849636	317.50	5.48	241.81	21.75	41.39	5.04	16.15
D11	7.786909	315.24	5.52	233.44	21.76	41.00	4.78	16.85

Table 4.1.2: 5 Year Average (2010-11 to 2014-15) Of Various Parameters at Sampling Sites At Dal Lake

	cod	nitrate-nitrogen	ammonical-nitrogen	ortho-phosphate	total phosphate
Site	**mg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**
D1	28.44	481.55	108.68	155.68	435.84
D2	31.67	471.25	152.16	164.41	458.02
D3	27.84	420.66	108.17	127.78	312.79
D4	32.79	419.79	116.04	150.07	401.10
D5	27.63	427.36	117.33	114.62	273.88
D6	30.08	418.87	118.91	140.99	358.79
D7	31.12	446.80	276.55	282.49	596.29
D8	29.71	422.81	147.83	171.31	457.51
D9	33.51	430.61	166.07	181.17	485.88
D10	37.15	545.63	257.25	310.57	777.61
D11	36.97	492.03	196.66	214.41	555.86

Table 4.2.1: 5 Year Overall Seasonal Average (2010-11 to 2014-15) Of Various Parameters At Dal Lake

	pH	conductivity	D.O	total alkalinity	chloride	calcium	magnesium	sulphate
Season		**µS/cm**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
spring	7.94	279.46	6.19	201.29	14.51	37.16	4.17	10.53
summer	8.09	241.13	5.81	198.95	17.24	38.69	4.53	11.77
autumn	7.84	264.52	5.60	187.89	16.58	37.92	4.50	11.50
winter	7.77	272.18	6.06	192.51	15.00	36.81	3.78	10.20

Table 4.2.2: 5 Year Overall Seasonal Average (2010-11 to 2014-15) Of Various Parameters At Dal Lake

	cod	nitrate-nitrogen	ammonical-nitrogen	ortho-phosphate	total phosphate
Season	**mg/l**	**µg/l**	**µg/l**	**µg/l**	**µg/l**
spring	32.07	452.12	150.7652	168.27	468.22
summer	32.63	479.35	161.4413	226.52	617.05
autumn	31.32	457.06	178.5966	209.47	526.26
winter	29.65	399.72	147.9242	141.70	389.49

4.1.1 Physico-chemical variation of properties of water quality parameters of Dal Lake Of 5 years (2010-11 to 2014-15) Average Site And Overall Season Wise Data

pH

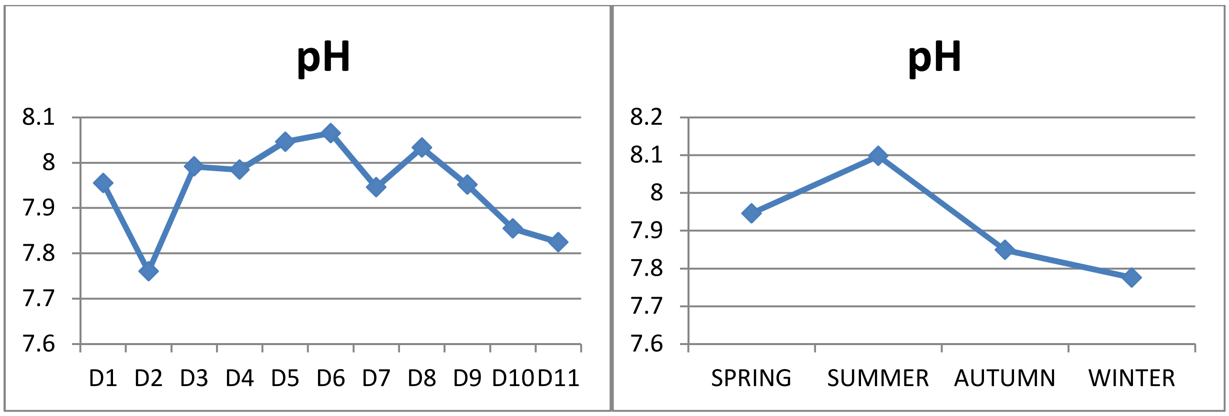


Figure 4.1: 5 year Average spatial and overall seasonal variation of pH

Dal Lake is characterized by alkaline pH values. Maximum 5 year annual average was found at D6 site near Kabootar Khana at 8.09 and the maximum overall seasonal 5 year average was detected in the summer season at 8.06. Minimum 5 year annual average was found at D2 site of Dhobi Ghat area at 7.76 and the minimum overall seasonal 5 year average was detected in the winter season at 7.75 In summer season phytoplankton is more active, it consumes carbon dioxide which makes water less acidic in summer. In winter there is less phytoplankton activity meaning more carbon dioxide and a hence a lower pH.

Conductivity

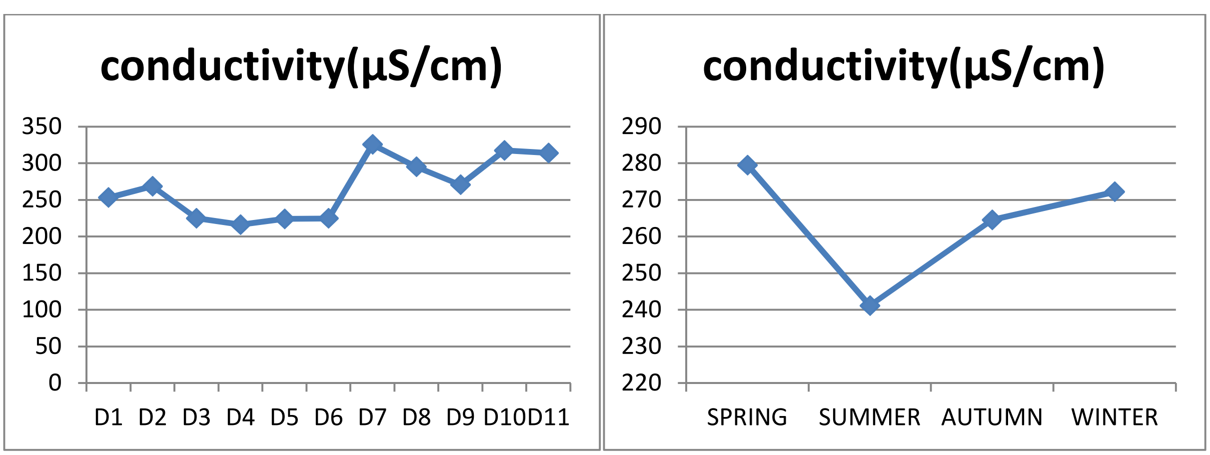


Figure 4.2: 5 year Average spatial and overall seasonal variation of conductivity

Low Conductivity (0 to 200 µS/cm) is an indicator of pristine background conditions. Midrange conductivity (200 to1000 µS/cm) is the typical background for most major freshwater lakes. Conductivity beyond this range could specify that the water is not appropriate for certain class of fish and bugs. High conductivity (1000 to 10,000 µS/cm) is an indicator of saline conditions. Maximum 5 year annual average was found at D7 site near Central site Nigeen at 352 µS/cm. and the maximum overall seasonal 5 year average was detected in the spring season at 279.468 µS/cm. Minimum 5 year annual average was found at D4 site near Nishat pipe line area at 216.11 µS/cm and the minimum overall seasonal 5 year average was detected in the summer season at 241.13 µS/cm. Low value of conductivity reported in summer can be attributed to dilution effect and caused due to melted glacial run-off and precipitation.

Dissolved Oxygen (D.O)

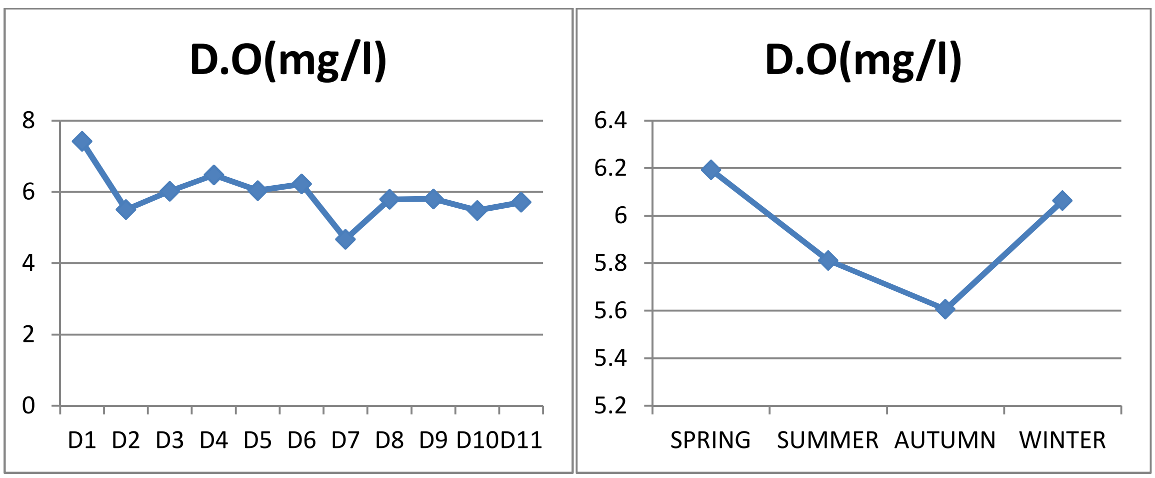


Figure 4.3: 5 year Average spatial and overall seasonal variation of D.O

Dissolved Oxygen has maximum 5 year annual average at site D1 inside the lake near the entry of Telbal Nallah with value of 7.41 mg/l and the maximum overall seasonal average value of 6.19 mg/l is obtained in spring season. Minimum 5 year annual average was found at D7 near central site Nigeen at 4.6 mg/l and the minimum overall seasonal 5 year average was detected in the autumn season at 5.6 mg/l. In summer and autumn dissolved oxygen is usually low because colder liquid is capable of dissolving more gas than warmer. Additionally there is more phytoplankton activity which depletes dissolved oxygen.

Total Alkalinity

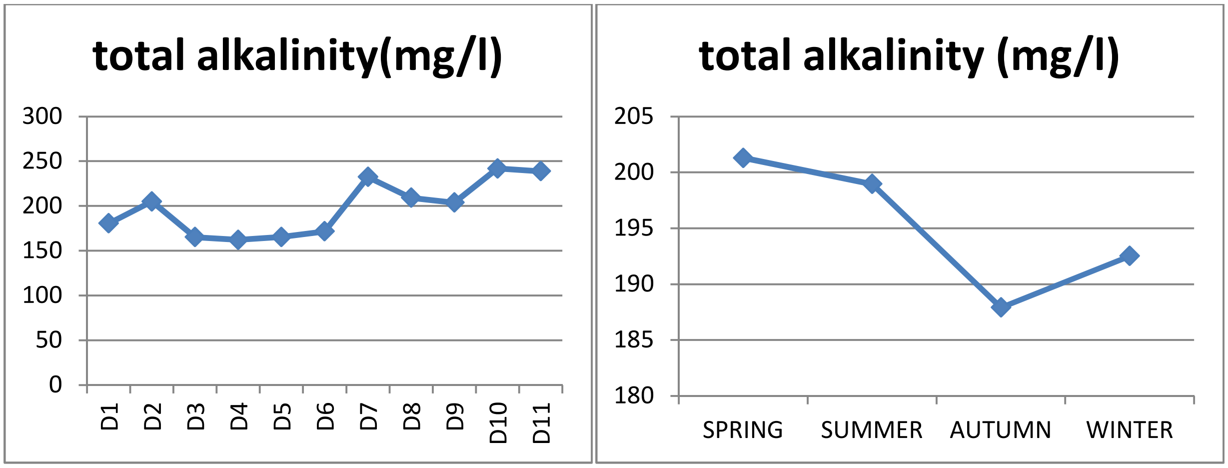


Figure 4.4: 5 year Average spatial and overall seasonal variation of total alkalinity

For total alkalinity, maximum 5 year annual average was found at D10 near outlet site of Hazratbal STP at 241.81 mg/l and the maximum overall seasonal 5 year average was detected in the spring season at 201.19 mg/l. Minimum 5 year annual average was found at D4 site near Nishat pipeline at 162.138 mg/l and the minimum overall seasonal 5 year average was detected in the autumn season at 187.89 mg/l. Moyle et al categorized the lake waters as soft, medium and hard on the basis of total alkalinity values. As per this classification waters having alkalinity up to 40 mg/1 are soft, with 40 – 90 mg/1 medium and above 90 mg/1 as hard. Therefore the water of Dal Lake falls under the hard water type.

Chloride

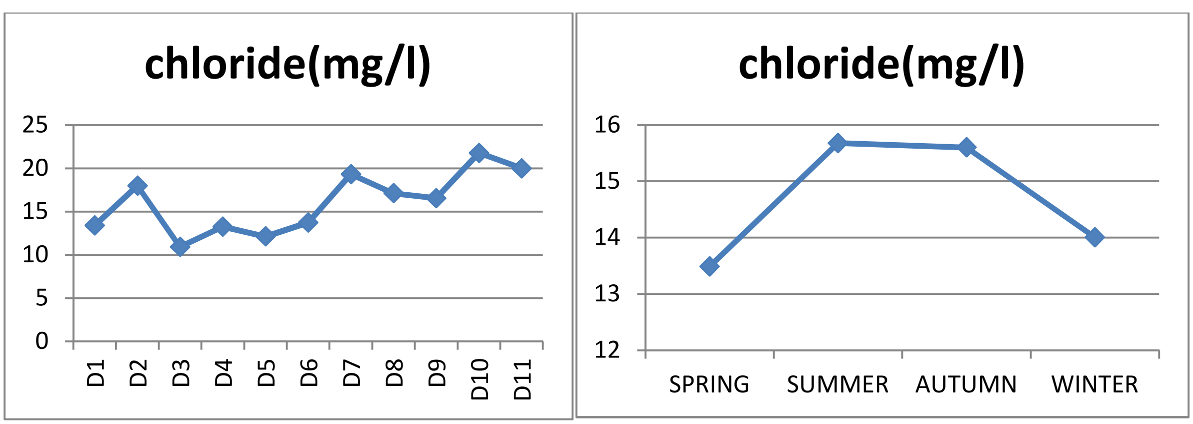


Figure 4.5: 5 year Average spatial and overall seasonal variation of chloride

Maximum 5 year annual average of chloride was found at D10 near outlet site of Hazratbal STP at 21.75 mg/land the maximum overall seasonal 5 year average was detected in the summer season at 15.67 mg/l. Minimum 5 year annual average was found at D3 site near Sona Lank at 10.91 mg/l and the minimum overall seasonal 5 year average was detected in the spring season at 13.48 mg/l. The high chloride value in summer is indicative of fecal and sewage proliferation augmented by high anthropogenic activity.

Calcium and Magnesium

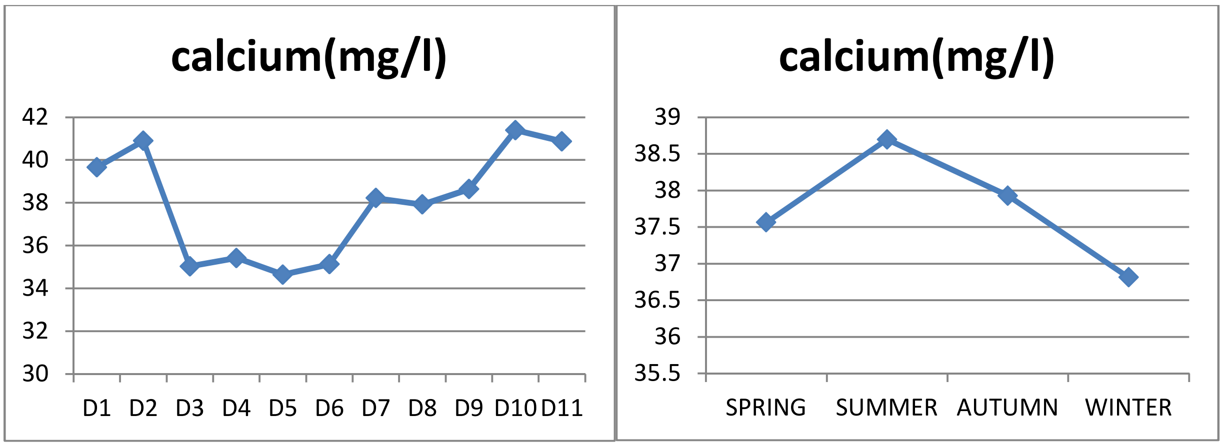


Figure 4.6: 5 year Average spatial and overall seasonal variation of calcium

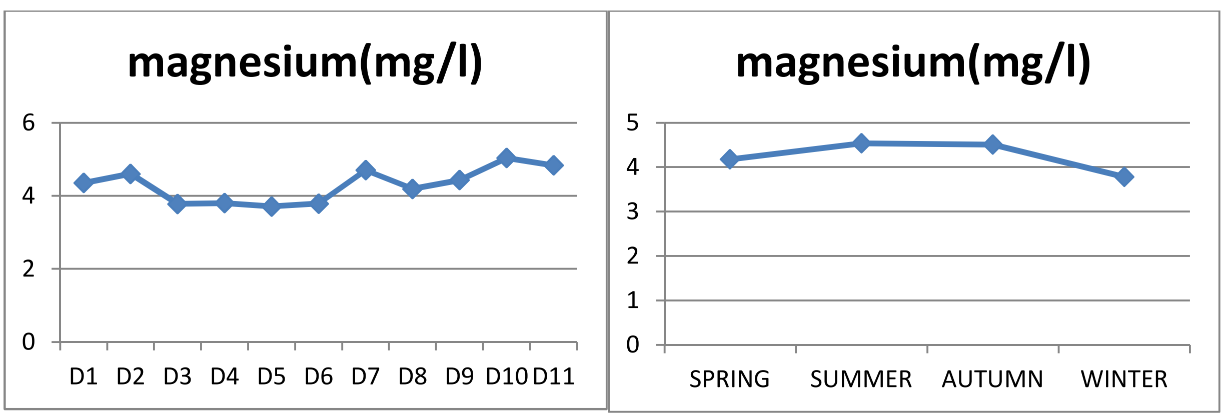


Figure 4.7: 5 year Average spatial and overall seasonal variation of magnesium

The maximum 5 year annual average of calcium was found at D10 near outlet site of Hazratbal STP at 41.39 mg/land the maximum overall seasonal 5 year average was detected in the summer season at 38.69 mg/l. Minimum 5 year annual average was found at D5 site near Char Chinari at 34.63 mg/l and the minimum overall seasonal 5 year average was detected in the winter season at 36.81 mg/l. The quantities of calcium in lake water are due to prevalence of lime rocks in the catchment. Magnesium follows a similar trend. The maximum 5 year annual average of magnesium was found at D10 near outlet site of Hazratbal STP at 5.03 mg/land the maximum overall seasonal 5 year average was detected in the summer season at 4.53 mg/l, minimum 5 year annual average was found at D5 site near Char Chinari at 3.70 mg/l and the minimum overall seasonal 5 year average was detected in the winter season at 3.78 mg/l. The elevated quantities of calcium and magnesium may be attributed to the addition of re-mineralised sewage effluent from the STPs. But still the temporal variation of calcium and magnesium is not that extreme.

Sulphate

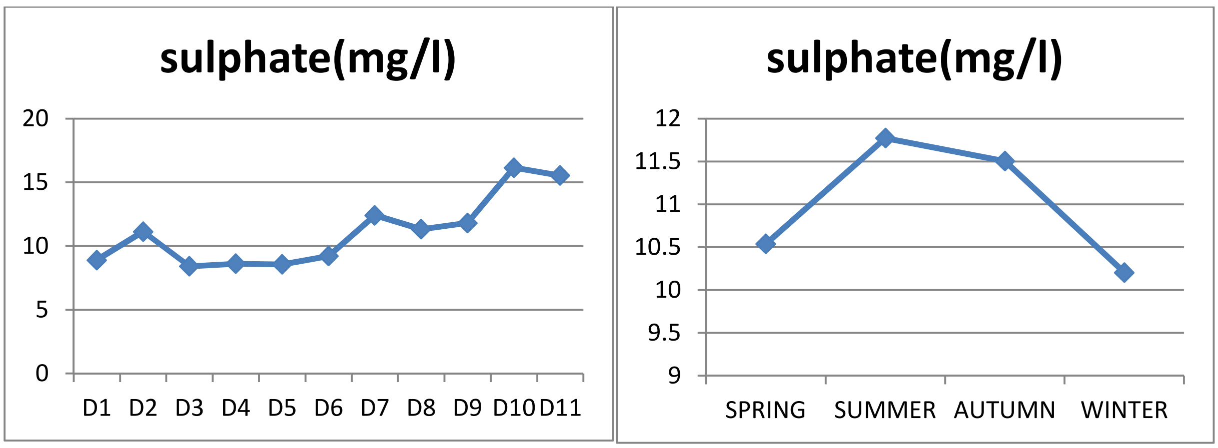


Figure 4.8: 5 year Average spatial and overall seasonal variation of sulphate

The maximum 5 year annual average sulphate was found at D10 near outlet site of Hazratbal STP at 16.15mg/l and the maximum overall 5 year average was detected in the summer season at 11.77 mg/l, minimum 5 year annual average was found at D5 site near Sona lank at 8.41 mg/l and the minimum overall seasonal 5 year average was detected in the winter season at 10.20 mg/l sources of sulphate could be sewage effluent, combustion of fossil fuels (which accounts for the majority of sulphur in the atmosphere), which can return to the surface as sulphate through precipitation or dry deposition and crushed limestone (commonly used in parking lots and road construction).

Nitrate Nitrogen

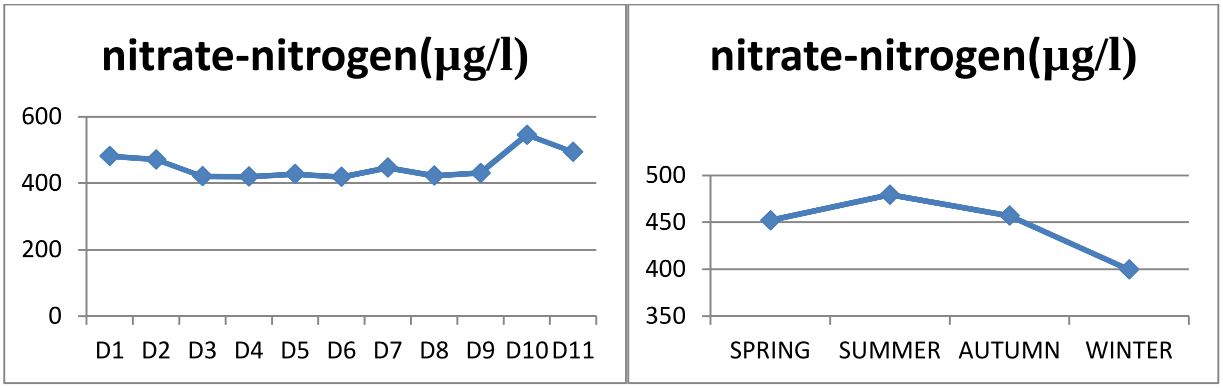


Figure 4.9: 5 year Average spatial and overall seasonal variation of nitrate-nitrogen

Maximum 5 year annual average of nitrate nitrogen was found at D10 near outlet site of Hazratbal STP at 545.62 µg/l and the maximum overall seasonal 5 year average was detected in the summer season at 479.35 µg/l. Minimum 5 year annual average was found at D6 site near Kabootar Khana at 418.86 µg/l and the minimum overall seasonal 5 year average was detected in the spring season at 399.71 µg/l. The high nitrate nitrogen value in summer indicates strong fecal and sewage contamination aided by great anthropogenic activity and the reverse holds true for winter.

Ammonical Nitrogen

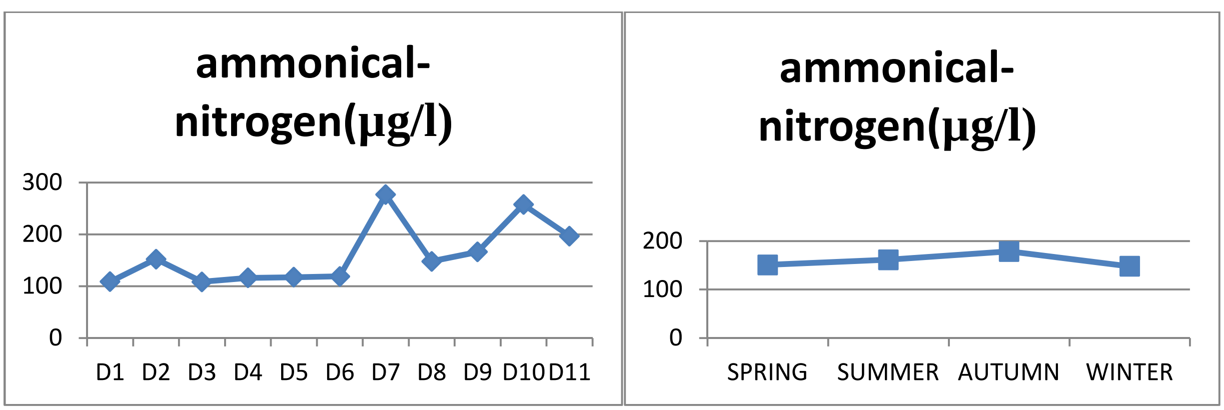


Figure 4.10: 5 year Average spatial and overall seasonal variation of ammonical-nitrogen

Maximum 5 year annual average of ammonical nitrogen was found at D7 near central site Nigeen at 276.55µg/land the maximum overall seasonal 5 year average was detected in the autumn season at 178.59 µg/l. Minimum 5 year annual average was found at D3 site near Sona Lank at 108.16 µg/l and the minimum overall seasonal 5 year average was detected in the winter season at 147.92 µg/l. Higher rates of ammonia concentration during autumn maybe attributed to relatively lower rate of assimilation by the biota. Reduced values in winter are because of lower anthropogenic generation of wastes and waste water.

Ortho Phosphate and Total Phosphate

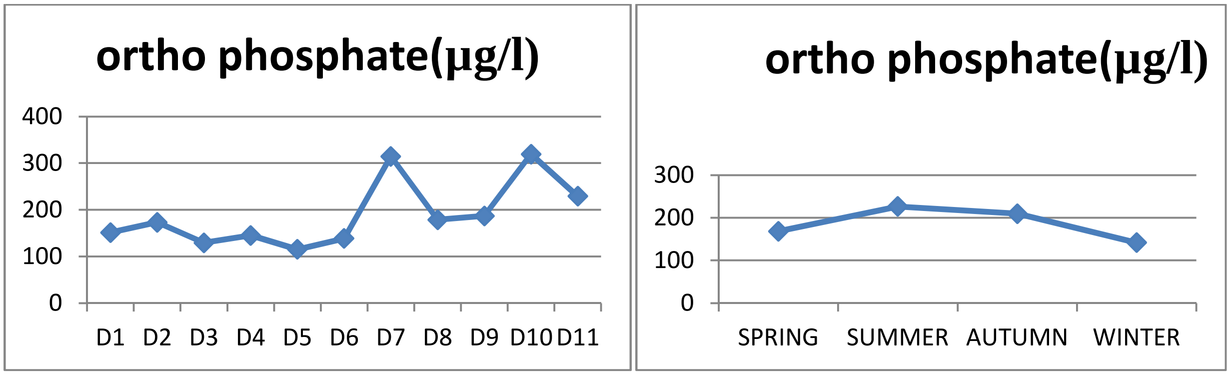


Fig 4.11: 5 year Average spatial and overall seasonal variation of ortho phosphate

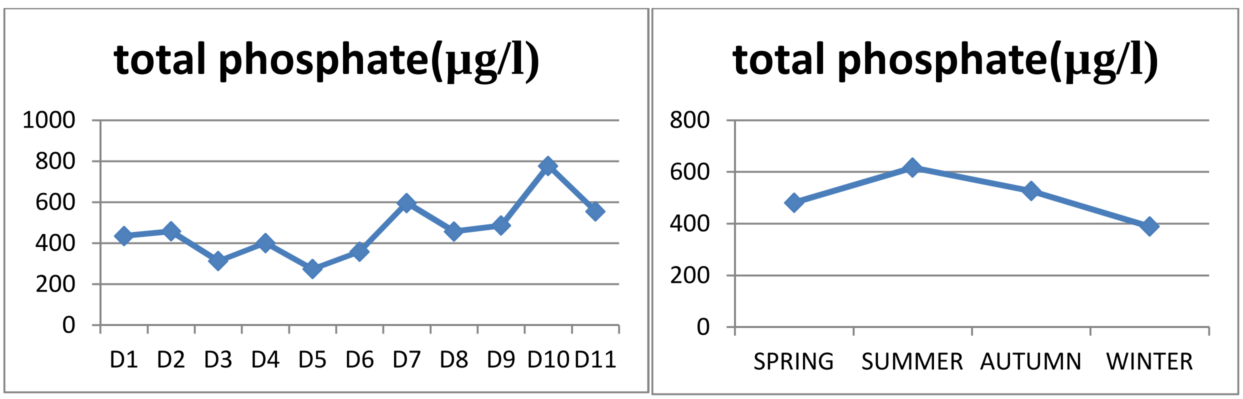


Figure 4.12: 5 year Average spatial and overall seasonal variation of total phosphate

Maximum 5 year annual average of orthophosphate was found at D10 near outlet site of Hazratbal STP at 319.40 µg/l and the maximum overall seasonal 5 year average was detected in the summer season at 226.51 µg/l. Minimum 5 year annual average was found at D5 site near Char Chinari at 115.16 µg/l and the minimum overall seasonal 5 year average was detected in the winter season at 141.69 µg/l. And for total phosphate also maximum 5 year annual average was found at D10 near outlet site of Hazratbal STP at 777.61 µg/l and the maximum overall seasonal 5 year average was detected in the summer season at 617.04 µg/l minimum 5 year annual average was found at D5 site near Char Chinari at 273.87 µg/l and the minimum overall seasonal 5 year average was detected in the winter season at 389.46 µg/l. Sawyer et al (1945) suggested that 0.3 mg/1 of orthophosphate and 0.15 mg/1 of nitrate nitrogen are critical levels beyond which algal bloom may appear indicating cultural eutrophication.

Chemical Oxygen Demand

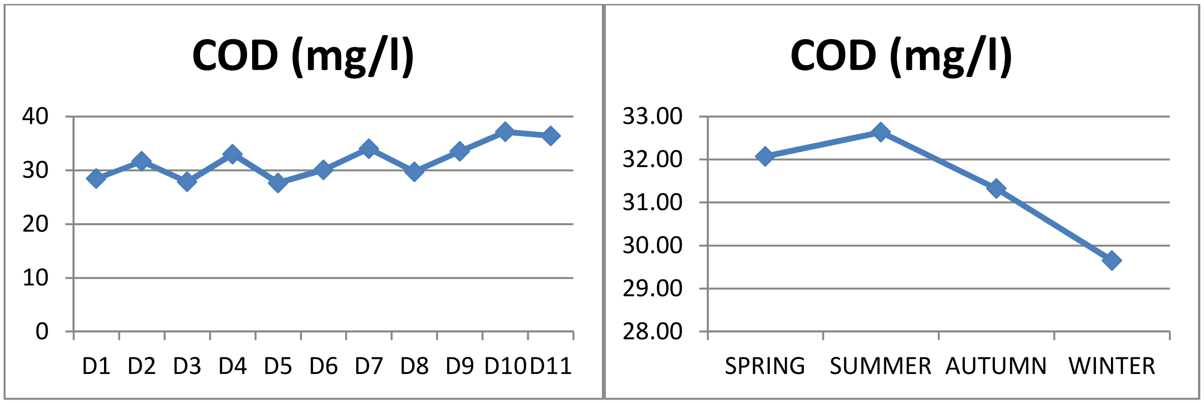


Figure 4.13: 5 year Average spatial and overall seasonal variation of COD

Maximum 5 year annual average of chemical oxygen demand (COD) was found at D10 near outlet site of Hazratbal STP at 37.15 µg/l and the maximum overall 5 year seasonal average was detected in the summer season at 32.63 µg/l. Minimum 5 year annual average was found at at D1 inside the lake near the entry of Telbal Nallah at 28.44 µg/l and the minimum overall seasonal 5 year average was detected in the autumn season at 31.32 µg/l. The high value of COD in every sampling site is found above the permissible limit of WHO (10 ppm), reflect pollution from degradable organic wastes from several sources.

4.2 Results of Season-wise Principal Component Analysis

Principal Component Analysis (PCA) is conducted on the acquired physico-chemical data using Statistical Package For Social Sciences (SPSS) version 20, after fragmentation of data into four sets season wise i.e., Summer(June-July-August) Winter(December-January-February), Autumn(September-October-November) and Spring(March-April-May).

4.2.1 Summer:

Kaiser-Meyer-Olkin (KMO) is an index for contrasting the magnitude of the observed correlation coefficients to the magnitude of the partial correlation coefficients. A value closer to KMO measure of 1 indicates a sizeable sampling adequacy (0.8 and higher are great, 0.7 is acceptable, 0.6 is mediocre, less than 0.5 is unacceptable). Practically large values are needed for a good factor analysis. Smaller KMO values indicate that a factor analysis of the variables may not be a good idea.

Table 4.3:KMO and Bartlett's Test (Summer)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.795
Bartlett's Test of Sphericity	Approx. Chi-Square	811.302
	df	78
	Sig.	.000

As the measure is 0.795 so, this shows that the sampling size is satisfactory and the correlation between parameters is normally acknowledged.

Principal Component analysis requires that the probability associated with Bartlett's Test of sphericity be less than the level of significance. The probability associated with the Bartlett test (Sig = 0) is <0.001, which satisfies this requirement.

4.2.1.1 Scree Plot

The inspection of the Scree plot as displayed in figure (4.13) delivers a graphic of the total variance pertaining to each factor; the steep slope shows the biggest factors.

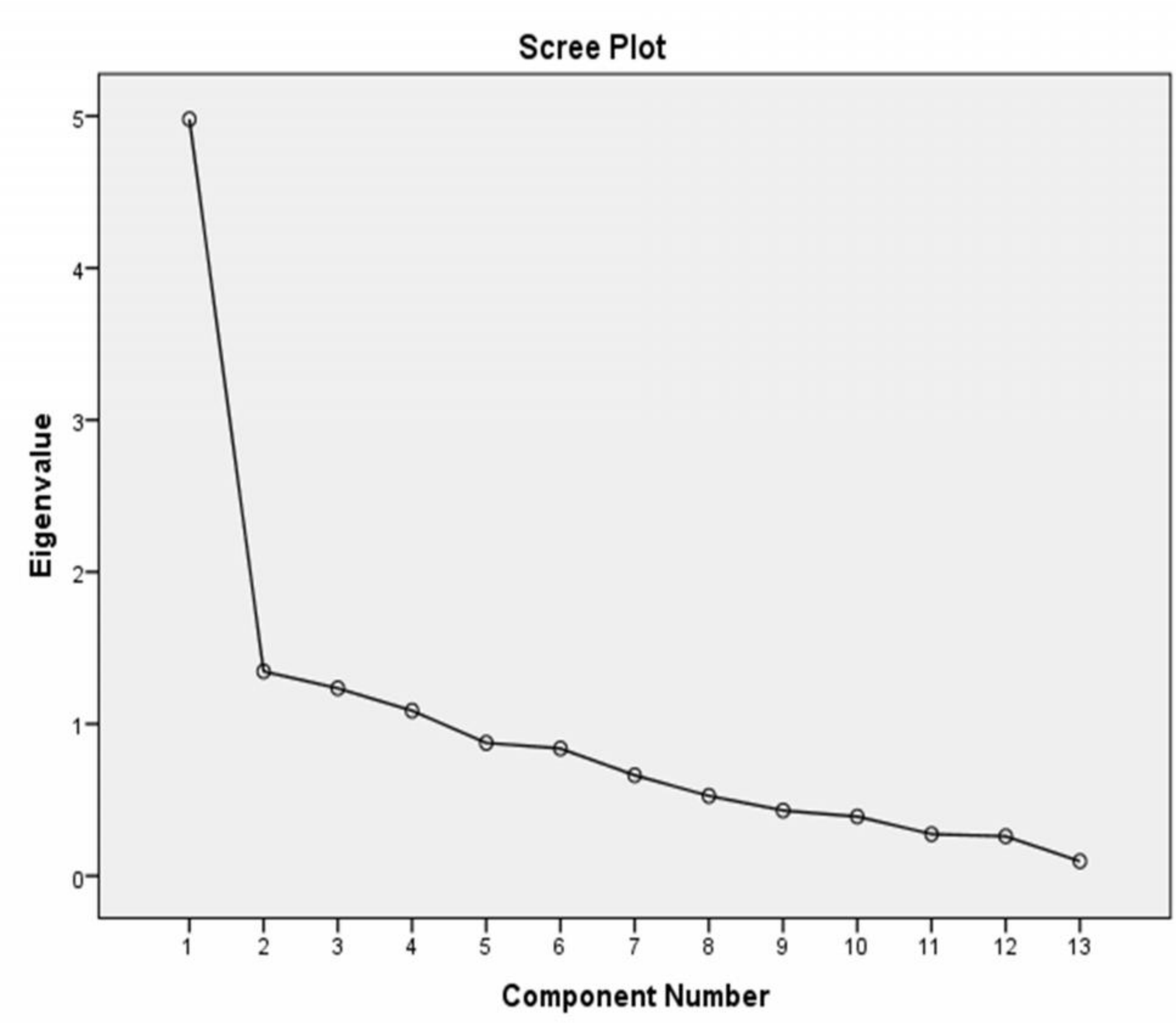


Figure 4.14: Scree plot for Summer

Here it is evident from the figure that there are two dominant factors of the total variance of the hydrochemistry of water.

4.2.1.2 Total Variance Explained:

The Principal Component analysis resulted in two Principal Components constituting 48.653 % of the total variance in the hydrochemistry of the study area as shown in the table (4.4). The first Principal Component (PC1) accounts for about 33.644 %. Principal Component two (PC2) accounts for about 15.009 %.

Table 4.4:Total Variance Explained (Summer)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.979	38.303	38.303	4.979	38.303	38.303	4.374	33.644	33.644
2	1.346	10.350	48.653	1.346	10.350	48.653	1.951	15.009	48.653
3	1.234	9.495	58.148						
4	1.087	8.363	66.511						
5	.875	6.731	73.242						
6	.838	6.446	79.688						
7	.662	5.093	84.781						
8	.526	4.048	88.828						
9	.430	3.310	92.139						
10	.390	3.003	95.142						
11	.275	2.113	97.255						
12	.260	2.003	99.259						
13	.096	.741	100.000						

Extraction Method: Principal Component Analysis.

4.2.1.3 Component Matrix

From the component matrix table, it is apparent that most variables have relatively high loadings only on one component and therefore varimax rotation is done to seek some structure of loading which is called “simple structure” Rotation does not change the position of variables relative to each other. i.e. correlation between variables and factors are being preserved. But factors remain orthogonal to each other.

Table: 4.5 Component Matrix (Summer)

	Component	
	1	2
pH	-.056	-.136
conductivity	.505	.477
DO	-.635	.241
total alkalinity	.584	.490
chloride	.748	.256
calcium	.646	.105
magnesium	.715	-.008
sulphate	.778	.010
COD	.552	-.195
nitrate nitrogen	.129	.572
ammonical nitrogen	.699	.014
orthophosphate	.701	-.444
total phosphate	.763	-.403

Extraction Method: Principal Component Analysis.

Table: 4.6 Rotated Component Matrix (Summer)

	Component	
	1	2
pH	.004	-.147
conductivity	.266	.642
DO	-.678	-.039
total alkalinity	.333	.686
chloride	.578	.539
calcium	.547	.360
magnesium	.656	.285
sulphate	.706	.327
COD	.583	.047
nitrate nitrogen	-.116	.575
ammonical nitrogen	.632	.298
orthophosphate	.822	-.119
total phosphate	.861	-.056

Rotation Method: Varimax

The first Principal Component PC1 shows a significant loading with orthophosphate, total phosphate, ammonical nitrogen, sulphate, calcium, magnesium, cod, chloride and a negative loading with dissolved oxygen. PC2 shows significant loading with, nitrate, total alkalinity and electrical conductivity. Positive loadings of COD, ammonical nitrogen, chloride and phosphates are associated with anthropogenic pollution. Negative loading of DO in PC1 with other parameters like phosphates and ammonical nitrogen occurs because high levels of dissolved organic matter consume large amounts of oxygen for decomposition. Sources of phosphates, nitrates and chloride may be traced to agricultural run-off, generation of waste water/sewage from the hospitality sector (hotels and houseboats). Calcium, magnesium and sulphates are naturally present in lakes and are representative of catchment geology and would thus exhibit noteworthy contribution to total variance in all seasons. Their proliferation may be due to the anthropogenic activities in the lake catchment.

4.2.2 Winter:

In this case the KMO value is 0.815 indicating the magnitude of the data is satisfactory and the correlation between parameters is generally accepted.

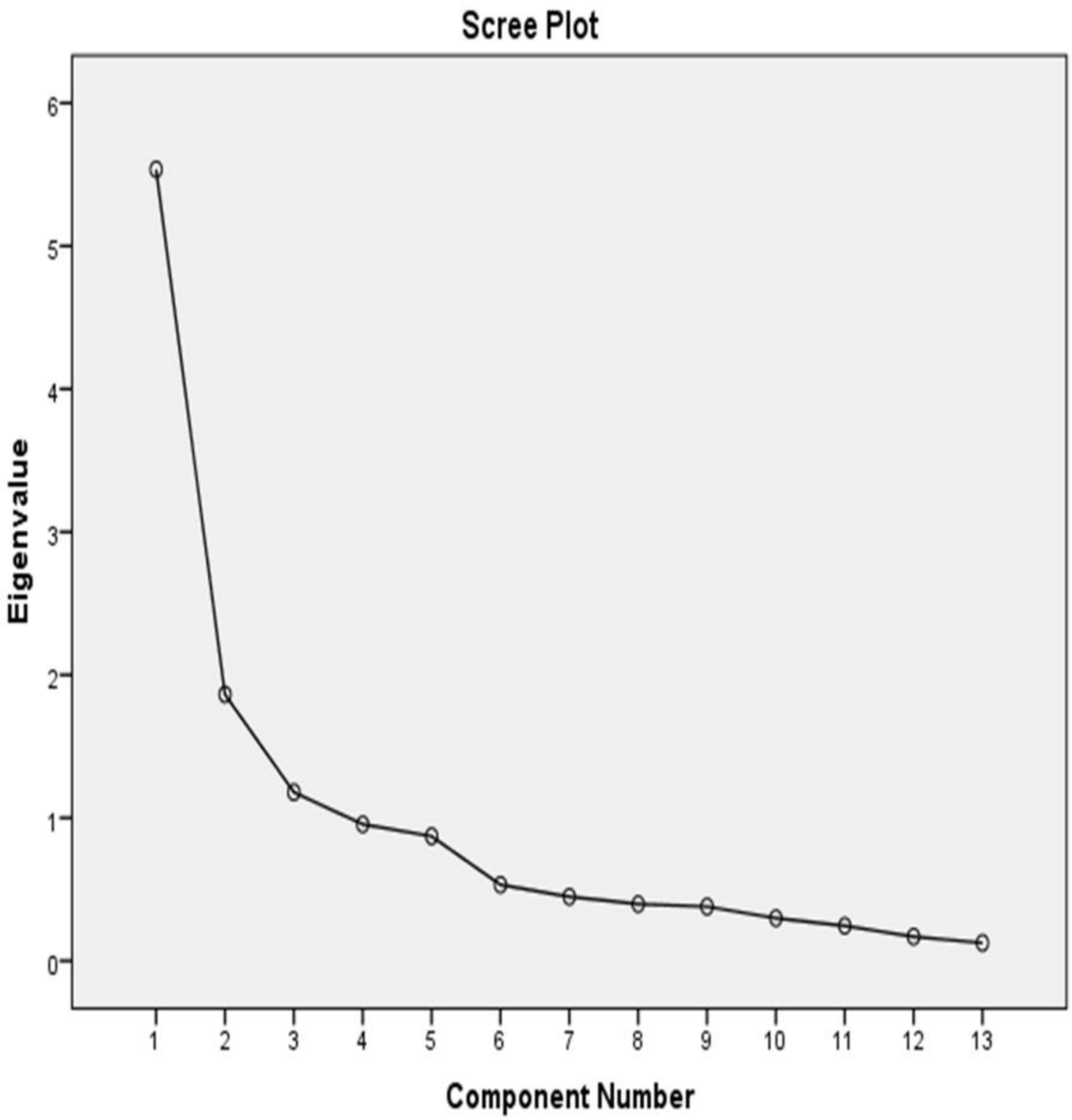
Also the Bartlett's Test of Sphericity has Sig=.000 which is the necessary value for running Principal Component analysis.

Table: 4.7 KMO and Bartlett's Test (Winter)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.815
Bartlett's Test of Sphericity	Approx. Chi-Square	956.695
	Df	78
	Sig.	.000

4.2.2.1 Scree Plot

The examination of the Scree plot as shown in figure (4.14) provides a visual of the total variance associated with each factor; the steep slope shows the biggest factors.



<u>Figure 4.15: Scree plot for Winter</u>

The scree plot shows that only two Eigen values dominate the total variance.

4.2.2.2 Total Variance Explained:

The Principal Component analysis occasioned in two Principal Components constituting 56.921 % of the total variance in the hydrochemistry of the study region as shown in the table (4.8). The first Principal Component (PC1) comprises 31.667 %. Principal Component two (PC2) accounts for about 25.254%.

Table 4.8: Total Variance Explained (Winter)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.536	42.585	42.585	5.536	42.585	42.585	4.117	31.667	31.667
2	1.864	14.336	56.921	1.864	14.336	56.921	3.283	25.254	56.921
3	1.180	9.073	65.994						
4	.955	7.348	73.342						
5	.871	6.704	80.046						
6	.532	4.092	84.138						
7	.448	3.449	87.587						
8	.397	3.052	90.639						
9	.379	2.918	93.557						
10	.299	2.299	95.856						
11	.245	1.884	97.740						
12	.169	1.297	99.037						
13	.125	.963	100.000						

Extraction Method Principal Component Analysis

4.2.2.3 Component Matrix

So as to extract a simple structure from the component matrix orthogonal rotation (varimax) is applied to the component matrix.

Table:4.9 Component Matrix (Winter)

	Component	
	1	2
pH	-.068	.359
conductivity	.673	.488
DO	-.426	.519
total alkalinity	.671	.421
Chloride	.789	-.215
Calcium	.790	.247
Magnesium	.769	.368
Sulphate	.548	-.587
COD	.357	.257
nitate nitrogen	.612	.344
ammonical nitrogen	.716	-.407
ortho phosphate	.752	-.289
total phosphate	.854	-.171

Extraction Method: Principal Component Analysis.

Table 4.10:Rotated Component Matrix (Winter)

	Component	
	1	2
pH	.170	-.323
conductivity	.830	.036
DO	-.011	-.671
total alkalinity	.787	.088
Chloride	.484	.658
Calcium	.773	.298
magnesium	.831	.190
Sulphate	.064	.801
COD	.439	.020
nitrate nitrogen	.693	.111
ammonical nitrogen	.307	.764
ortho phosphate	.409	.694
total phosphate	.563	.665

Rotation Method: Varimax

PC1 shows a significant loading with electrical conductivity, total alkalinity, calcium, magnesium, and nitrate nitrogen .Electrical conductivity is an indicator of nutrient enrichment Awasthi et al had the same findings and has attributed it to the elevated levels of total dissolved solids in the winter season due to the decreased water levels (water levels are generally highest during summer because of melted glacial inflow) which results in increased concentration of different salts in water. PC2 shows significant loadings with chloride, sulphate, ammonical nitrogen and phosphates. Positive loadings of calcium, magnesium and sulphate relate to catchment geology. Negative loading of DO in PC2 with positive loading of other parameters like ammonical nitrogen and phosphates shows inverse relationship due to nutrient decomposition by phytoplankton.

4.2.3 Autumn:

The KMO measure is 0.816, this conveys that the size of the data available is satisfactory and the correlation between parameters is generally accepted.

The Bartlett's Test of Sphericity has Sig=.000 which is the desirable value for running Principal Component analysis.

Table 4.11:KMO and Bartlett's Test (Autumn)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.816
Bartlett's Test of Sphericity	Approx. Chi-Square	798.574
	Df	78
	Sig.	.000

4.2.3.1 Scree Plot

The inspection of the Scree plot as revealed in figure (4.15) provides a graphic of the total variance associated with each factor; the steep slope shows the biggest factors.

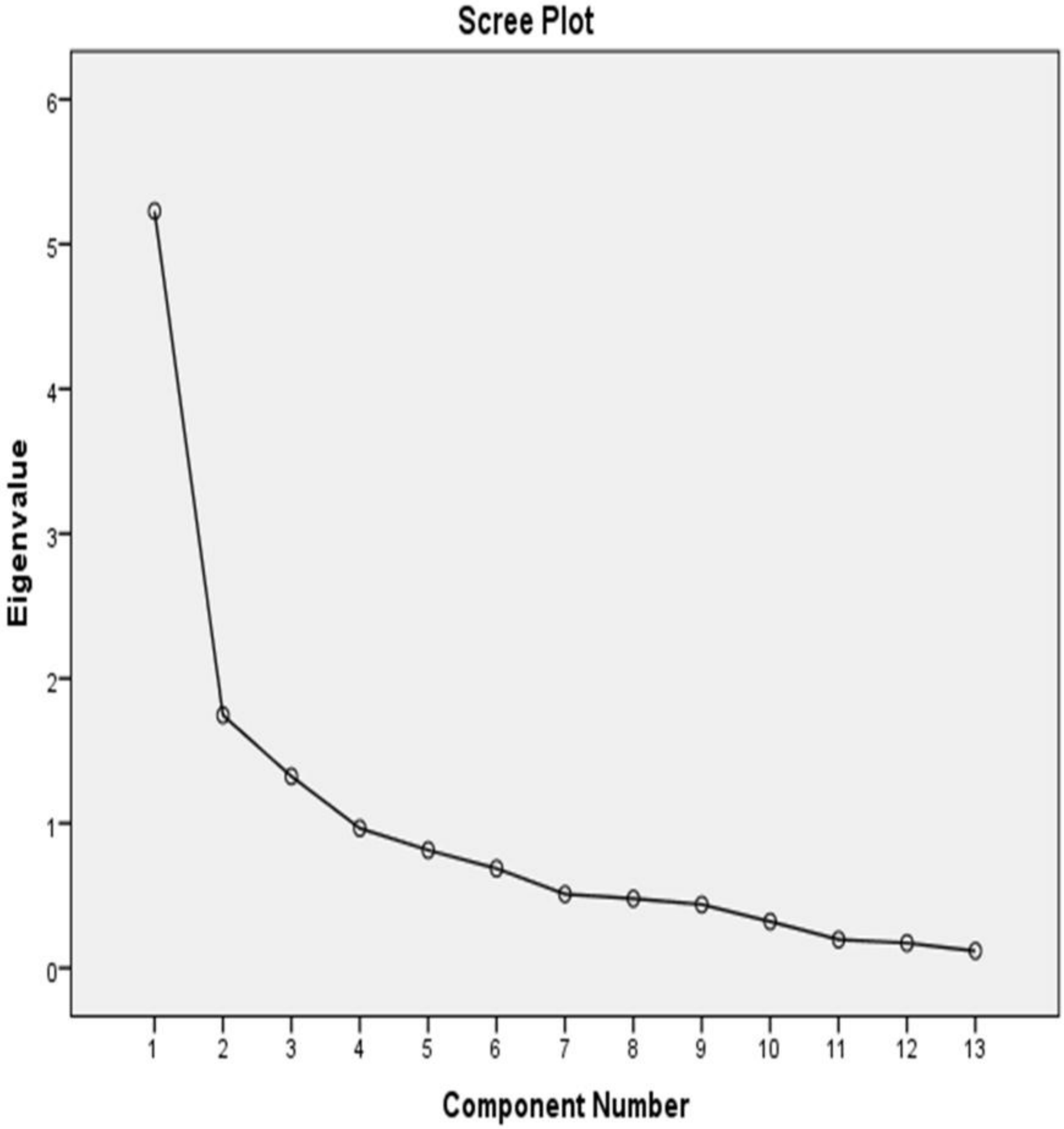


Figure 4.16: Scree plot for Autumn

The scree plot shows that only three Eigen values dominate the total variance.

4.2.3.2 Total Variance Explained:

The Principal Component analysis occasioned in three Principal Components constituting 63.830% of the total variance in the hydrochemistry of the study region as revealed in the table (4.12). The PC1 comprises 32.497%. PC2 accounts for about 16.406% and PC3 accounts for 14.927%.

Table 4.12 Total Variance Explained (Autumn)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.228	40.217	40.217	5.228	40.217	40.217	4.225	32.497	32.497
2	1.746	13.431	53.648	1.746	13.431	53.648	2.133	16.406	48.903
3	1.324	10.182	63.830	1.324	10.182	63.830	1.940	14.927	63.830
4	.965	7.425	71.255						
5	.814	6.262	77.517						
6	.687	5.285	82.802						
7	.510	3.923	86.725						
8	.479	3.688	90.412						
9	.439	3.373	93.785						
10	.321	2.470	96.255						
11	.196	1.509	97.764						
12	.172	1.326	99.090						
13	.118	.910	100.000						

Extraction Method: Principal Component Analysis.

4.2.3.3 Component Matrix

In order to extract a simple structure from the component matrix orthogonal rotation (varimax) is applied to the component matrix.

Table 4.13: Component Matrix (Autumn)

	Component		
	1	2	3
pH	-.100	-.183	-.424
Conductivity	.686	-.109	.268
DO	-.344	.042	.676
total alkalinity	.726	-.076	.313
Chloride	.852	-.158	-.174
Calcium	.810	-.177	.104
Magnesium	.778	-.162	.208
Sulphate	.717	-.021	-.447
COD	.473	-.483	.179
nitrate nitrogen	.661	-.041	.224
ammonical nitrogen	.730	.074	-.382
ortho phosphate	.418	.836	.050
total phosphate	.484	.819	.055

Extraction Method: Principal Component Analysis.

Table 4.14: Rotated Component Matrix (Autumn)

	Component		
	1	2	3
pH	-.191	-.238	.360
Conductivity	.729	.148	.034
DO	-.041	-.023	-.758
total alkalinity	.770	.196	.006
Chloride	.713	.123	.508
Calcium	.793	.113	.238
Magnesium	.802	.124	.129
Sulphate	.444	.186	.695
COD	.638	-.281	.056
nitrate nitrogen	.667	.200	.059
ammonical nitrogen	.448	.284	.634
ortho phosphate	.095	.929	.066
total phosphate	.160	.935	.089

Rotation Method: Varimax

PC1 shows a significant loading with electrical conductivity, total alkalinity, chloride, calcium, magnesium, cod and nitrate nitrogen .Electrical conductivity remains significant for the same reason as mentioned earlier.PC2 shows significant loadings with orthophosphate and total phosphate.PC3 shows positive loadings with sulphate, ammonical nitrogen and a negative loading with dissolved pH again depicting an inverse relationship. This is because of more restrained phytoplankton activity as compared to summer season leading to less consumption of ammonical nitrogen and also more dissolved carbon dioxide is available which lowers pH.

4.2.4 Spring:

The KMO measure is .724 which tells us that the size of the data existing is satisfactory and the correlation among parameters is commonly acknowledged.

The Bartlett's Test of Sphericity has Sig=.000 which is the acceptable value for running Principal Component analysis.

Table 4.15: KMO and Bartlett's Test (Spring)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.724
Bartlett's Test of Sphericity	Approx. Chi-Square	757.700
	Df	78
	Sig.	.000

4.2.4.1 Scree Plot

The inspection of the Scree plot as revealed in figure (4.16) provides a pictorial of the total variance associated with all factors; the steep slope shows the prime factors.

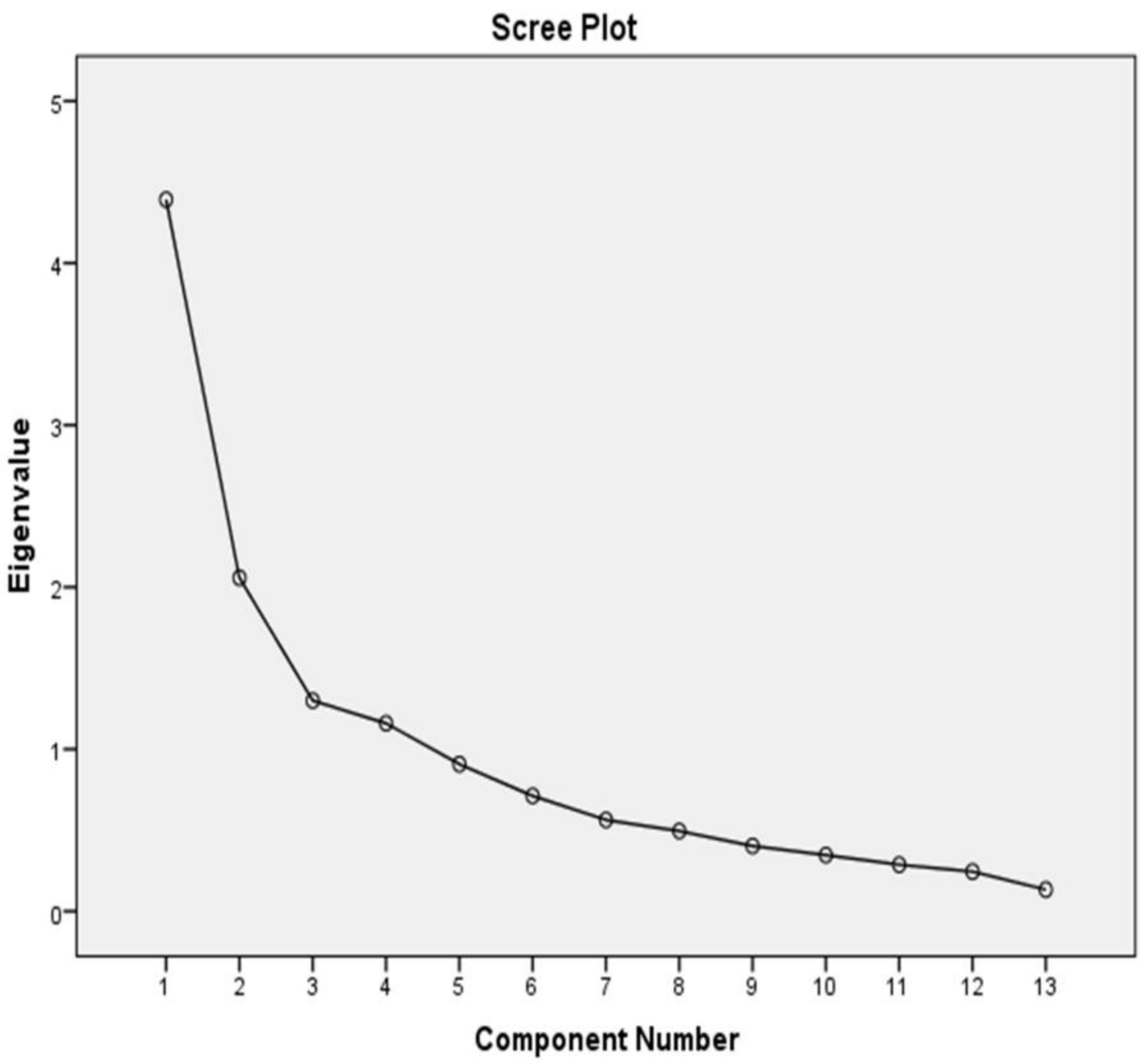


Figure 4.17: Scree plot for Spring

The scree plot shows that four Eigen values dominate the total variance.

4.2.4.2 Total Variance Explained:

The Principal Component analysis occasioned in four Principal Components accounting for 68.535% of the total variance in the hydrochemistry of the study area as shown in the table (4.16). The PC1 accounts for 19.12%. PC2 for 17.38%, PC3 for 16.34%, PC4 for 15.69%.

Table 4.16: Total Variance Explained (Spring)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.392	33.785	33.785	4.392	33.785	33.785	2.486	19.121	19.121
2	2.058	15.830	49.615	2.058	15.830	49.615	2.260	17.384	36.505
3	1.300	9.998	59.613	1.300	9.998	59.613	2.124	16.340	52.845
4	1.160	8.922	68.535	1.160	8.922	68.535	2.040	15.690	68.535
5	.907	6.980	75.515						
6	.712	5.474	80.989						
7	.563	4.335	85.324						
8	.495	3.807	89.130						
9	.402	3.095	92.225						
10	.346	2.662	94.887						
11	.287	2.208	97.095						
12	.245	1.881	98.976						
13	.133	1.024	100.000						

Extraction Method: Principal Component Analysis.

4.2.4.3 Component Matrix

So as to extract a simple structure from the component matrix orthogonal rotation (varimax) is applied to the component matrix as follows.

Table 4.17: Component Matrix (Spring)

	Component			
	1	2	3	4
pH	-.302	.621	-.048	.087
conductivity	.476	.525	-.278	.003
DO	-.521	.191	.371	.517
total alkalinity	.558	.525	-.359	.029
chloride	.687	-.289	-.059	.100
calcium	.744	-.031	.003	.497
magnesium	.617	-.367	.126	.478
sulphate	.755	-.189	-.146	-.004
COD	.305	-.316	.655	-.073
nitrate nitrogen	.459	.568	.141	.317
ammonical nitrogen	.572	-.447	-.375	-.168
ortho phosphate	.645	.275	.426	-.397
total phosphate	.685	.365	.377	-.327

Extraction Method: Principal Component Analysis.

Table 4.18: Rotated Component Matrix (Spring)

	Component			
	1	2	3	4
pH	-.345	.403	-.447	-.075
conductivity	.075	.729	.136	.154
DO	.026	-.157	-.810	-.178
total alkalinity	.133	.801	.204	.124
chloride	.583	.084	.437	.179
calcium	.814	.334	.100	.131
magnesium	.856	-.040	.137	.087
sulphate	.505	.216	.526	.220
COD	.335	-.431	-.014	.574
nitrate nitrogen	.327	.609	-.281	.311
ammonical nitrogen	.336	.021	.763	-.017
ortho phosphate	.083	.232	.177	.859
total phosphate	.119	.350	.143	.833

Rotation Method: Varimax

PC1 shows a significant loading with chloride, calcium and magnesium. PC2 shows significant loadings with conductivity and nitrate nitrogen. Again high conductivity reading may be caused by high concentration of dissolved solids at lower water levels. PC3 shows positive loadings with sulphate, ammonical nitrogen and a negative loading with dissolved oxygen and pH. This can again be attributed to the opposite relationship between phytoplankton proliferation and availability of dissolved oxygen. More phytoplankton activity means lesser available ammonical nitrogen and vice versa. Thus when dissolved oxygen decreases ammonical nitrogen content increases. PC4 has strong loading with COD and the phosphate compounds.

4.3 Results of Cluster analysis:

4.3.1 Dendogram For Sampling Sites

A hierarchical cluster analysis (HCA) using Ward Linkage by way of SPSS version 20 was performed to highlight the spatial inter-relationships and similarities between the sampling locations considered in the lake, based on the 5 year average physico chemical data from year 2010-11 to 2014-15.

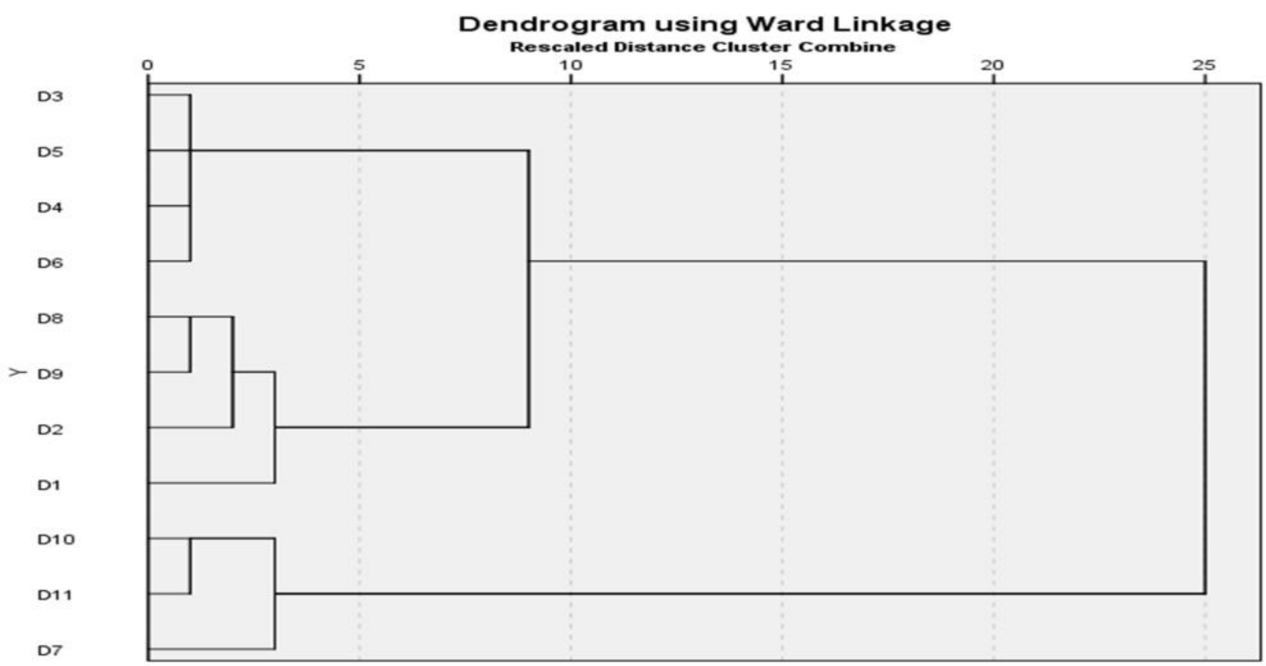


Figure 4.18: Sampling Site Dendogram

The Dendogram shows that that the sampling locations have been clustered into four groups as per the following schedule:

Table 4.19: Cluster Membership (Site-wise)

Case	4 Clusters
1:D1	4
2:D2	2
3:D3	3
4:D4	3
5:D5	3
6:D6	3
7:D7	1
8:D8	2
9:D9	2
10:D10	1
11:D11	1

From the table it is clear that sites D7, D10 and D11 corresponding to sampling locations near Central site Nigeen, Outlet site of Hazratbal STP, and Outlet site of Habak STP respectively have been grouped together. These are the sites with the highest nutrient and pollution levels due to the anthropogenic nutrient proliferation from the various houseboats at Nigeen and the sewage disposal from STPs at Habak and Hazratbal.

The second cluster pertains to sites D2, D8 and D9 which represents sampling locations near Dhobi Ghat area, Saderabal Area and Pokhribal area respectively. All three areas are proximate to high density population centres and thus receive nutrient rich effluents from the same.

The third group includes sites D3, D4, D5 and D6 referring to locations near Central site near Sona lank, Near Nishat Pipe line bund, Central site near Char Chinari and Near Kabootar Khana. Sonilank and Char Chinari are tiny islands within the lake which attract lots of tourists and consequently contribute to undesirable nutrient enrichment. The other two sites are peripheral sites near the shore of the lake.

The fourth group includes only a singular site D1which marks location inside lake near the entry of Telbal Nallah. This is supposed to reflect the water quality at the entry of the Dal Lake but it is also prone to nutrient input from the nearby dwellings.

4.3.2 Dendogram For The Four Seasons

Another hierarchical cluster analysis (HCA) using Ward Linkage by way of SPSS version 20 was conducted to depict the temporal inter-relationships and similarities between the four weather seasons prevailing in the lake on the basis of the acquired physico-chemical data (5 year average data from year 2010-11 to 2014-15).

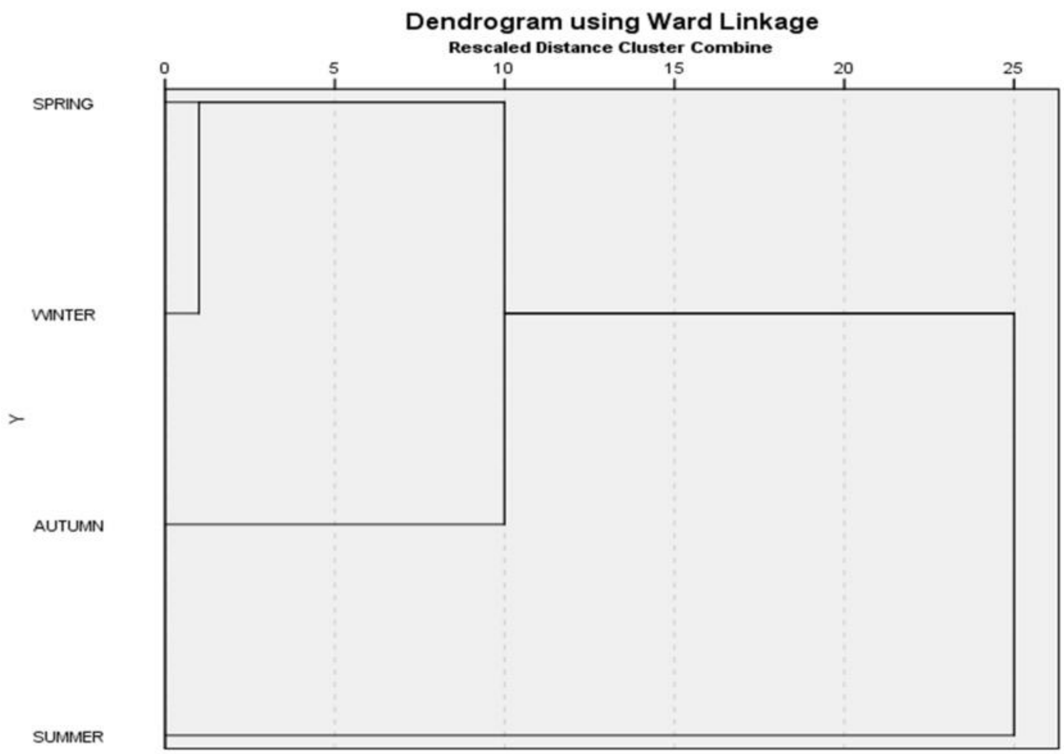


Figure 4.19: Seasonal Dendogram

The dendogram shows that the hydro-chemical behaviour of lake is most similar during spring and winter perhaps because of the comparable metrological conditions, followed by Autumn but albeit at a much higher dissimilarity than between that of the preceding two seasons. Summer is most dissimilar to all other seasons because of the high anthropological activities and consequent nutrient loadings and also high biological activity of phytoplankton due to elevated temperatures.

4.4 Results of Water Quality Index:

Water Quality Index (WQI) was developed using Equations vide (1) to (5).

4.4.1 Spatial WQI

Year wise Average Annual WQI at all sampling sites for the period between 2010-11 to 2014-15 is determined in addition to the 5 year average WQI for the same, for a longitudinal assessment using weighted arithmetic methodology.

Table 4.20: Calculation for the standard permissible values and the unit weights (all units are in mg/l except for pH; and conductivity which is in µS/cm)

Parameter	Standard Permissible Value(S) (BIS)	1/S	K=1/ Σ(1/S)	Unit Weight(W=K/S)
pH	8.5	0.117647	2.195216437	0.258261
conductivity	300	0.003333	2.195216437	0.007317
D.O	5	0.2	2.195216437	0.439043
total alkalinity	200	0.005	2.195216437	0.010976
chloride	250	0.004	2.195216437	0.008781
calcium	75	0.013333	2.195216437	0.02927
magnesium	30	0.033333	2.195216437	0.073174
sulphate	150	0.006667	2.195216437	0.014635
COD	20	0.05	2.195216437	0.109761
nitrate	45	0.022222	2.195216437	0.048783
SUM		**0.455536**		**1**

Table 4.21: Annual average site-wise WQI for all locations from 2010-11 to 2014-15

	Year Wise Average Annual WQI At The Sampling Locations				
Sampling Site	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**
D1=Near entry of Telbal Nallah	67.43596	65.7169	66.69034	73.7852	70.24446
D2=Dhobi Ghat area	75.59513	72.1606	72.72645	78.6694	83.00186
D3=Central site near Sonilank	74.97776	69.1747	73.1116	78.5089	80.65831
D4=Near Nishat Pipe line bund	77.51827	73.1701	68.91635	79.1895	83.0373
D5=Central site near Char Chinari	74.5204	75.054	70.16735	79.5311	80.50517
D6=Near Kabootar Khana	74.97827	77.0118	73.36529	79.9144	78.62106
D7=Central site Nigeen	74.4705	75.0539	80.68121	92.5394	93.41624
D8=Saderabal Area	78.13776	72.4651	75.5825	82.9307	82.75324
D9=Pokhribal area	77.08522	73.7386	76.01923	84.7141	84.96498
D10=Outlet site of Hazratbal STP	83.97436	77.1162	74.90788	85.7436	86.81048
D11=Outlet site of Habak STP	79.01196	77.3184	76.30596	81.0563	83.36011

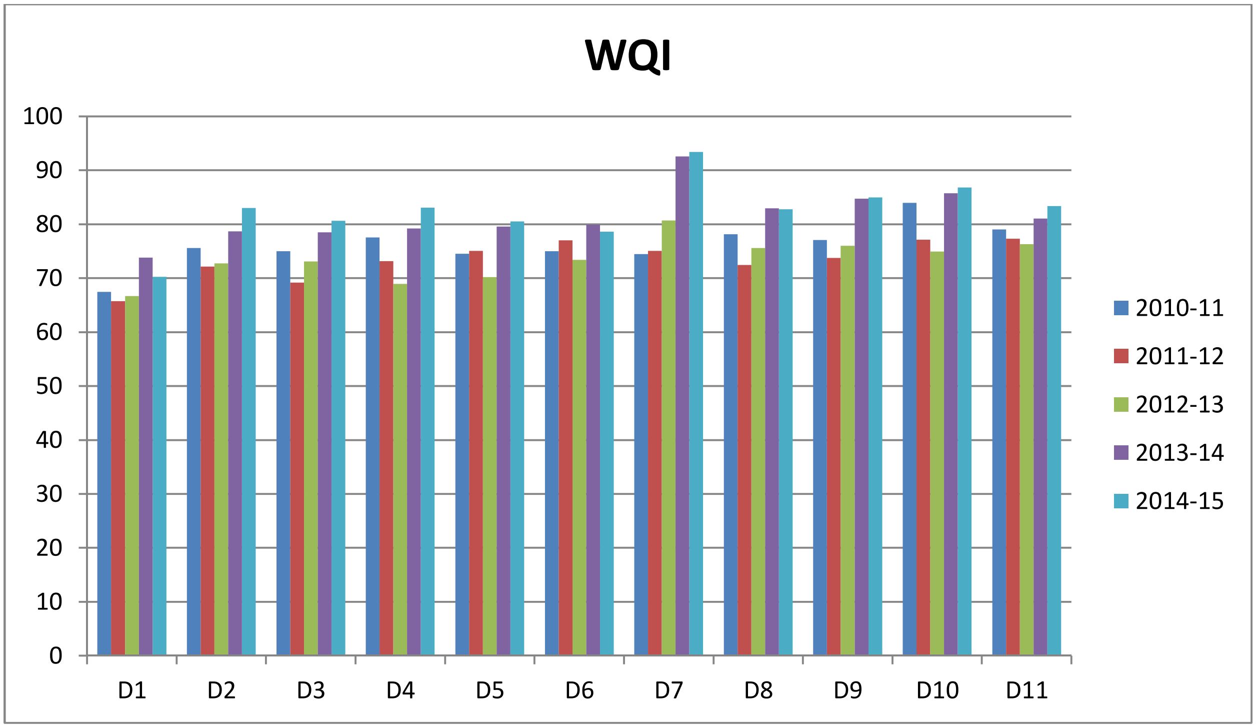


Figure 4.20: Year Wise Average Annual WQI At The Sampling Locations

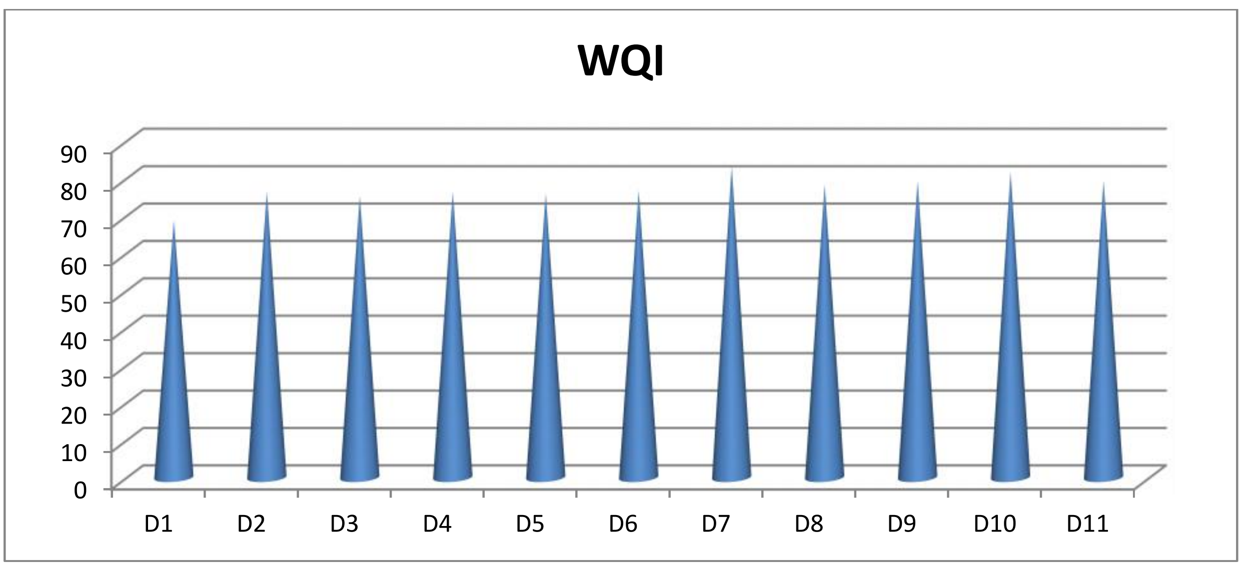


Figure 4.21: 5 Year Average WQI at the Sampling Locations

The calculated annual average site-wise WQI for all locations for the period 2010-11 to 2014-15 gives us a reasonable idea with regards to the water quality characteristics prevailing at various locations of Dal Lake. It is evident from table (4.21), that the site D7 corresponding to Central site Nigeen with WQI value reaching **93.41** in the year 2014-15, is the most polluted site in the lake under consideration, followed closely by STPs outlet sites of Hazratbal (**$WQI_{2014\text{-}15}$=86.81**) and Habak **($WQI_{2014\text{-}15}$=83.36).** This can be attributed to the proliferation of the floating population in the form of houseboats and the mushrooming of the unchecked hospitality sector in the Nigeen area which has led to undesirable nutrient enrichment of the same. The high WQI values at Habak and Hazratbal could be blamed on the sewage discharge for the STPs operating there.

The **$WQI_{2014\text{-}15}$=70.24** for inside the lake near Telbal Nallah is lowest since it is the entry point of the Dal Lake watershed. It is clear that the lake generally exhibits increasing annual average trends of WQI i.e. water quality has deteriorated from year 2010-11 to 2014-15.The overall spatial WQI for Dal Lake in the year 2014-15 was found to be **82.48** which puts the status of the lake in the "Very Poor" category.

4.4.2 Seasonal WQI

WQI for all seasons from 2010-11 to 2014-2015 is determined in addition to the 5 year average seasonal WQI for a longitudinal assessment, using weighted arithmetic methodology.

Table 4.22: Annual Average Overall Season-Wise WQI From 2010-11 To 2014-15

Annual Average Overall Season-Wise WQI					
Season	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**
Spring	77.60848	75.49131	71.55318	77.80285	80.58557
Summer	78.889	75.6732	77.23236	84.66285	91.17587
Autumn	78.82084	74.551	75.10293	84.07059	86.38266
Winter	72.74304	64.89313	70.6674	78.39731	77.0865

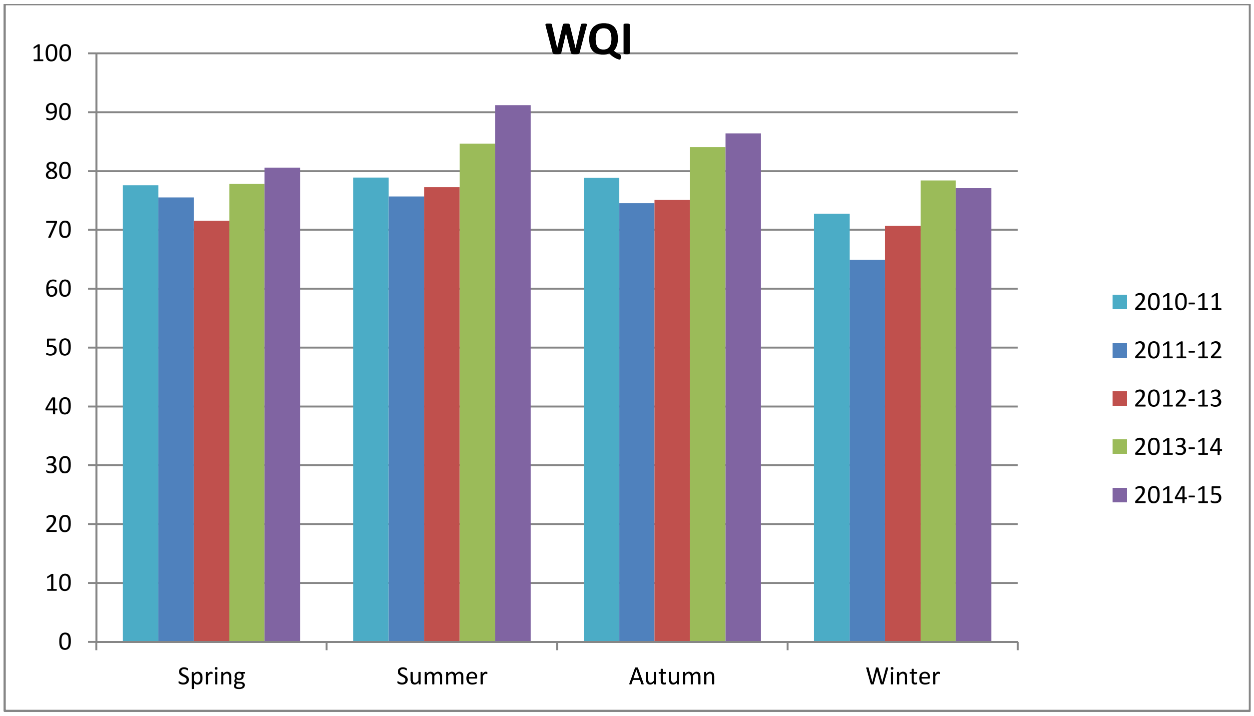


Fig 4.22: Year Wise Average Annual Season-Wise WQI Of Dal Lake

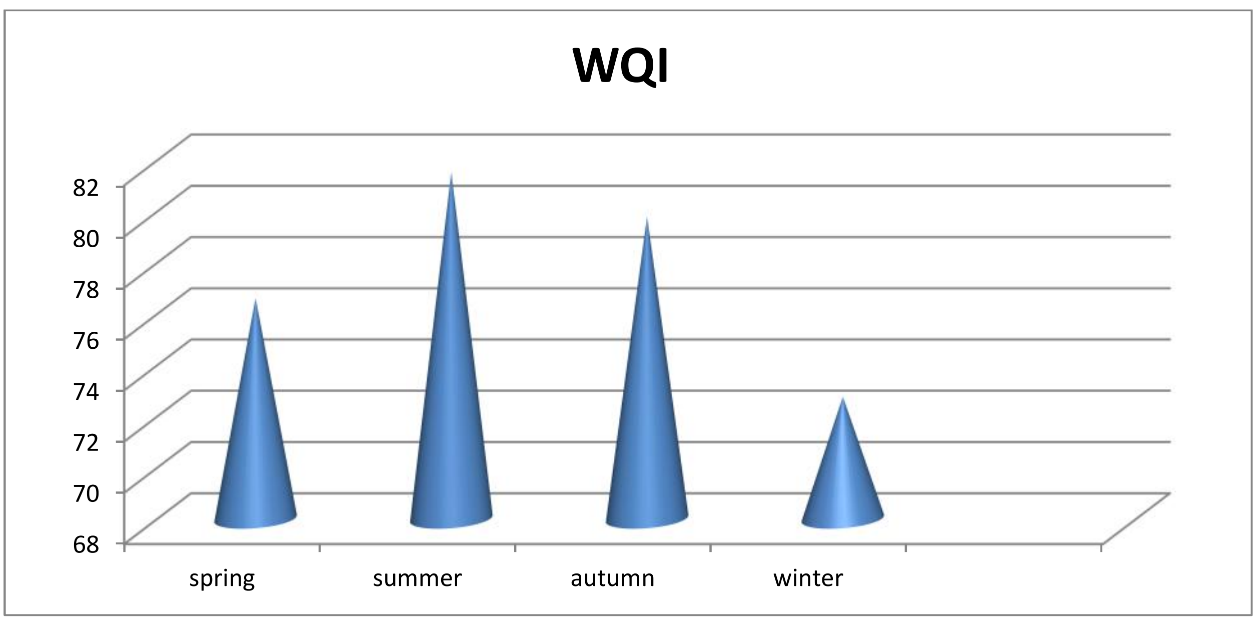


Fig 4.23: 5 Year Average Seasonal WQI Of Dal Lake

From figure (4.21) it is clear that the WQI value is highest in Dal Lake for summer followed by autumn, spring and winter respectively. The summer WQI for the year 2014-2015 was found to be **91.1758** and that for autumn, spring and winter was **86.38.41, 80.58** and **77.08** respectively in decreasing order. This puts the water quality of lake for all seasons in the “Very Poor” category. The graph also demonstrates a general deteriorating seasonal water quality trend in the duration from year 2010-11 to 2014-15. This result illustrates that the water quality of the lake is closely associated with the prevailing seasonal conditions. As already mentioned summer season is the most polluted season, courtesy of the intensification of phytoplankton biological activity due to elevated temperatures and the increased tourist influx for the same period which causes unwarranted nutrient enrichment. Winter is apparently least polluted due to declining temperatures and diminished anthropological activities.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

This Chapter is the concluding chapter. The first section entails the main contributions and outcomes of the holistic assessment realised in the current study of Dal Lake. The second section encapsulates feasible recommendation with regards to development of the water quality status.

5.1 Conclusion:

From the study following conclusions were drawn:

1. Dal Lake suffers steady eutrophic deterioration.

2 There is significant spatio-temporal variability as most parameters indicated considerable spatio-temporal variations.

3. As per the principal component analysis it is construed that the lake water quality is mainly influenced by waste water discharge and agricultural run-off in the form of proliferation of nutrients like nitrate-nitrogen, ammonium-nitrogen, phosphates and chlorides in addition to the impact of seasonal variations.

4. From the spatial cluster analysis it is clear that the Central Site Nigeen, Outlet Sites of Habak and Outlet Site of Hazratbal are the most polluted sites of Dal Lake and need immediate remediation strategies.

5. From the temporal cluster analysis it is clear that Spring and Winter are the most hydro-chemically similar seasons of the year followed by Autumn. Summer is significantly varied in hydro chemical behaviour to all other seasons, courtesy of increased anthropogenic and biological activities observed during the season.

6. The computation of spatial WQI reiterates the findings of the multivariate analysis (spatial cluster analysis). The calculated spatial WQI, asserts the high pollution levels of water quality at the Central Site Nigeen, Outlet Sites of Habak and Outlet Site of Hazratbal, also indicates increasing annual trends of spatial lake water deterioration. The spatial annual average calculation of overall WQI puts the status of the Dal Lake in the “Very Poor” category of water quality.

7. The computation of seasonal WQI also corroborates the findings of the multivariate analysis (temporal cluster analysis). The calculated temporal WQI, identifies Summer as the season which suffers most from the lake water pollution, having the highest WQI among all seasons, and also reflects the generally increasing annual trends of seasonal lake water deterioration. The average seasonal overall WQI of Dal Lake again puts the status of Dal Lake in the “Very Poor” category of water quality.

5.2 Recommendation:

From the study following recommendations were made:

1. Gradual dislodgement of houseboats and hotels, and rehabilitation of respective proprietors at a more appropriate locality.

2. Relocation of the riparian population of Dal Lake to areas away from the vicinity of Dal Lake.

3. Setting up of STPs at all entry channels and immediate upgradation of existing STPs. For instance the STPs at Habak and Hazratbal are the major causes of eutrophic acceleration in the proximate lake area.

4. Setting up of toilets for the riparian inhabitants who do not have access to normal sanitation facilities so as to reduce direct disposal of night soil into the lake.

5. Systematically regulated application of chemical pesticides by the cultivators in the lake catchment. Strategies to develop biological pest control measures to mitigate pest problem should be encouraged.

6. Systematically regulated application of chemical fertilisers by the cultivators in the lake catchment. Methodologies should be developed to reduce the necessity of chemical fertilisers for agricultural soils near and around the Dal Lake.

7. Lastly, but most importantly, the public community needs to be educated about the deplorable state of the Dal Lake. Tools like WQI can be employed to communicate to the public the degree of contamination which the lake faces at present, so as to take the public into confidence and develop collaborative plans to remediate the deterioration of the Dal Lake.

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