Anthropogenic Induced Evolution of Chemical Quality of Water in Dal Lake, Srinagar

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Abstract

Dal Lake, a famous urban fresh water lake, plays a fundamental role in the social, cultural and economic dynamics of the Kashmir Valley. A detailed study was carried out to assess the impact of anthropogenic activities on the chemical quality of water in the Lake. Monthly water samples were collected in 2014 and 2015 from 28 sites across the lake. Spatial and temporal variation maps were prepared using ARC Gis 10.2 with geostatistical analyst extension tools. The distribution maps clearly showed that the anthropogenic activities have significantly increased the concentration of nutrients in lake water. At present, the concentration of phosphorus varied from 102-6025 (μg L-1), whereas the concentration of NO3- varied from 360-13000 (μg L-1). Phosphorus and NO3- were recorded at higher concentration in Hazratbal and Nigeen basins. Comparison of results obtained from the present study with those of earlier results indicated that increasing trends in concentrations of nutrients are probably caused by discharge of untreated domestic sewage through small drains, faulty STP's and the discharge of fertilizers from agricultural activities in the catchment.

Keywords: Chemical quality, pollution, Dal Lake, nutrients, kriging technique.

Introduction

Lake water resources are of great importance to human life, and economy (irrigation, transportation, recreation, and hydropower) and are the main sources of meeting the demand for drinking, irrigation and industrial purposes (Meybeck, 1995; Leonard and Crouzet, 1999; Kalff 2001; Shiklomanov and Rodda, 2003; Saleem *et al.,* 2015). They provide shelter for variety of flora and fauna. There are more than 110,000 lakes larger than 1 km2 (0.39 mi2) covering a total area of 2.3 × 106 km2 (0.9 × 106 mi2, 1.7% of the Earth terrestrial surface) (Meybeck, 1995; Finlayson and Davidson, 1999; Wetzel, 2001). Besides the many millions of smaller lakes (less than 1 km2), approximately 800,000 artificial lakes and reservoirs have been constructed covering 0.5 × 106 km2 (0.2 ×106 mi2) (Meybeck, 1995; Kalff, 2001; IPCC, 2001). Lake ecosystem contains solutes derived from both natural and anthropogenic processes (Drever, 1982; Jeelani and Shah, 2006; Saleem *et al.,* 2015). Transport of these solutes depends on topography, climate and land use activities within the catchment (Jeelani and Nadeem 2010; Jeelani *et al.,* 2011; Sheikh *et al.,* 2014). Chemical water quality parameters that are fabricated by human influence include: pH, turbidity, conductivity, alkalinity, dissolved oxygen, nitrate, phosphorous, silica, chlorides, sulfate along with calcium, magnesium, sodium and potassium. Most of these parameters may pose some health risks if they are above the standards set by World Health Organization and Bureau of Indian Standard (BIS, 1999; McArleton *et al*., 2001; WHO, 2006). Information and case studies reviewed worldwide indicate that the lakes and reservoirs are at risk from overexploitation, over enrichment, toxic contamination, and sedimentation (Sheikh *et al.*, 2014; Oke *et al.*, 2013; Saleem *et al.,* 2015). These entries have forced future environmental and water resource professionals to take necessary actions to mitigate lake and reservoir pollutions because availability of good quality water is a necessary feature for preventing diseases and improving quality of life (Oluduro and Aderiye, 2007; Jeelani *et al.,* 2014). Dal Lake has tremendous societal and economic significance and is one of the main attraction for tourists in Kashmir, the anthropogenic inputs (nitrogen and phosphorus) have greatly decreased its water quality during the past two decades due to near-lake development and anthropogenic inputs (Jeelani and

Shah, 2006; Qadri and Yousuf, 2008; Singh *et al.,* 2008; Khan *et al.,* 2012; Saleem *et al.,* 2015). Till date very long and consistent systematic scientific work has been carried out on this lake (Trisal, 1987; Kundangar *et al*., 2003; Jeelani and Shah, 2006; Singh *et al.,* 2008; Yaqoob *et al.,* 2008 and Khan *et al.,* 2012). The objectives of the present study are, a) to assess the anthropogenic activities on lake, b) to generate/prepare thematic maps of chemical parameters to provide better understanding of the present water quality scenario in lake and c) to identify the anomalous areas of pollution.

Study area

Dal Lake (Figure 1 is situated between 34°04´-34o11' N, 74o48'-74o53' E in the north-east township of Srinagar in the heart of Kashmir Valley in western Himalayas (1583 m above the sea level). The lake has a total area of above 23 km2 of which approximately 12 km2 is the total open water spread area. Total area of its catchment is about 314 km2 and it is divided into 4 sub-catchments namely: i) Tailbal Dachigam, ii) Lake Hillside, iii) Srinagar north sub-catchment, and iv) Srinagar center sub-catchment. Tailbal Dachigam sub-catchment contributes 70% areal distribution of drainage catchment (AHEC 2000; Jeelani and Shah 2006; Saleem *et al.,* 2015). The geological formations of the catchment area are dominated by alluvium, Karewas, Triassic limestones, Panjal Traps and Slates. Panjal Traps consist of thick series of andesites and basalts (Thakur and Rawat 1992; Jeelani and Shah 2006). Mountain range in the east is a part of the Panjal Traps, at many places agglomerate slates are also present in the south eastern side. The lake comprises a myriad of inter-connecting channels and is divisible into four major sub-basins viz., Hazratbal, Boddal, Gagribal and Nigeen basins (Jeelani and Shah 2006; Saini *et al.,* 2008: Saleem *et al.,* 2015). Teilbal nallah main stream enters in to the lake on the northern side of Hazratbal basin after originating from the Marsar Lake, high up in the dachigam subcatchemnt (Saini *et al.,* 2008; Saleem *et al.,* 2015).

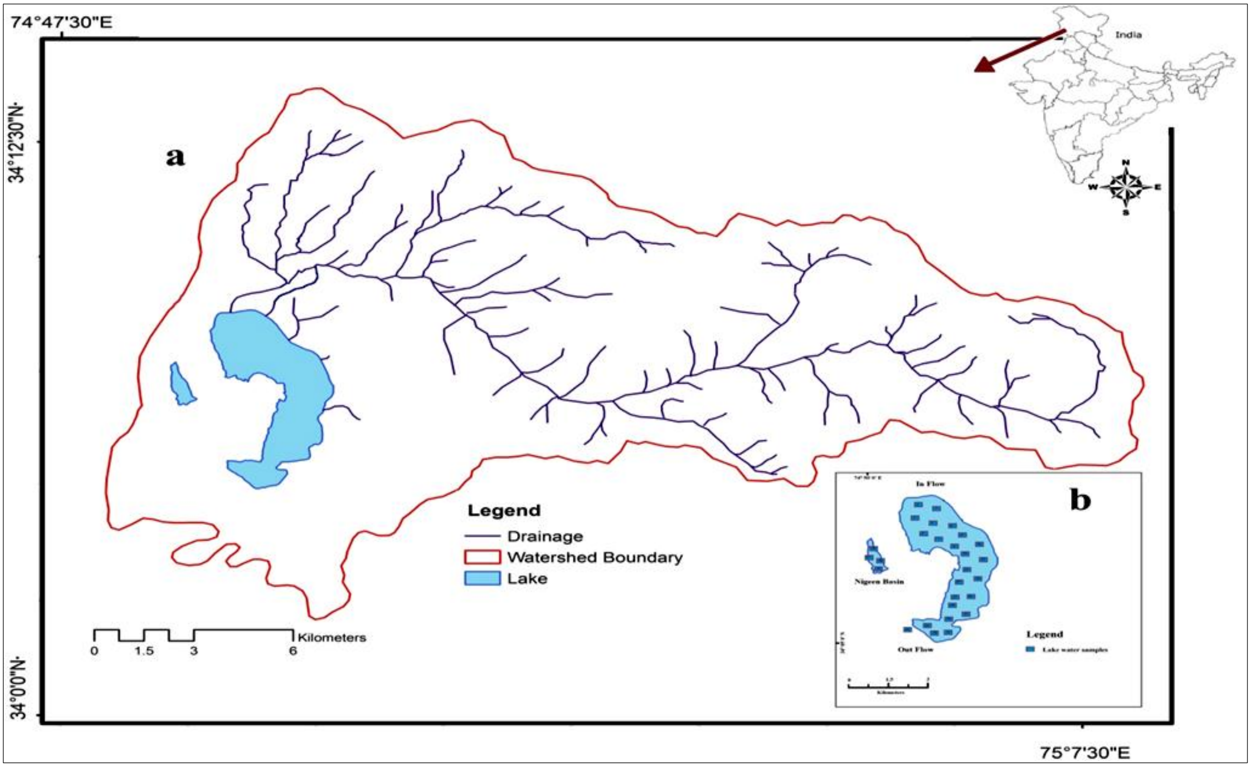

Figure 1: Study area map a) drainage pattern of its catchment b) sampling location

Material and Methods

Spatial and temporal variation of chemical water quality is one of the main feature of different types of water bodies, and is largely determined by the hydrodynamic characteristics within the water body. It varies in all the three dimensions of lake which are further modified by flow direction, discharge and residence time. Consequently, water quality cannot usually be measured in only one location within a water body, but may require a grid or network of sampling sites. Water samples (n = 672) were collected across the lake from twenty eight sampling sites in high density polyethylene (HDPE) bottles in 2014 and 2015 (Figure 2). Physical parameters were measured and recorded: pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured with the help of multi-parameter water quality sensor (HACH HQD sension$^+$). For major ion analysis the samples were brought to the Geochemistry Laboratory, Department of Earth Sciences, and University of Kashmir. Samples were analyzed as per the standard methods (APHA 2005). Alkalinity (including HCO_3^- and CO_3^{2-}) was analyzed by acid-base titration. Total hardness as $CaCO_3$ and Ca^{2+} was analyzed titrimetrically, using EDTA titration. Magnesium (Mg^{2+}) was calculated from the total hardness and Ca^{2+}. Cl^- was determined by standard $AgNO_3$ titration. Flame emission photometry has been used for the determination of Na^+ and potassium (K^+). SO_4^{2-} and NO_3^- were determined by colorimetric method (HACH DR/890), while as silica by spectrophotometric method. To facilitate the presentation of data in the Arc GIS 10.2 some simplifications were done. In the present study, the two year monthly values were averaged down to seasonal basis to prepare the thematic maps of various water quality parameters. These maps were made in the software using geostatistical analyst extension tools (kriging and inverse distance weighted interpolation technique).

Results and Discussion

a) Chemical quality of lake water

i)pH: It is one of the most important parameter in water chemistry and is defined as -log [H^+]. It indicates the intensity of acidity and alkalinity and measures hydrogen ions in water (Williams, 2001; Kishe, 2004). High pH in water causes a bitter taste, water pipes and water-using appliances become encrusted with deposits, and it depresses the effectiveness of the disinfection of chlorine, thereby causing the need for additional chlorine when pH is high (Araoye, 2009). Low-pH water will corrode or dissolve metals and other substances. The lake water is alkaline in nature with pH ranging from 7.3 to 8.4 with an average of 7.8 during two years period. The pH was considerably found/noted high around the peripheries of the lake and in some patches where the plant growth is high. The spatio-temporal maps of pH in lake showed significant variation during different seasons of the year. Boddal basin showed a little variation in pH than Hazratbal and Gagribal basins as shown in **Figure 2**. High pH around the peripheries of lake and in some areas may be due to use of CO_2 from the lake water by excessive growth of algae and aquatic plants. Significant changes in pH also occur due to discharge of agricultural and domestic waste into the lake.

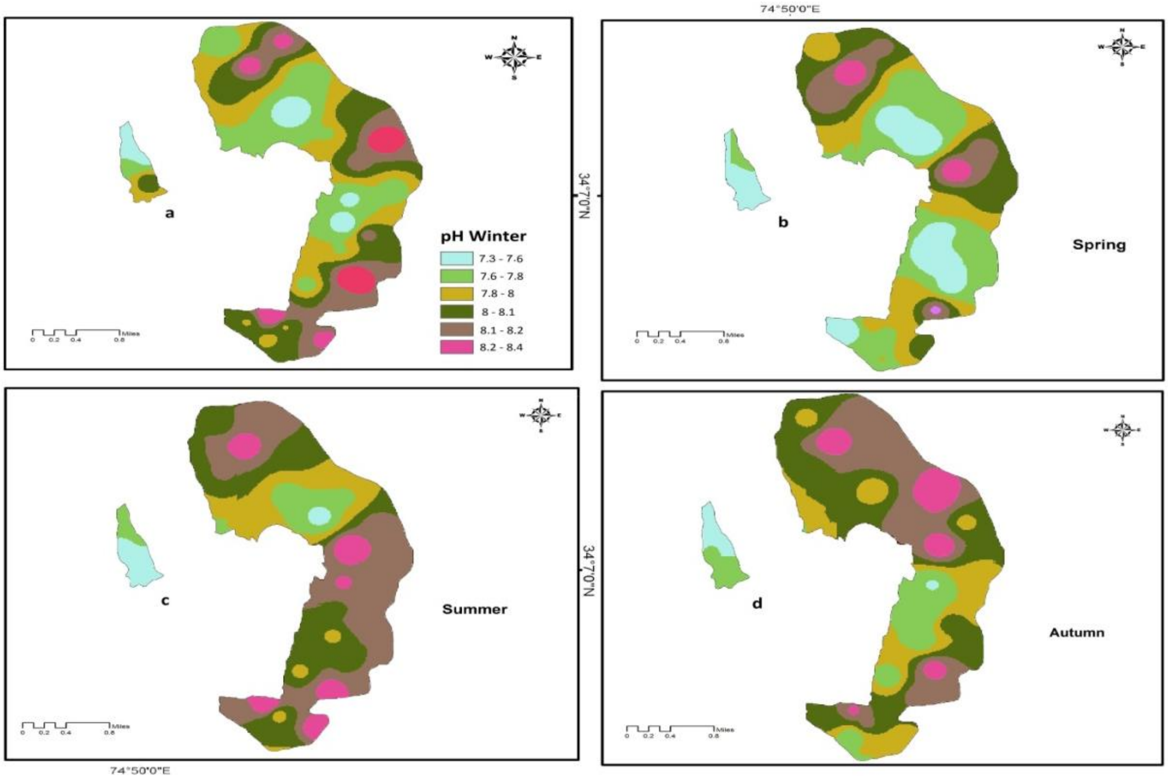

Figure 2: Spatial variations of pH in Dal Lake during a) winter b) spring c) summer d) autumn season.

ii) Total dissolved solids (TDS): TDS in water is represented by the weight of residue left when a water sample has been evaporated to dryness (WHO 2006). TDS are compounds of inorganic salts (principally Ca^+, Mg^+, K^+, Na^+, HCO_3^-, Cl^- and SO_4^{2-}) and of small amounts of organic matter that are dissolved in water. It ranged from 101 to 195 mg L^{-1} with an average of 138 mg L^{-1}. Spatial distribution of TDS in lake shows that higher concentration were noted in the northern and southern part of the water body. In terms of basin, higher values of TDS were found in Nigeen during summer season and in Hazratbal basin during autumn season.

iii) Electrical conductivity (EC): The electrical conductivity (EC) is a measure of the total salt content of water based on the flow of electrical current through the sample. It is the reciprocal of resistivity (R) and is reported in ms cm^{-1} or µs cm^{-1}. Pure water is a weak electrolyte, and the EC of aqueous solutions will thus depend on the presence of charged ions. Electrical conductivity increases with the number of ions in solution and mobility. Because the mobility of a charged ion depends on ionic size and charge, the overall EC of a fluid will depend on which chemical species are present and not just their concentration. In the lake it ranged from 175 to 330 µs cm^{-1} and was found higher in Nigeen basin during spring season and lower in winter season. Spatio temporal variability map of EC shows the high degree of anthropogenic activities such as waste disposal and agricultural runoff into the lake basin (**Figure 3**).

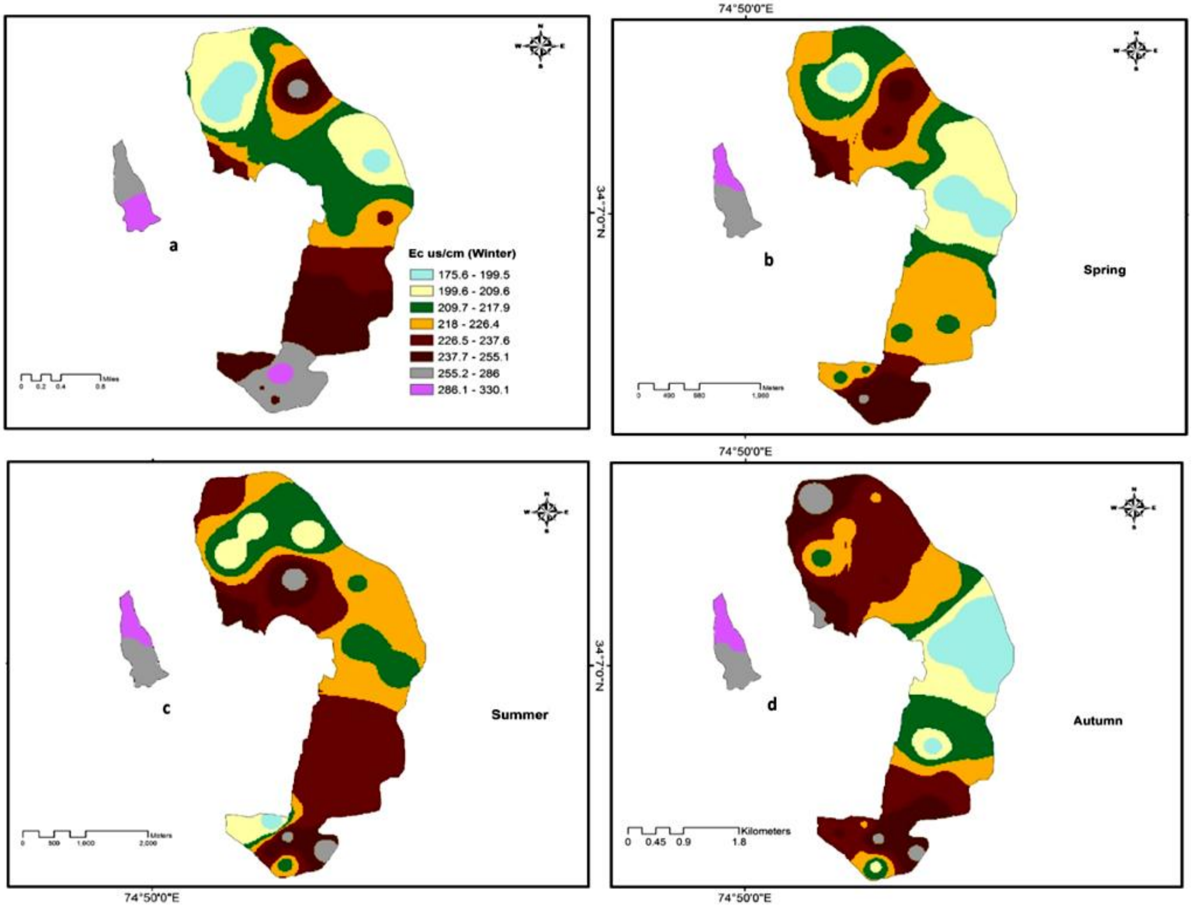

Figure 3: Spatial variations of EC in Dal Lake during a) winter b) spring c) summer d) autumn season

iv) Calcium: Calcium is abundant in both surface and groundwater and is readily dissolved from rocks rich in calcium minerals (limestone and gypsum). The salts of calcium, together with those of magnesium, are responsible for the hardness of water. Calcium was found most abundant cation in the Dal Lake water, and contributes 72-80% to the major cation budget with average concentration ranged from 24-44 mg L^{-1} with an average of 30 mg L^{-1}. Results clearly indicate that the calcium is high around the groundwater inputs in the basin. It was found higher during spring season in Nigeen basin and lower in summer in Gagribal basin. It may be due to high residence time of groundwater in aquifers in winter and summer which resulted in prolonged rock-water interaction and thus more calcium is acquired in the lake
water. On the other hand, during summer, due to dilution effect concentration of Ca^{2+} decreases in lake water.

v) Magnesium (Mg^{2+}): Magnesium arises principally from the weathering of rocks containing ferromagnesium minerals (e.g. Panjal Traps) and from some carbonate rocks (dolomites). It occurs in many organometallic compounds and in organic matter, since it is an essential element for living organisms. In the lake water Mg^{2+} contributes 10.6 to 12.6 % to major cation and its values varied from 3.2 to 8.5 mg L^{-1} with an average of 4.5 mg L^{-1}. Its values were found higher in Nigeen basin during winter and lowest value in Hazratbal basin during spring season.

vi) Sodium and Potassium: Sodium (Na^+) and potassium (K^+) are the most important minerals occurring naturally. The major source of both the cations is from weathering of rocks besides the sewage and industrial effluents. In natural waters its (Na^+) source are from silicate minerals, atmospheric precipitation and halite deposits. It is a major component of silicate rocks and is mainly present as albite component of plagioclase. It values ranged from 3.1 to 6.2 mg L^{-1} with an average of 4.2. It was found highest in Hazratbal basin during spring season and lowest in Gagribal basin during autumn. The highest amount of sodium recorded during the spring season may be due to the addition of waste water containing soap solution and detergent from the inhabitants living within and outside of the lake. The lowest amount was recorded during autumn season because of bioaccumulation by living organisms.

Potassium (K^+) is found in low concentrations in natural waters since rocks which contain potassium are relatively resistant to weathering. However, potassium salts are widely used in industry and in fertilizers for agriculture and enter freshwaters with waste discharges and run-off from agricultural lands. Potassium (K^+) ranged from 1.8 to 3.5 mg L^{-1} with an average of 2. Maximum K^+ was found in Hazratbal basin during spring season minimum during summer season in Gagribal basin. Low K^+ may be due to its low geochemical mobility.

vii) Bicarbonate: Its value ranged from 69 to 128 mg L-1 with an average of 93 mg L-1. It was found highest in Nigeen basin during spring season and lowest in Gagribal during summer indicating that the carbonate dissolution is the main sources and is maximum in the spring season.

viii) Sulphate: Sulphates occur naturally in numerous minerals, including barite (BaSO4), epsomite (MgSO4•7H2O) and gypsum (CaSO42H2O) (Sami, 1992; Fisher and Mullican, 1997) Sulphates are discharged into the aquatic environment in wastes from industries that use sulphates and sulphuric acid, such as mining and smelting operations, kraft pulp and paper mills, textile mills and tanneries. In the lake SO42- value ranged from 1.5 to 13.9 mg L-1. Hazratbal basin showed highest values during winter and Boddal basin

showed lowest values during spring season. In Hazratbal basin higher values are due to the maximum influence of sewage plants than in Boddal basin (**Figure 4**). Spatial distribution map of SO42- concentrations show distinct variations from the northern to the southern part of the lake. The northern part has shown more variation in SO42- concentration compared to the southern part. This map also suggests that SO42- was recorded higher at sites close to houseboats, human settlements, restaurants, sewage drains in the Hazratbal and Nigeen basin while the low values was found in fresh water inflow channels and deeper sites of the Boddal basin. SO42- values were also found higher along the peripheries of the lake due to use of fertilizers in paddy cultivation and in floating gardens.

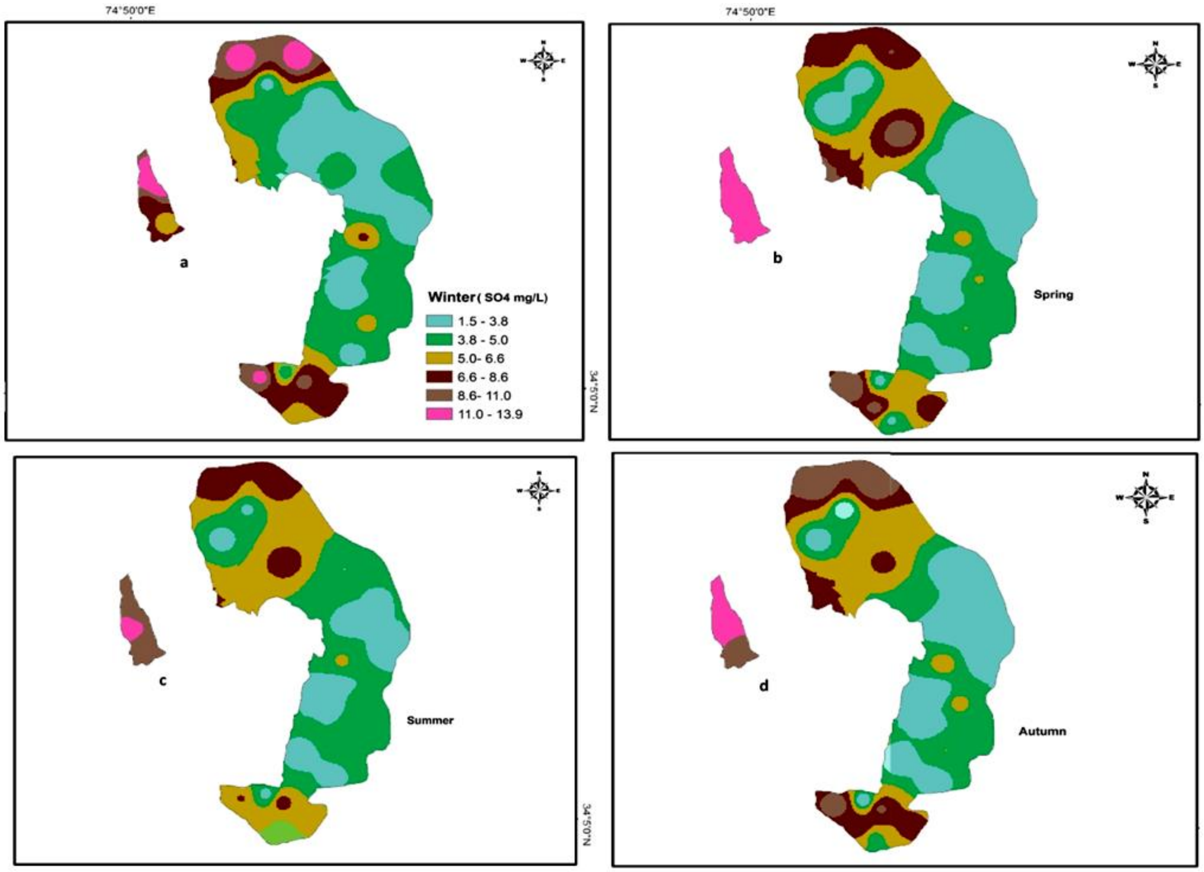

Figure 4: Spatial variations of SO_4^{2-} in Dal Lake during a) winter b) spring c) summer d) autumn seasons

ix) Chloride: Chloride is a salt compound resulting from the combination of the gas chlorine and a metal. Common chlorides include sodium chloride (NaCl) and magnesium chloride (MgCl2). Chlorine alone is highly toxic and is often used as a disinfectant. In combination with a metal such as sodium, it becomes essential for life. Small amounts of chlorides are required for normal cell functions in plants and animals. Chlorides are not usually harmful to people; however, the sodium part of table salt has been linked to heart and kidney disease. Chloride (Cl-) concentration is the most useful parameter for evaluating atmospheric input to the lakes as it shows little fractionation (Saini *et al.*, 2008; Saleem *et al.*, 2015). In lake water it ranged from 2 to 17 mgL-1 with an average of 8 mg L-1. It was found maximum in Nigeen during winter season and minimum in Gagribal during summer season (Figure 5). Spatio-temporal variability map of Chloride (Cl-) illustrate that chloride concentrations is higher in residential areas and around sewage treatment plants (STP's). Another reason for increased Cl- during winter months is due to the flushing of sanitary waste disposal sites and surrounding soils in settlements without sewage and waste water treatment. However, dilution effect of pollutants during summer (rainwaterand surface runoff) decreases the chloride content in lake water.

x). Nutrients: Nutrients are chemical elements or compounds necessary for the growth of living organisms (He 2002; Zhenzhen *et al.*, 2015). Although nutrients are essential to algae, but excessive nutrient levels can cause eutrophication in lake. Eutrophication is one of the most widespread environmental problems of and refers to the changes in chemical properties of water due to accumulation of these nutrients such as nitrogen and phosphorus (Zhang 1999; Le *et al.*, 2010). It can lead to rapid production of phytoplankton and other microorganisms and is detrimental to normal functioning of the lake (Vitousek *et al.*, 1997; He 2002; Qin and Zhu 2005; Zhenzhen *et al.,* 2015).

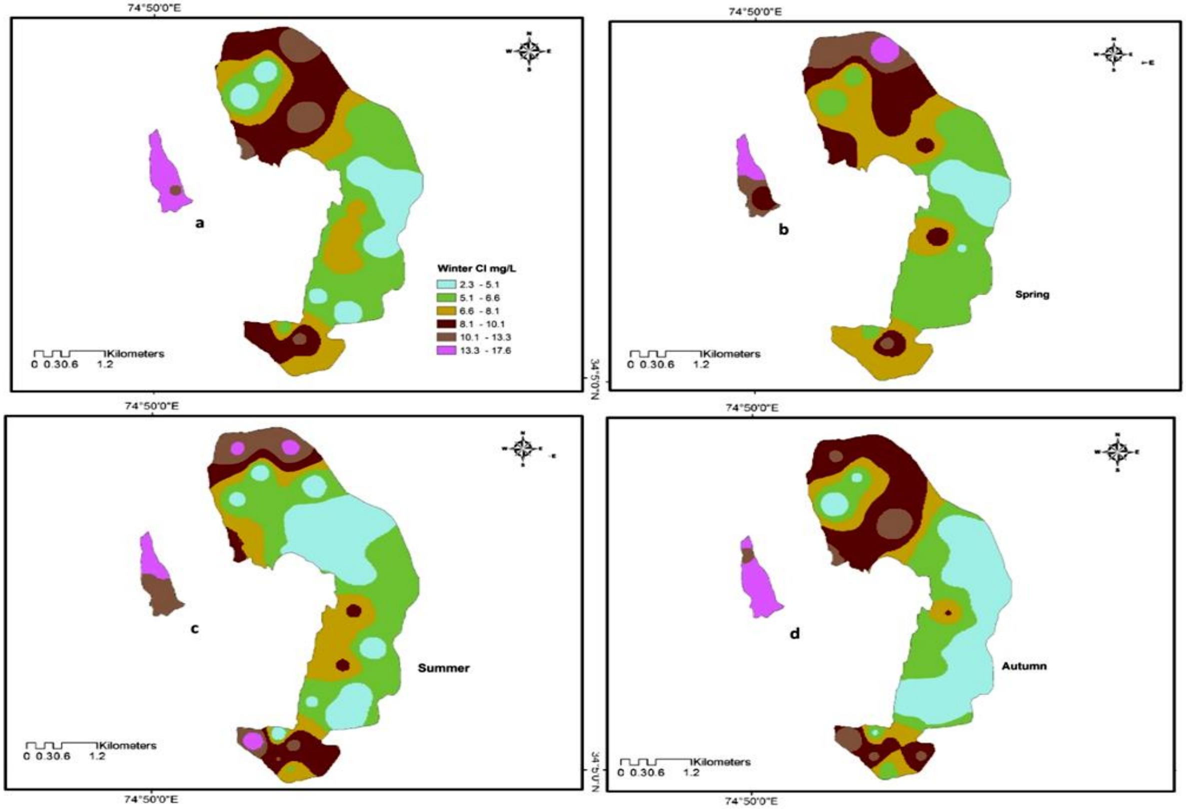

Figure 5: Spatial variations of Cl- in Dal Lake during a) winter b) spring c) summer d) autumn season

The high nitrogen content is an indicator of organic pollution. It may results from the added nitrogenous fertilizers, decay of dead plants and animals, animal urine, or feces. They are all oxidized to nitrate by natural process and hence nitrogen is present in the form of nitrate. The increase in one or all the above factors is responsible for the increase of nitrate content. In Dal Lake nitrate ranged from 400 µg L-1 to 2065 µg L-1. **Figure 6** shows the seasonal spatial-temporal variations of nitrate in the lake water. Higher values were observed in Hazratbal basin during winter season and lower values were observed in Boddal basin in spring season. The higher values of nitrate recorded during winter season were due to the inflow of nitrate rich drainage and sewage treatment plants. The lowest amount of nitrate in water recorded during summer can be due to the utilization by plankton and aquatic plants for metabolic activities. Phosphorous is an essential nutrient for all life forms and is a key element in many physiological and biochemical processes. In lake environment, phosphorous is supplied through the mineral weathering (apatite) and dissolution of rocks. Total phosphorous in lake water ranged from 102 to 3000 (ug L-1). Higher concentration was found in Hazratbal basin during winter season and lower concentration in Boddal basin in summer season. Major anthropogenic sources include: animal wastes, soil erosion, detergents, faulty STP's and runoff from farmlands or lawns.

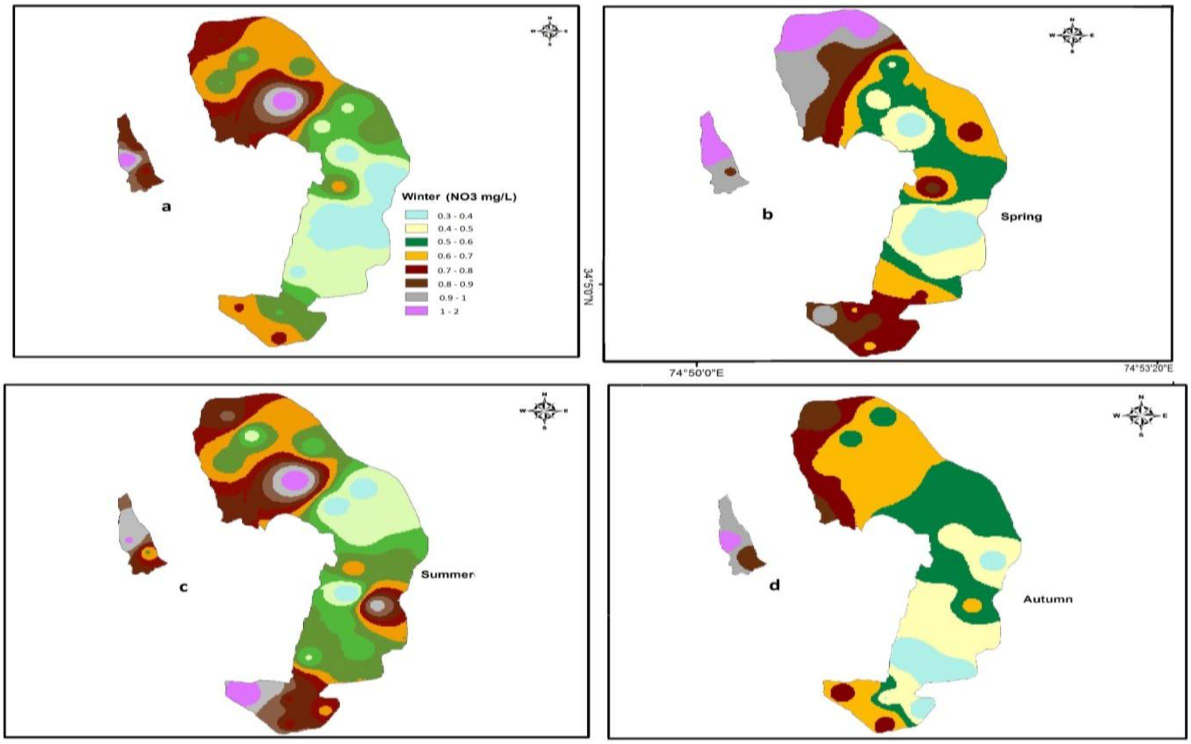

Figure 6: Spatial variations of NO3- in Dal Lake during a) winter b) spring c) summer d) autumn season

b) Comparison with earlier results

The contamination of water in the Dal Lake began with the urban development and pressure of the Srinagar city from point and non-point wastage sources. The studies on the lake carried out by different workers on the physical and biological parameters of the the lake goes back to 1987. All these chemical water quality parameters performed by different workers (Trisal, 1987, Kundangar *et al.*, 2003, Jeelani and Shah 2006, Kawnsar *et al.*, 2008, Qadri and Yousuf 2008, Murtaza *et al.*, 2011, Khan *et al.*, 2012, Mushtaq *et al.*, 2013 and Saleem *et al.*, 2015 were correlated/ compared with our present results. The comparative study reveals that the average values of electrical conductivity varied from 181 µs/ cm (Singh *et al.*, 2008) to 286 µs/cm in present study. The average concentration of NO3- and TP as recorded by Trisal 1977 varied from 365 µg/L to 2065 µg/L and 468 µg/L to 3000 µg/L (**Figure 7**). Generalized results of the studies on the lake performed during 1987 to 2004 indicate that water quality was fresh and nutrient free. And during the last one decade time the enrichment of the lake waters by nitrates and phosphates caused mass development of weed in lake which led to the increasing eutrophication rate. This eutrophication in hyper state in the lake basin resulted in deterioration and in worst case scenarios resulted in destruction in the water clarity and look. Overall the concentration of main ions including; Ca^{2+}, Mg^{2+}, Na^{2+}, HCO_3^- has remained same or unchanged, but the concentration of Cl^-, SO_4^{2-}, NO_3^- and TP has increased.

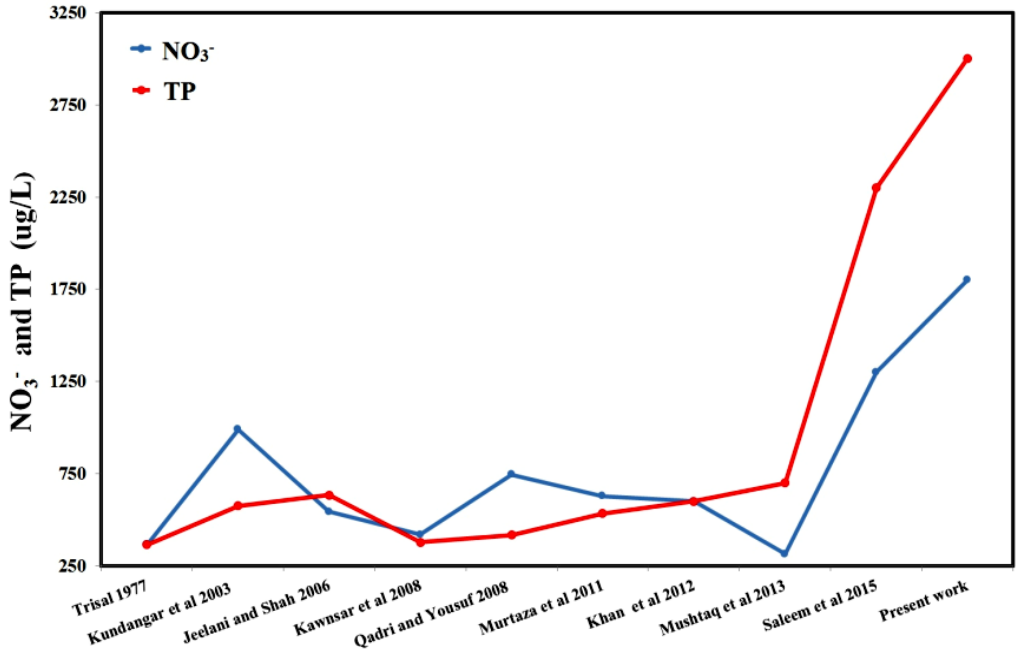

Figure. 1.7: Showing the variation of NO3- and TP in lake water 1987 to 2016

Conclusion

The chemical quality of lake water was presented as seasonal maps, which suggested that the lake water is generally alkaline in nature with moderate electrical conductivity. The concentration of most of the major ions was higher in Nigeen basin than the other baisns, which may be attributed to higher residence time of water in Nigeen basin. It is clear from the maps that anomalous concentration of chemical parameters was found nearer to sewage drains, STP's, residential areas/hotels, houseboats and floating gardens. The concentration of sulfate and chloride was higher near the hotels surrounding the lake, suggesting their source from these hotels. In this study, it was demonstrated that lake as a natural reserve, is threatened by all types of anthropogenic activities, which have the impact and potential to alter the productivity of the lake ecosystem. The urban, agricultural and extensive land uses were found to be responsible for elevated levels of nutrients. While comparing the current hydrogeochemical data ot he lake water with the ealier published data, we found that the concentrations of Ca2+, Mg2+, Na2+ and HCO3- has remained the same, However, the concentration of SO42-, Cl-, NO3- and TP has increased significantly from 2008 to 2015 (NO3- 400 µg/L to 2065 µg/L; TP: 370 µg/L to 3000 µg/L).

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