Chapter 4:
Pollution status of three lakes
4.1 Introduction

A lake is a reflection of its watershed and as watershed landscape- the topography, soil, geology and vegetation- determines the kinds of materials entering into the lake that in turn reflect on its water quality (Dong et al., 2010). Nutrient enrichment of lakes is one among the major environmental problems in many countries (Oczkowski and Nixon, 2008). Though it stimulates the growth of plants (algae as well as higher plants), nutrient enrichment ultimately leads to deterioration of water quality and degradation of the entire ecosystem (Guyuan et al., 2011). In recent decades, population growth, agricultural practices and sewage run-off from urban areas have increased nutrient inputs many folds than the level of their natural occurrence, resulting in accelerated eutrophication and pollution (Zan et al., 2011). Thus lake eutrophication is a nutrient enrichment of lakes. Every lake fits into a particular ‘trophic state’, according to its degree of eutrophication and the lake’s trophic status changes over a period of time. Eutrophication of lakes is caused by both natural and human factors. Natural eutrophication is the process by which lakes as they gradually age become more productive which normally takes thousands of years to progress. However, this process is accelerated by excess nutrients from human activities and is called “cultural eutrophication” (Guyer and Ilhan, 2011). It is caused by excess plant nutrients (primarily N and P) disposed into lakes mainly as untreated or partially treated domestic sewage, runoff from agricultural fields and so on. Most urban and rural lakes have vanished under this pressure and have led to worldwide environmental concerns (Prasanna et al., 2011). In those lakes which could endure, drinking water supply has been substantially reduced or become totally non potable.
and/or flood absorption capacity is impaired and biodiversity is threatened besides the diminished fish production (Zhang et al., 2009).

Periodic monitoring and assessment of water quality helps to develop management strategies to control surface water pollution (Shuchun et al., 2010). Water quality monitoring programs have generated huge databases describing variations of the water quality. These large data sets are often difficult to analyze for meaningful interpretation and require data reduction methods not only to simplify the data structure but also to extract useful and interpretable information which could lead to the development of its management strategies (Simeonova and Simeonov, 2006). However since the state of an ecosystem depends simultaneously on many factors/parameters, monitoring systems are multivariate in nature and hence the classification, modeling and interpretation of the monitoring data sets have to be performed using chemometrics and environmetrics (Simeonova, 2007; Astel et al., 2008). Multivariate methods, such as factor analysis identify the possible factors/sources that influence water systems (Boyacioglu and Boyacioglu, 2008; Dolotov et al., 2010) and offer valuable tool for developing appropriate strategies for effective management of these water resources (Astel et al., 2008; Bu et al., 2010; Palma et al., 2010).

4.2 Review of literature on lakes

Studies on Kashmir lakes have been initiated with the work of Edmonson and Hutchison (1934) which described some physico-chemical characteristics of Dal Lake and Manasbal Lake. Zutshi et al., (1972) while studying the limnology of Kashmir valley lakes have divided them into three categories- glacial lakes, pine forest lakes and valley lakes on the basis of origin, altitudinal location and the nature of biota they harbor. Zutshi and Vass
reported on the changing trophic status of Dal Lake and Anchar Lake and the progressive increase in BOD and COD based on the water analysis data sets. Kant and Kachroo (1974) studied the diurnal changes in temperature and pH in Dal Lake. According to Enex (1978) a net flow of 5.5 tons of phosphorous and 88.9 tons of nitrogen enter into the Dal Lake from immediate catchment. Zutshi and Khan (1978) reported high nutrient concentration of inshore waters as compared to offshore in Dal Lake. Zutshi and Vass (1978) made liminological studies and revealed Dal Lake to be alkaline and slightly buffered. Zutshi et al., (1980) on studying comparative limnology of nine lakes of Jammu and Kashmir Himalayas, ranked these lakes from sub-tropical monomictic to dimictic type based on the difference in their morphology and thermal behavior. Zutshi and Wanganeo (1984) evaluated the trophic status of some Kashmir lakes based on nutrient load model and reported export of phosphate and nitrate into the lakes from catchments. Wanganeo (1984) studied primary production characteristics of Manasbal Lake based on the seasonal and annual rates of carbon fixation in the water column by plankton population which were related to physical and chemical parameters on specific days. Vass et al., (1989) studied comparative limnology of Kashmir Himalayan mountain lakes and documented the cold monomictic thermal behaviors of the lakes. Wanganeo and Wanganeo (1991) revealed that lakes in Kashmir, manifested a marked change in algal assemblage with change in physical and chemical environment. Kundanger and Abubakr (2004) on comparing the previous limnological data of Dal Lake reported an increase in chemical parameters but with a decrease in dissolved oxygen and pH. Bhat and Pandit (2003) reported that increasing phosphorous concentrations have direct impact on primary productivity in Anchar Lake. Pandit and Rather (2006) reported on higher
concentration of nitrates and phosphates leading to eutrophication in Ahansar Lake. Siraj et al., (2010) reported wide seasonal and site-specific fluctuations in physico-chemical parameters of Dal Lake. Romshoo and Muslim (2011) studied nutrient loading of Manasbal Lake using GIS and concluded that nutrient loading of nitrate and phosphate is mainly from agricultural runoff.

Many recent studies have highlighted research in the field of water quality monitoring and assessment (Yu et al., 2003; Lambrakis et al., 2004; Simeonova, 2006; Shrestha and Kazama, 2007; Solanki et al., 2010; Juahir et al., 2011; Malik and Nadeem, 2011). Comprehensive application of different multivariate statistical techniques in water quality assessment has been over a period of time (Liu et al., 2003; Simeonov et al., 2003; Singh et al., 2005; Simeonova and Simeonov, 2006; Simeonova, 2007; Zhang et al., 2009; Dolotov et al., 2010; Guyer and Ilhan, 2011).

4.3 Results

The physicochemical nature of the water of the three lakes (Anchar Lake, Khushlsar Lake and Dal Lake) displayed a marked variability between the lakes and are analysed following the methods of APHA (2005). The methodology is discussed in detail under the chapter 2 Materials and methods, under the subhead collection and analysis of water samples.

The results of water quality parameters measured from 10 sampling stations of three the lakes are given in Fig. 4.1. Temperature showed significant variation within ($F = 181.60$, $p < 0.05$) and among ($F = 2$, $p < 0.05$) the sampling stations with a value of $11.51 \pm 0.70 ^\circ C$ in Anchar Lake, $12.27 \pm 0.74 ^\circ C$ in Khushalsar Lake and $12.34 \pm 0.66 ^\circ C$ in Dal Lake (Fig. 4.1a).
pH varied significantly within ($F = 12.34$, $p < 0.05$) and among ($F = 5.34$, $p < 0.05$) the sampling stations with a range from a minimum of $7.29 \pm 0.03$ in Khushalsar Lake, followed by $7.33 \pm 0.04$ in Anchar Lake to a maximum of $7.43 \pm 0.03$ in Dal Lake (Fig. 4.1b).

Electrical conductivity (EC) exhibited significant variation within ($F = 15.29$, $p < 0.05$) and among ($F = 14.93$, $p < 0.05$) the sampling stations. Higher values of EC was recorded in Khushalsar Lake ($0.32 \pm 0.02$ mS/cm$^2$ and Anchar Lake ($0.28 \pm 0.01$ S/cm$^2$) as compared to Dal Lake ($0.20 \pm 0.01$ mS/cm$^2$) (Fig. 4.1c).

Calcium (Ca) difference was significant within ($F = 12.66$, $p < 0.05$) and among ($F = 4.58$, $p < 0.05$) the sampling stations. The concentration of Ca was $33.45 \pm 1.62$ mg/l (Anchar Lake), $29.94 \pm 1.12$ mg/l (Khushalsar Lake) and $27.76 \pm 1.24$ mg/l (Dal Lake) (Fig. 4.1d).

Magnesium (Mg) exhibited significant variation within ($F = 11.29$, $p < 0.05$) and among ($F = 6.92$, $p < 0.05$) the sampling stations. Mg showed a maximum value of $17.75 \pm 0.45$ mg/l in Khushalsar Lake, followed by $17.11 \pm 0.56$ mg/l in Anchar Lake and least $16.12 \pm 0.50$ mg/l in Dal Lake (Fig. 4.1e).
Figure 4.1 Box-and-whisker plots of water quality parameters of three lakes (o: outlier, #: far outlier).
Figure 4.1 Box-and-whisker plots of water quality parameters of three lakes (o: outlier, *: far outlier) (continued).
Sodium (Na) showed significant variation within (F = 4.02, p < 0.05) and among (F = 18.20, p < 0.05) the sampling stations, with a value of 14.04 ± 0.48 mg/l for Anchar Lake, 21.53 ± 0.62 mg/l for Khushalsar Lake and 15.59 ± 0.67 mg/l for Dal Lake (Fig. 4.1f).

Potassium (K) content varied significantly within (F = 4.10, p < 0.05) and among (F = 15.75, p < 0.05) the sampling stations, with highest value in Khushalsar Lake (17.53 ± 1.08 mg/l) as compared to Anchar Lake (7.55 ± 0.69) and Dal Lake (8.44 ± 0.88 mg/l).

Phosphate phosphorous (PO₄) content differed significantly within (F = 4.11, p < 0.05) and among (F = 111.69, p < 0.05) the sampling stations. Concentration of PO₄ was highest in Khushalsar Lake (460.08 ± 14.31 µg/l) compared to Anchar Lake (231.90 ± 12.49 µg/l) and Dal Lake (146.13 ± 5.65 µg/l) (Fig. 4.1h).

Nitrate nitrogen (NO₃-N) showed significant variation within (F = 9.21, p < 0.05) and among (F = 34.87, p < 0.05) sampling stations. NO₃-N exhibited a range of 211.86 ± 2.88 µg/l (Anchar Lake), 248.79 ± 6.75 µg/l (Khushalsar Lake) and 185.10 ± 3.90 µg/l (Dal Lake) (Fig. 4.1i).
Ammonical nitrogen (NH$_4$-N) varied significantly within (F = 17.18, p < 0.05) and among (F = 199.86, p < 0.05) the sampling stations with higher values in Khushalsar Lake (399.27 ± 4.42 µg/l) and Anchar Lake (349.18 ± 6.73 µg/l) as compared to Dal Lake (250.07 ± 4.21 µg/l) (Fig. 4.1j).

Dissolved oxygen (DO) showed significant variation within (F = 7.43, p < 0.05) and among (F = 44.23, p < 0.05) the sampling stations with a range from a minimum of 2.50 ± 0.05 mg/l (Khushalsar Lake) followed by 3.03 ± 0.06 mg/l (Dal Lake) to a maximum of 3.16 ± 0.04 mg/l (Anchar Lake) (Fig. 4.1k).

Biological oxygen (BOD) demand differed significantly within (F = 4.12, p < 0.05) and among (F = 23.69, p < 0.05) the sampling stations. The observed value of BOD was 2.57 ± 0.4 mg/l (Anchar Lake), 3.07 ± 0.09 mg/l (Khushalsar Lake) and 2.74 ± 0.08 in Dal Lake (Fig. 4.1l).

Chemical oxygen demand (COD) exhibited significant variation within (F = 8.66, p < 0.05) and among (F = 1.94, p < 0.05) the sampling stations, with high value in Khushalsar Lake (32.62 ± 0.79 mg/l) as compared to Anchar Lake (28.07 ± 0.70 mg/l) and Dal Lake (24.87 ± 0.54 mg/l) (Fig. 4.1m).

Cluster analysis was applied to find out similarity groups between the sampling stations in these three lakes. It resulted in a dendrogram (Fig. 4.2), grouping all the 10 sampling stations in three lakes into three statistically significant clusters. Cluster 1 which represented low polluted stations (LP) includes station S8, S9 and S10, cluster 2 incudes station S7, S2, S1 and S3, and corresponds to moderately polluted stations (MP). Cluster 3 represents highly polluted stations (HP) and comprises of stations S4, S5 and S6. The three groups correspond with the natural background features and the water
quality characteristics are affected by different environmental impacts/pollutants the stations are exposed to.

Principal component analysis/factor analysis was executed on 13 variables for three lakes with 10 sampling stations in order to identify variation in water quality. An eigenvalue greater than 1 (Fig. 4.3) considered significant (Shrestha and Kazama, 2007) was taken as criterion for extraction of principal components required to explain the variance in the data. The different factors, total variance (%), cumulative variance (%) and component loadings for the three components from the principal components (PC) analysis for three lakes is given in Table 4.1. This analysis led to the explanation of 69.84%, 65.05% and 71.76% cumulative variance in case of Anchar Lake, Khushalsar Lake and Dal Lake respectively. Liu et al., (2003) classified the factor loadings as “strong,” “moderate” and “weak,” corresponding to absolute loading values of > 0.75, 0.75 - 0.50 and 0.50 - 0.30, respectively.

In Anchar Lake, PC1 has strong loading on NH₄-N, DO, NO₃-N, moderate loading on Ca and EC, but has a strong negative loading on T. PC2 explaining has a strong positive loading on BOD, K, Na, moderate positive loading on COD and PO₄. PC3 has strong positive loading on pH and moderate negative loading on EC.

In Khushalsar Lake, PC1 has strong positive loading on DO and Mg, moderate positive loading on NH₄-N, NO₃-N and PO₄ where as strong negative loading on T. The PC2 has a strong positive loading on BOD, COD, moderate positive loading on NH₄-N and pH. PC3 has strong positive loading on Ca, Na and K.

In Dal Lake, PC1 has strong positive loading on NH₄-N, BOD, moderate positive loading on COD, Na, NO₃-N and strong negative loading on DO. PC2 has strong positive
loading on Ca, Mg, moderate positive loading on K and strong negative loading on T. PC3 has moderate positive loading on EC, NO$_3$-N, PO$_4$ and strong negative loading on pH.

Biplot for Principal component analysis 1+2, 1+3 and 2+3 components of water quality for the three lakes is given in Fig. 4.4 - Fig. 4.6.

**Figure 4.2** Dendrogram of cluster analysis based on surface water quality of the sampling stations of three lakes.
Figure 4.3 Scree plot of the eigenvalues of principal components for three lakes.
Table 4.1 Factor loading values and explained variance of water quality parameters of three Lakes.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anchar Lake</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH(_4)-N</td>
<td>0.764</td>
<td>0.498</td>
<td>-0.039</td>
</tr>
<tr>
<td>BOD</td>
<td>-0.042</td>
<td>0.791</td>
<td>0.34</td>
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<tr>
<td>Ca</td>
<td>0.742</td>
<td>0.126</td>
<td>0.335</td>
</tr>
<tr>
<td>COD</td>
<td>0.131</td>
<td>0.723</td>
<td>-0.031</td>
</tr>
<tr>
<td>DO</td>
<td>0.753</td>
<td>-0.292</td>
<td>0.024</td>
</tr>
<tr>
<td>EC</td>
<td>0.657</td>
<td>0.035</td>
<td>-0.612</td>
</tr>
<tr>
<td>K</td>
<td>0.153</td>
<td>0.842</td>
<td>0.019</td>
</tr>
<tr>
<td>Mg</td>
<td>0.544</td>
<td>0.369</td>
<td>0.445</td>
</tr>
<tr>
<td>Na</td>
<td>-0.023</td>
<td>0.829</td>
<td>0.126</td>
</tr>
<tr>
<td>NO(_3)-N</td>
<td>0.838</td>
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</tr>
<tr>
<td>pH</td>
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</tr>
<tr>
<td>PO(_4)</td>
<td>0.022</td>
<td>0.712</td>
<td>-0.138</td>
</tr>
<tr>
<td>Temp</td>
<td>-0.894</td>
<td>-0.029</td>
<td>-0.083</td>
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<tr>
<td><strong>Khushalsar Lake</strong></td>
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<td></td>
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<tr>
<td>NH(_4)-N</td>
<td>0.635</td>
<td>0.516</td>
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</tr>
<tr>
<td>BOD</td>
<td>0.092</td>
<td>0.913</td>
<td>0.112</td>
</tr>
<tr>
<td>Ca</td>
<td>0.277</td>
<td>0.103</td>
<td>0.751</td>
</tr>
<tr>
<td>COD</td>
<td>0.030</td>
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</tr>
<tr>
<td>DO</td>
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</tr>
<tr>
<td>EC</td>
<td>0.035</td>
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<tr>
<td>K</td>
<td>0.237</td>
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</tr>
<tr>
<td>Mg</td>
<td>0.847</td>
<td>0.135</td>
<td>-0.239</td>
</tr>
<tr>
<td>Na</td>
<td>0.300</td>
<td>0.198</td>
<td>0.873</td>
</tr>
<tr>
<td>NO(_3)-N</td>
<td>0.615</td>
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<td>0.008</td>
</tr>
<tr>
<td>pH</td>
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<td>0.557</td>
<td>-0.080</td>
</tr>
<tr>
<td>PO(_4)</td>
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<td>0.290</td>
<td>-0.411</td>
</tr>
<tr>
<td>Temp</td>
<td>-0.765</td>
<td>-0.254</td>
<td>-0.356</td>
</tr>
<tr>
<td><strong>Dal Lake</strong></td>
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</tr>
<tr>
<td>NH(_4)-N</td>
<td>0.881</td>
<td>0.158</td>
<td>0.154</td>
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<td>BOD</td>
<td>0.891</td>
<td>0.095</td>
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<tr>
<td>Ca</td>
<td>0.239</td>
<td>0.762</td>
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</tr>
<tr>
<td>COD</td>
<td>0.738</td>
<td>0.471</td>
<td>0.142</td>
</tr>
<tr>
<td>DO</td>
<td>-0.794</td>
<td>0.385</td>
<td>-0.261</td>
</tr>
<tr>
<td>EC</td>
<td>-0.075</td>
<td>0.471</td>
<td>0.689</td>
</tr>
<tr>
<td>K</td>
<td>0.297</td>
<td>0.525</td>
<td>0.398</td>
</tr>
<tr>
<td>Mg</td>
<td>0.273</td>
<td>0.779</td>
<td>0.195</td>
</tr>
<tr>
<td>Na</td>
<td>0.699</td>
<td>0.216</td>
<td>-0.163</td>
</tr>
<tr>
<td>NO(_3)-N</td>
<td>0.621</td>
<td>0.198</td>
<td>0.624</td>
</tr>
<tr>
<td>pH</td>
<td>-0.083</td>
<td>0.129</td>
<td>-0.831</td>
</tr>
<tr>
<td>PO(_4)</td>
<td>0.353</td>
<td>0.236</td>
<td>0.618</td>
</tr>
<tr>
<td>Temp</td>
<td>0.128</td>
<td>-0.771</td>
<td>-0.277</td>
</tr>
<tr>
<td>Eigenvalues</td>
<td>5.379</td>
<td>2.25</td>
<td>1.69</td>
</tr>
<tr>
<td>Total variance (%)</td>
<td>30.72</td>
<td>21.9</td>
<td>19.13</td>
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<tr>
<td>Cumulative variance (%)</td>
<td>30.72</td>
<td>52.62</td>
<td>71.76</td>
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</table>
Figure 4.4 Biplot for Principal component analysis 1+2, 1+3 and 2+3 component of water quality (Anchar Lake).
Figure 4.5 Biplot for Principal component analysis 1+2, 1+3 and 2+3 component of water quality (Khushalsar Lake).
Figure 4.6 Biplot for Principal component analysis 1+2, 1+3 and 2+3 component of water quality (Dal Lake).
4.4 Discussion

4.4.1 Characteristics of water quality

Water temperature exerts a major influence on the chemical and biological activity and growth of aquatic organisms (Pawar, 2010). pH recorded in the present study was in alkaline range suggesting that the lakes were well buffered throughout the study period. pH range between 6.0 to 8.5 indicates productive nature of water body (Garg et al., 2010). EC depends upon the quantity of dissolved salts present in water (Gupta et al., 2008) and among the three lakes Khushalsar exhibited higher value of EC (0.32 ± 0.02 mS/cm²) as the lake is subjected to high degree of anthropogenic activities such as waste disposal and agricultural runoff. Eutrophic nature of Anchar Lake, Khushalsar Lake and Dal Lake has been attributed to nutrient enrichment (Pandit, 2001). Among the Ca, Mg, Na and K, Ca is the most dominant cation with concentration of 33.45 ± 1.62 mg/l (Anchar Lake), 29.94 ± 1.12 mg/l (Khushalsar Lake) and 27.76 ± 1.24 mg/l (Dal Lake) which is attributed to the predominance of lime rich rocks in the catchment area (Khan et al., 2004). Another factor for higher content of sodium and potassium in fresh waters is the domestic sewage (Bhat et al., 2001). Ca and Mg concentration of freshwater bodies of Kashmir Valley has been associated with thick population of plankton, especially Cyanophyceae (Bhat and Pandit, 2003). Concentration of PO₄ and NO₃-N was highest in Khushalsar Lake (460.08 ± 14.31µg/l and 248.79 ± 6.75 µg/l) followed by Anchar Lake (231.90 ± 12.49 µg/l and 211.86 ± 2.88 µg/l) and Dal Lake (146.13 ± 5.65 µg/l and 185.10 ± 3.90 µg/l). PO₄ enters the lakes through domestic wastewater, accounting for the accelerated eutrophication (Vyas et al., 2006). Increased concentration of PO₄ and NO₃-N in lakes has resulted in enhanced productivity (Pandit and Yousuf, 2002).
Khushalsar Lake recorded a highest concentration of $\text{NH}_4\text{-N}$ ($399.27 \pm 4.42 \mu\text{g/l}$) among the three lakes. Organically polluted waters with high levels of $\text{NH}_4\text{-N}$, which is readily available as a nutrient for plant uptake may contribute to increased biological productivity (Sheela et al., 2010). DO is an essential factor for maintaining aquatic life and its level in lakes also vary according to the lake trophic levels. Lowest value of DO was recorded in Khushalsar Lake ($2.50 \pm 0.05 \text{mg/l}$). Depletion of DO in water probably is the most frequent result of certain forms of water pollution (Srivastava et al., 2009). BOD exhibited a range of $2.57 \pm 0.4 \text{mg/l}$ in Anchar Lake to $3.07 \pm 0.09 \text{mg/l}$ in Khushalsar Lake whereas COD was $24.87 \pm 0.54 \text{mg/l}$ in Dal Lake to $32.63 \pm 0.79 \text{mg/l}$ in Khushalsar Lake. BOD and COD are important parameters that indicate contamination with organic wastes (Siraj et al., 2010). Khuhawari et al., (2009) associated higher value of COD with increased anthropogenic pressures on lakes.

4.4.2 Cluster analysis

Cluster analysis resulted in the development of a dendrogram with groups or clusters based on the different physicochemical parameters. The clusters exhibited high internal (within clusters) homogeneity and high external (between clusters) heterogeneity and corroborates the reports of McGarial et al., 2000. Cluster 1 (LP) is represented by Dal Lake, receive pollutants from non-point sources, i.e., mostly from agricultural and catchment runoff. Cluster 2 (MP) comprises of Anchar Lake and one station of Dal Lake (station 7). Anchar Lake and stations 7 of Dal Lake receive pollutants mostly from point and non-point sources. Point sources include domestic wastewaters and non-point sources include agricultural and catchment runoff. Cluster 3 (HP) is represented entirely by
Khushalsar Lake and receives huge quantities of domestic wastewaters throughout its shoreline as most of the drains of the catchment area have outlets into the lake.

### 4.4.3 Principal component analysis/factor analysis (PCA/FA)

For the data set pertaining to Anchar Lake, among three PCs, the PC1 explaining 30.68% of the total variance, the positive loading on NH$_4$-N, NO$_3$-N and EC has been associated with agricultural runoff (Malik and Nadeem, 2011). The negative loading of temperature is associated with seasonal variation (Jayaraman et al., 2003). The inverse relationship between temperature and dissolved oxygen is a natural process in lakes (Solanki et al., 2010) and at lower temperature the solubility of Ca increases (Jyoti and Akhtar, 2007). Thus PC1 represents agricultural runoff and seasonal variation factor. PC2 explaining 27.34% of total variance and the positive loading on BOD, COD, PO$_4$, K and Na indicates loading of organic matter from domestic wastewaters (Shrestha and Kazama, 2007). Thus PC2 represents pollution from domestic wastewaters. PC3 explaining 11.82% of total variance has positive loading of pH and is attributed to high rates of photosynthesis by autotrophs, where more consumption of carbon dioxide result in rise of pH (Bini et al., 2010) and negative loading of EC has been associated with nutrient assimilation by autotrophs (Lu et al., 2010), therefore PC3 represents biological factor.

For the data sets pertaining to Khushalsar Lake, among the three PCs, the PC1 explaining 25.86% of the total variance has strong positive loading on DO and Mg, moderate positive loading on NH$_4$-N, NO$_3$-N and PO$_4$ where as strong negative loading on T, which is in correlation with the reports of Jeelani and Shah (2006). With negative loading of T interpreted as influence of seasonal variation (Garg et al., 2010). PC1 represents seasonal variation and organic pollution from domestic wastewaters. The PC2
explaining 19.84% of total variance, the positive loading on BOD and COD is correlated with organic pollution (Zhou et al., 2007) due to waste disposal activities. As the lake is used for dumping of organic wastes—food wastes generated from various social/community functions, PC2 thus represents organic pollution. PC3 explaining 19.35% of total variance with positive loading on Ca, Na and K has been attributed to agricultural runoff (Juahir et al., 2011) and thus PC3 then stands for agricultural runoff factor.

For the data set pertaining to Dal Lake, among the three PCs, the PC1 explaining 30.72% of the total variance with positive loading on NH$_4$-N, BOD and COD points to the influence of organic pollution from domestic wastewaters (Zhou et al., 2007). Thus PC1 represents the organic pollution factor due to domestic wastewaters. PC2, explaining 21.91 % of total variance and with positive loading of Ca, Mg and K is linked with parent rock materials in the catchment area (Singh et al., 2006; Khan et al., 2004) and the negative loading of temperature with seasonal variation (Garg et al., 2010) thus PC2 represents lake catchment geology and seasonal variation. PC3 explaining 19.13 % of the total variance and the positive loading on EC, NO$_3$-N and PO$_4$ has been associated with agricultural runoff (Uzarski et al., 2005) thus PC3 represents agricultural runoff factor.

### 4.5 Conclusions

Hierarchical cluster analysis grouped 10 sampling stations of three lakes into three clusters of similar water quality characteristics, between the sampling stations that reflect different physiochemical properties and pollution levels in the lakes. Although FA/PCA did not result in significant data reduction but helped to extract and identify the factors/sources responsible for variation in water quality in three lakes. Factor analysis
revealed that BOD, Ca, DO and temperature are the highly variable parameters in all the three lakes. Principal components obtained through factor analysis indicate that factors responsible for water quality variations are mainly related to domestic wastewaters, seasonal variation, agricultural runoff and catchment geology. Further in all the three lakes inputs from domestic wastewaters and agricultural runoff has resulted in accelerated eutrophication phenomenon. With the identification of the sources of pollution, different measures are needed to control the anthropogenic influx of pollutants to achieve the goal of sustainability of water resources.

References


