6.1. Physico-chemical characteristics of water

Limnological studies include the physico-chemical and biological parameters of fresh waters (Idowu et al., 2013). The interaction of various physico-chemical variables of water not only reflect the productivity and quality of an aquatic ecosystem but also play important role in determining the distribution, composition, abundance and productivity of aquatic organisms (Bagenal, 1978; Boyd and Tucker, 1998; Ghavzan et al., 2006; Tas and Gonulol, 2007). It also gives an insight in understanding the structure and function of a particular water body in relation to its inhabitants. The equilibrium between physico-chemical characteristics of water in shallow lakes and wetlands is an important factor for successful production of aquatic resources (Mustapha and Omotosho, 2005). As water is a binding element between different factors that play a significant role in wetland ecology, water quality and water management is a vital component of wetland conservation programs.

The Kashmir Himalayan lakes and wetlands acts as suitable niches for fish and habitat for a variety of waterfowl, migrating from neighbouring countries, besides being a very rich source of food, fodder and other economically important biological products. These shallow water bodies are undergoing trophic evolution under various natural and anthropogenic factors which makes them to exhibit considerable differences in their physical, chemical and biological set up. Of late, there has been a cry about deterioration of these water bodies and a subsequent decline in their area. The severe biotic interference coupled with cultural activities along the drainage basins are the factors responsible for their degradation. Hence, it becomes imperative to undergo a detailed study of these aquatic ecosystems, as such inventories are basic for management and sustainable development.

The present study carried out on Wular lake revealed appreciable variations in its physical and chemical milieu. Wular lake enjoys special status of being the largest freshwater body within Indian sub-continent and plays a major role in the hydrological regime of the Kashmir valley by acting as a huge absorption basin for floodwaters of Jhelum floodplain. The ox-bow type lake is mono-basined, elliptical in shape and is of fluviatile in origin, formed by the meandering of River Jhelum. Its depth on average is 3.6 m throughout length, reaching 5.8 m at its deepest point (Pandit, 2002). Like most of the Kashmir Himalayan lakes and wetlands, Wular lake is under the influence of varied anthropogenic pressures. The immediate catchment,
comprising mostly of agricultural land and domestic households, has a direct impact on the water quality of Wular lake.

The depth of a water body is one of the major physical factors which act as a controlling factor for determining the water quality. Depth of a water body is determined by the hydrological factors like the amount of water brought in and sent out (Steward and Kantrud, 1971). The depth of the water body under study ranged between a mean maximum of 4.6 m (at Site VII) during spring 2011 as against the mean minimum depth of 0.3 m (at Site I), being recorded during winter 2012. Lower values of mean depth have been used as an important criterion to establish the trophic status of lakes (Hayes, 1957; Pandit, 2002). Further, on the basis of low water depth ranges making a large expanse of wetland zone, Wular lake was in 1990 recognized as Ramsar Site, along with other attributes. The greater water depth in Wular lake during spring is the result of more direct precipitation input than the evaporation output, thus serving as a source of water during spring and as a strong sink for other seasons (Kumar and Pandit, 2005). During summer the total output of water increased by virtue of evapotranspiration and surface water output for irrigation purposes of the adjoining fields which continued throughout the autumn as well. Wular lake, on the basis of low mean depth values (0.3-1.5 m) can be placed in shallow lake type of Buraschi et al. (2005). Depth and water volume are related factors that influences temperature of a water body (Atobatele and Ugumba, 2008). Wular lake, in general, having little depth, did not show any thermal stratification.

Secchi disc transparency, being a function of the amount of light reflected from the surface of water, is influenced by the absorption characteristics of water and the amount of dissolved and particulate matter contained in the water (Wetzel and Likens, 2000). The light in water is of paramount importance for its role in the photosynthetic processes of all chlorophyll bearing aquatic plants and thus for the primary production (Mahar, 2003). The secchi disc transparency showed slight insignificant spatial as well as temporal variations (F= 1.659, P= 0.195), though low transparency of water was found in lake invariably during the spring. The high biological activity particularly that of phytoplanktons and addition of silt-laiden runoff may explain the low values of water transparency recorded in spring (Hakanson and Boulion, 2002). In contrast, the high values of transparency observed during winter may be attributed to the low plankton population and to the reduction in
allochthonous substances that find their way into the lake (Ikomi et al., 2003; Mahar, 2003). Similar observations were made by Mustapha and Omotosho (2005) in Moro lake and Ayoade et al. (2006) in Asejire and Oyan lakes. In Wular lake the littoral macrophytes act as sinks and filter the nutrients and suspended particles, thus helping in maintaining relatively clear water in the limnetic areas (Lindholm et al., 2008). Higher values of transparency at Site VII may be attributed to the presence of dense submerged macrophytic vegetation which acts as effective barrier for sediment resuspension, resulting in improving the transparency (De-Vicente et al., 2006; Huang et al., 2007).

Water temperature is an important factor that influences limnological phenomenon such as stratification, solubility of gases, pH, conductivity and occurrence, distribution and productivity of aquatic organisms as well (Nazneen, 1980; Singh, 1990; Lewis, 2000). It depends on the climate, sun light and depth (Akinyemi and Nwakwo, 2006; Atobatele and Ugumba, 2008). In the present study, the annual cycle of the surface water temperature showed a close relationship to that of air temperature. This type of observation for shallow water bodies is in conformity with the earlier findings of Ried and Wood (1976), Singhal et al. (1985) and Mahar (2003). In the lake under study the atmospheric temperature showed a difference of 27.2 °C (5.1-32.3 °C) while, the water temperature recorded a fluctuation of 22.2 °C (4.2-26.4 °C), thereby showing that the former has a large influence on the latter. The temperature variations recorded during the study were optimal for normal growth and survival of aquatic organisms (Boyd, 1979). Increase in both air and water temperature from April to August is attributed to the increase in solar radiation due to comparatively longer day length. Similarly, a gradual reduction in solar radiation may explain fall in temperature from October to February and again it begins to increase from March onwards. A direct relationship of water temperature with bright sunshine and its duration has also been reported by Munawar (1970) and Harshey et al. (1982).

Specific conductivity, being principally a function of ions and an indication of total salt concentration, is often related with the trophic status of aquatic ecosystems (Berg et al., 1958). Rainfall patterns, incoming waters, evaporation rates, drainage type and nutrient status are the major factors that influence conductivity of a lake (Kinnear and Garnett, 1999). Wular lake, witnessed a seasonal trend and depicted comparatively higher values of conductivity. The seasonal fluctuations in conductivity
of waters is mostly related with biological activity as the low value during summer months is due to uptake of ions by macrophytes and their attached microflora during their growing season along with precipitation of calcium carbonate which is the main contributor to conductivity (Otsuki and Wetzel, 1974; Vymazal, 2002; Mustapha and Omotosho, 2005). Absence of most of the vegetation during winter causes accumulation of nutrients in the water, hence higher specific conductivity was recorded during the winter evincing lowest biological activity (Kumar and Pandit, 2007; Bhat, 2010). The strongly significant positive correlation of conductivity with calcium (p<0.01, r = 0.964) and alkalinity (p<0.01, r = 0.953) suggests that these parameters have a major influence on the conductivity of the lake. Wular lake, on the basis of specific conductivity (200-500 µScm⁻¹), can be placed in β-mesotrophic category of Olson (1950).

Total dissolved solids (TDS) indicates the amount of organic and inorganic matter in the samples. Total dissolved solids are very useful parameters describing chemical constituents of the water and can be, in general, related to the edaphic factor that contributes to the productivity of the water body (Goher, 2002). Depending upon solubility of minerals the concentration of total dissolved solids (TDS) in water varies in different geological regions (Connolly et al., 1990). Total dissolved solids followed the same trend as that of specific conductivity, witnessing its peak amount during winter and then following a decline to reach the lowest value during summer where after an increasing trend was evinced towards the autumn. The highly significant perfect positive correlation between total dissolved solids and conductivity was evident from the results which was proved statistically (p<0.01, r = 0.999). The seasonal fluctuations in TDS values of waters is mostly related with biological activity as the low concentration during summer months is due to very high macrophytic cover in Wular lake which enhances sedimentation and counteracts resuspension of sediment particles, and therefore restricts the return of nutrients from sediments (Sondergaard et al., 1992; Kufel and Kufel, 2002; Bhat, 2010). Absence of most of the vegetation during winter causes accumulation of salts ions in the water, hence higher TDS values were recorded during the winter evincing lowest biological activity (Sondergaard et al., 2003).

The free CO₂ depicted well marked seasonal fluctuations at all the sites, registering a minimum values (5.7±0.6 mg/L at Site IV) in summer and a maximum
in winter (24.3±3.5 mg/L at Site VI). The lower values of free carbon dioxide in Wular lake during summer is due to removal of carbon dioxide from the water column by the photosynthetic activity of phytoplankton and macrophytes (Otsuki and Wetzel, 1972; Kaul and Trisal, 1984; Wetzel, 2001), as well as the important role of temperature in increasing photosynthetic activity (Aboul Kassim, 1987). In contrast, the higher values of free carbon dioxide during winter may be attributed to the higher CO$_2$ content produced as a result of algal degeneration, as well as the increased decomposition of organic matter under least water depth (Reimer et al., 2008). The high value of the free carbon dioxide content is an indication of high degree of pollution (Todd, 1970; Cole, 1979). An inverse relation between carbon dioxide and pH was found which is in consonance with the observations made by Swarup and Singh (1979), Jhingran (1982) and Mahar (2003).

Dissolved oxygen is a parameter of immense importance in aquatic ecosystems and is considered to be the most reliable criterion in assessing the trophic status and magnitude of eutrophication of aquatic ecosystems (Edmondson, 1966; Wetzel, 2001). In aquatic ecosystems, the dissolved oxygen is the fundamental factor that reveals more about the metabolism of the aerobic aquatic organisms than any other single measurement and, therefore, its dynamics is important for the understanding of their distribution, behaviour and growth (Wetzel, 2001). Being required by producers, consumers and decomposers, dissolved oxygen, therefore, regulates nutrient availability and hence productivity of aquatic ecosystems (Wetzel, 2001). The dynamics of oxygen distribution in lakes is governed by balance between inputs from atmosphere and photosynthesis and losses by way of chemical and biological oxidation (Wetzel, 2001; Gupta and Gupta, 2006). The ability of water to hold oxygen is greatly affected by the temperature of the water body (Wetzel, 2001; Singh, 1990). The results of the present study showed that Wular lake had adequate dissolved oxygen with a mean concentration ranging from 6.7 mg l$^{-1}$ to 9.6 mg l$^{-1}$. Contrary to the findings of Egborge (1994), dissolved oxygen showed inverse relationship with temperature in Wular lake. Lower levels of dissolved oxygen in summer than the other seasons could be due to the combined effect of the rise in temperature, increased biological activity, respiration of organisms and the increased rate of decomposition of organic matter (Lewis, 2000; Okbah and El-Gohary, 2002). In productive lakes and wetlands like Wular, during periods of maximum biotic
activities, there is discernible oxygen deficit on account of respiration by organisms especially algae and the oxidation of organic humus (Wetzel, 2001; Mwaitega, 2003; Kumar and Pandit, 2007). Conversely, high dissolved oxygen concentration during winter can be attributed to low biological activity, under saturation of oxygen, low temperature and instability of water masses, caused by loss of sufficient heat (Serruya and Serruya, 1972; Idowu, 2013). At Site VII high concentration of dissolved oxygen is due to luxuriant growth of submerged macrophytes which act as main sources of aeration for the lake, thereby enhancing light penetration and hence photosynthesis (Kumar and Pandit, 2007; Srivastava et al., 2008). The strong positive correlation between transparency and dissolved oxygen in the Wular lake also substantiate the fact that increased transparency increases dissolved oxygen content by enhancing photosynthetic input.

Wular waters were alkaline with pH ranging from 7.1 to 8.5 recorded over a period of two years. pH, principally a function of amounts of calcium, magnesium, carbonates and carbon dioxide in the water expresses the intensity of acidity or alkalinity of an aqueous solution (Wetzel, 2001). The interaction of both the $H^+$ generated by dissociation of $H_2CO_3$ and $OH^-$ produced during the hydrolysis of $HCO_3^-$ governs the pH of natural waters to a large extent (Wetzel, 2001). Both spatial as well as temporal variations in pH were found to be statistically significant in Wular lake ($F= 23.06, P< 0.01$). The gradual increase in pH during summer is due to removal of carbon dioxide from the water column by the photosynthetic activity of phytoplankton and macrophytes (Otsuki and Wetzel, 1972; Nassar and Dutta-Munshi, 1975; Wetzel, 2001). Large pH changes of one unit or more have been reported under a combination of low to moderate alkalinity and high algal or submerged macrophyte biomass resulting in large daytime $CO_2$ and $HCO_3^-$ withdrawal (depletion), thereby increasing pH (Boyd, 1990). On the other hand, lower pH during winter is because of the increased decomposition of organic matter under least water depth (Reimer et al., 2008). The pH variations recorded during the present study fall within the recommended range for the support of aquatic life (Boyd, 1979; Kamran et al., 2003).

In aquatic ecosystems the concentration of chloride is not only an index of eutrophication, but also of pollution caused by sewage and other waste waters (Munawar, 1970; Hasalan, 1991; Berzas-Nevado et al., 2009). Dissolution of rock minerals, pollution and run off from catchment area are the major sources of chloride.
The concentration of chloride is generally low in natural waters and its higher amount always comes from the contamination of sewage. In general, the waters of Wular showed high amounts of chlorides ranging from 7.3 mg l\(^{-1}\) to 22.7 mg l\(^{-1}\). Lake waters, during both the years of study, recorded very noticeable seasonal trend in the amounts of chloride, registering its highest during spring and lowest during winter at all the sites. However, clear spatial variations occurred in the lake with sites in the vicinity of human habitation (Site IX) receiving domestic sewage depicting higher concentration of the ion. The higher amount of chloride during spring season is attributed to inflow through direct precipitation and subsequent run-off from the catchment area. This viewpoint further gains support from the recent studies of Bhat et al. (2001), Kumar et al. (2004), Kumar and Pandit (2007) and Bhat (2010), who opined that the high chloride content, an indicator of organic pollution, owes its origin to the influx of sewage from human settlement. Metabolic utilization of chlorides does not cause significant variations in spatial and seasonal variations within a water body and therefore, the variations observed in Wular lake can be associated with hydrological factors like inflow through direct precipitation and run-off reaching the lake through inflow channels.

In fresh water ecosystems the hardness of water is mostly governed by the carbonates and bicarbonates of calcium and magnesium (Cole, 1983). The type of minerals in the soil and watershed bedrock, and the amount of lake water coming into contact with these minerals are the major factors that influence hardness of a lake (Tepe et al., 2005). The hardness was significantly higher in winter months as compared to summer months. This may be due to the high density of macrophytes and plankton in summer which use most of the salts for their growth and life processes, thereby increasing the pH of water and accelerating the de-calcification, resulting in decrease of hardness (Wetzel, 2001; Kufel and Kufel, 2002; Kumar and Pandit, 2007; Bhat, 2010). This is also substantiated by highly significant positive correlations of pH with total hardness (p<0.01, r = -0.907), calcium content (p<0.01, r = -0.907) and magnesium content (p<0.01, r = -0.888) in this lake.

Calcium is generally the dominant cation in Kashmir lakes on account of the predominance of lime rich bed rock in the catchment area (Zutshi et al., 1980; Pandit, 1993). The amounts of Ca \(^{2+}\) depicted summer fall in Wular lake, a trend similar to that of alkalinity, due to uptake of CO\(_2\) by photosynthetic activity especially by...
submerged and subsequent precipitation of calcium as calcium carbonate as a result of combination of elevated temperature in macrophytes beds and reduced CaCO₃ solubility (Kaul and Trisal, 1984; Wetzel, 2001; Kufel and Kufel, 2002; Kumar and Pandit, 2007). The deposition of calcite crystals is easily seen on submerged plants in the lake as white encrustations.

Like calcium, magnesium also varied seasonally in the lake with decrease in its concentration during summer months corresponding to peak growth of macrophytes. Low values of magnesium content in summer period is possibility due to its uptake by the plants in the formation of chlorophyll-porphyrin metal complexes and in enzymatic transformation (Wetzel, 1975). This is also substantiated by significant positive correlation of magnesium with calcium content (p<0.01, r = 0.975). The dominance of calcium over magnesium in Wular lake could be attributable to calcium rich lime rocks in the catchment (Zutshi, et al., 1980; Pandit, 1993; Jeelani and Shah, 2006).

Alkalinity, the acid consuming capacity of water, is mainly imparted by the presence of HCO₃⁻ and CO₃²⁻. Most of the alkalinity present in water is due to dissolution of carbonates and aluminosilicates (Das and Dhiman, 2003). The formation of carbonic acid by the interaction of CO₂ and H₂O in soil play significant role in the dissolution of carbonate rocks in the catchment, producing calcium bicarbonate which is soluble in water and this increases the alkalinity of the water (Wetzel, 2001). In the present investigation, the alkalinity of water was exclusively due to bicarbonate ions. However, there was a predominance of bicarbonates and calcium over chloride and magnesium as is true for all fresh waterbodies (Rodhe, 1949). On the basis of total alkalinity values, Wular lake can be categorised as “hard water type “as per the classification of Moyle (1945). The total alkalinity depicted summer minima in Wular lake, a trend opposite to that of pH, due to removal of CO₂ and HCO₃⁻ by the photosynthetic activity of phytoplankton and macrophytes which exhibit luxuriant growth during this period. Thus, this increases pH and consequently shift the chemical equilibrium towards the formation of carbonate ions which then precipitate with calcium in the form of calcite that significantly leads to decline of alkalinity (Stumm and Morgan, 1996; Wetzel, 2001; Kufel and Kufel, 2002). The strongly significant negative correlation of alkalinity with pH (p<0.01, r = -0.799) suggests that pH has a major influence on the alkalinity of Wular lake. In contrast, the
higher values of total alkalinity during winter may be due to fall in water level. Researchers like Cook and Powers (1958) and Singhal et al. (1986) also reported that bicarbonates increase with the fall in water level.

The most abundant minerals in the earth’s crust are aluminosilicate minerals (Schlesinger, 1997) but, due to their limited solubility, they are not the major dissolved ion in water (Stumm and Morgan, 1981). Lower silicate values were recorded in Wular lake during winter for all sites. This may be due to the slow rate of regeneration of silicate from the sediments as well as to the decreased decomposition of siliceous compounds under the influence of oxygen rich waters (Kinawy, 1974; Okbah and El-Gohary, 2002). In contrast, the higher content of silicate in spring and summer months is a result of inflow through direct precipitation and subsequent run-off from the catchment and increased silt laden inflow from inlet channels into the lake. This viewpoint further gains support from the studies of Okbah and El-Gohary (2002) who opined that the high content of reactive silicate is directly proportional to drainage water discharged into a lake. Further, the solubility of silica is known to increase at higher pH values and higher temperatures (Willen, 1991) and, therefore, a combination of warm water and elevated pH values may have caused the observed enhanced silicate concentrations during spring and summer months. The slight higher values of silicate obtained in the present study suggest the dissolution of aluminium silicate minerals in the rocks that are found around the lake.

Phosphorous is the key nutrient which controls the reproduction and growth of aquatic organisms (Wetzel, 2001; Sondergaard et al., 2003a, b; Mehner et al., 2008). Many organisms utilize both organic and inorganic forms of phosphorous; however plants have been reported to preferentially take up the inorganic phosphorous than organic phosphorous (Riley and Chester, 1971). There was a general trend of decrease in the concentration of dissolved inorganic phosphorus during summer months owing to its utilization by primary producers and its precipitation induced by photosynthesis. The increased pH associated with high temperature and higher alkalinity are favourable for precipitation of calcium carbonate due to rapid carbon assimilation from dissolved bicarbonates and under such conditions phosphate ion is reported to co-precipitate with carbonate (Kaul and Trisal, 1984; Wetzel, 2001; Dittrich et al., 2004). The high concentration of both the forms of phosphorous during winter months may be due to decay and subsequent mineralization of dead organic matter (Cole,
The strong positive correlation between the two forms of phosphorus in Wular lake (p<0.05, r = 0.792) suggests their co-fluctuation. The concentration of total phosphate phosphorous was quite high as compared to the orthophosphate phosphorous. Thornton and Nduku (1982) suggested the values of dissolved inorganic phosphorus >30 μg/L as indicative of eutrophic status in temperate lakes. The average concentration of both total phosphorus and orthophosphate phosphorus, remained generally high placing the wetland in hypertrophic category according to Wetzel (1983). This is substantiated by the fact that almost the whole water body is infested by the macrophytes, which is possible only when this important nutrient is available in sufficient quantities (Shah and Pandit, 2012).

In aquatic ecosystems the rate of nitrification is regulated by factors like NH$_4^+$ availability, pH, temperature, dissolved oxygen concentration and organic carbon availability (Triska et al., 1990; Verhagen and Laanbroek 1991; Jones et al., 1995; Strauss and Dodds, 1997; Strauss and Lamberti, 2000). On the other hand, the distribution of ammonia, the end-product of the breakdown of nitrogenous organic and inorganic matter in soil and water as well as excretion by biota and reduction of nitrogen gas by microbes (Wetzel 2001), is highly variable in lakes and depends upon the level of productivity, sewage inflow, decomposition, input of nitrogen fertilizers and organic loading (Heathwaite and Johnes, 1995; Ogato, 2007; Lumbreras, et al., 2009). The higher level of nitrate-nitrogen than ammonical-nitrogen is probably related to the fact that plants have been reported to preferentially take up the reduced NH$_4^+$ rather than oxidized NO$_3^-$, so that lower levels of ammonia occur in water (Kalff, 2002). The spatial and temporal variations within the lake were obvious for both the forms of nitrogen. The decrease in their concentration from spring till late summer is related to rapid uptake and assimilation by autotrophs i.e., phytoplankton and macrophytes which exhibit luxuriant growth during this period (Xie, et al., 2004; Shilla et al., 2006; Bhat, 2010). It has been emphasized that quick flushing away of nutrients during high water level periods (spring and summer) may also be the possible reason for low nitrogen content in waters which again seems to be true for Wular waters (Kaul, 1977; Mwaitega, 2003). The strong positive correlation between the two forms of nitrogen in Wular lake (p=<0.01, r = 0.903) suggests their co-fluctuation. The increase in NO$_3^-$N concentration during winter may be attributed to the fact that under high oxygen concentration, the nitrogen rich sediments add
appreciable quantity of nitrate-nitrogen to the water (Kaul and Trisal, 1984; Kumar and Pandit, 2007). On the other hand, the winter increase in the concentration of ammonia may be due to decomposition of organic matter (Kaul and Trisal, 1984; Wetzel, 2001; Okbah and El-Gohary, 2002) and bird droppings into the lake as it is visited by many aquatic birds (Zuber, 2007).

Iron is an important micronutrient of microflora, plants and animals as it plays an important role in many enzymatic transformations. The quantity of total iron in oxygenated surface waters of neutral or alkaline lakes ranges from about 50-200 µg/L and much higher levels may occur in certain alkaline and closed lakes rich in organic matter. A perusal of the data revealed that there was a summer fall in total iron content in the lake waters. The autumn and spring season registered modest amounts of total iron and the values peaked during winter. Similar observations were made by Kumar and Pandit (2007) in Hokersar wetland, Kashmir Himalaya and Ramesh and Selvanayagam (2013) in Kolavoi lake, India. On the other hand, the winter increase in the concentration of total iron may be due to the release of phosphorus bound iron compounds from the sediments at lower pH during mineralization (Golterman, 2001). Akram (1992) related higher iron content in lake waters to agricultural activities and increased diffusion of ferrous ion from the sediments at lower oxygen concentration near the sediment surface.

6.2. Vegetation
6.2.1. Species composition

Biotic communities are dynamic in nature changing more or less regularly in time and space. There exists direct relationship between environmental conditions and structure and function of biotic communities as any change in the environment is manifested by changes in the structure and function of the community. Macrophytes constituting ecologically dominant community of shallow lakes and wetlands, therefore, form an important tool for biomonitoring of such ecosystems (Wetzel, 2001; Lacoul and Freedman, 2006).

The present study on Wular lake revealed clear differences in the community structure of macrophytes. Even though all the life-form classes viz., emergents, rooted floating-leaf type, submergeds and free floating type constituted the macrophytic community of the wetland, their contribution to overall community structure varied considerably. The wetland not only depicted spatial variability in species composition
but significant spatial differences were also observed regarding various community characteristics and, therefore, community architecture. This could be due to the presence of significant variations in physicochemical variables that determine the species composition and community architecture of macrophytes (Wetzel, 2001; Jafari et al., 2003).

It is well known that aquatic plants show relatively little taxonomic differentiation compared with the terrestrial groups (Less, 1988; Cook, 1990). The amount of evolutionary diversification dwindles as one goes from amphibious and emergents groups to fully submerged hydrophytes. Since the wetland ecosystems, as in case of Wular lake, represent the transition between the two extreme diversifications, sustaining both amphibious as well as purely aquatic taxa, harbour a very complex taxonomic makeup of the macrophytic community (Smith, 1980). In Wular lake, unlike lakes, no typical macrophytic zonation was distinguishable; instead various macrophytic species either grow intermixed with one another which result in the complex physiognomy of the wetland vegetation or grow in pure communities to form a characteristic type of vegetation which differs qualitatively and quantitatively from the lake vegetation. According to Wilson and Keddy (1986) complex macrophytic physiognomy and multi-specific meadow formations in the wetlands is an example of mutualism, where neighbours help to protect other plants from the damage caused by waves. The study revealed that the wetland harbours the mixed vegetation comprised of families, both advanced (e.g., Asteraceae) as well as primitive (e.g., Alismataceae). Though the open water areas of Wular lake exhibited the growth of all the types of macrophytes growing intermixed, the emergents outnumbered all other life-form classes of macrophytes in the wetland which could be due to their ability to tolerate greater water-level fluctuations (Kumar and Pandit, 2008; Tamire and Mengistou, 2012). Moreover, emergents also depicted greater variations regarding species composition compared to other life-form classes.

6.2.2. Community features

Significant spatial and temporal and variations were found in the density and abundance of macrophytes in Wular lake during the two years of study period. This is in consonance with the results of many other workers who reported a definite seasonality in the density and diversity of macrophytes in their studies (Pompeo and Moschini-Carlos, 1996). According to Pompeo and Moschini-Carlos (1996), the
seasonal variation in the density of macrophytes is attributable to seasonal fluctuations in water levels. The presence of significant difference in density and abundance of macrophytes in Wular lake could be due to the presence of significant seasonal variation in physicochemical variables that determine the density and abundance of macrophytes (Barko et al., 1991; Wetzel, 2001; Jafari et al., 2003). Further, the density and abundance of these macrophytes in the lake seems to be affected by differences in the nutrient levels among sites, and their ability to colonize these varied sites indicates their potential to adapt to diverse trophic conditions. Their density was higher at sites where nutrient concentrations were higher, which implies that increase in the concentration of nutrients particularly nitrogen and phosphorus in the lake to a certain level would further encourage infestation by these macrophytes (Heegaard et al., 2001; Murphy, 2002). The strong positive correlation between density and nutrients in the Wular lake also substantiate the fact that increased nutrient concentration increases the diversity of macrophytes. The study of IVI values revealed that *Lemna-Salvinia* complex dominated all the sites and was co-dominant at Site II indicating its absolute dominance over other species in the Wular lake. The dominance of *Lemna-Salvinia* weed complex over other species is attributed to its high aggressive capacity, colonization of sites rich in organic matter and also lake littorals (Pandit, 2008). The author further opined that there occurs a shift in the under-water vegetation by the development of *Lemna-Salvinia* association with excessive eutrophication resulting in the replacement of *Potamogeton lucens* by more eutrophic *Ceratophyllum demersum*. In the present study it was growing as free floating at all the sites indicating the high pollution load of Wular lake.

### 6.2.3. Species richness

Species richness in the wetland under study reflected a seasonal trend with maximum richness being recorded during summer and early autumn. Grime (1973) opined that perturbations increases the species richness by allowing new species to establish which seems to be a probable explanation for greater species richness in Wular lake where water draw-down during summer, the main growing season, results in the invasion of new species and the subsequent richer and diverse growth of emergents and rooted floating-leaf types. The study further gains support from the findings of Nurminen (2003), who reported that higher turbidity and fluctuations in water level limits the distribution of macrophytes to mainly turbidity tolerant species,
for example rooted floating-leaf types and emergents. Temperature can influence plant performance, especially photosynthetic rates and is considered to be the single environmental variable profoundly influencing the propagule germination and shoot elongation in many aquatic plants over the whole range of their occurrence (Gorham, 1974; Madsen and Adams, 1988; Pilon and Santamaria, 2002). In the present study it also seems that temperature have profound influence on the species richness and diversity of macrophytes. The diverse growth for most of the macrophytes corresponds to the period of maximum atmospheric temperature. Further, the species richness and diversity during spring were found to be lower which might be due to higher precipitation and comparative low temperatures during spring. There seems to be a greater correlation between species diversity and lake area as Wular lake depicted higher species diversity and species richness. A few studies have indicated that this relationship may be due to the habitat heterogeneity, as larger lakes encompass more microhabitats more species are able to find a suitable habitat with increasing area (Rorslett 1991; Jones et al., 2003; Heegaard, 2004; Capers et al., 2010). Further, greater diversity of macrophytes in Wular lake seems to be linked with its slightly eutrophic status (Heegaard et al., 2001; Lougheed et al., 2001; Murphy, 2002).

6.2.4. Distribution and zonation

Macrophytes play an important role in the structure and functioning of freshwater ecosystems (Wetzel, 2001; Hrivnak et al., 2009). The function of macrophytes in these ecosystems is related to their structural attributes like species composition, distribution, abundance and diversity which in turn depend on a myriad of factors. Foremost, among these are light, depth and fluctuations in water levels, water temperature, water quality changes and nutrient enrichment and sediment composition (Kaul et al., 1978; Pandit 1984, 1992; Barko and Smart, 1986; Wetzel, 2001; Hudon et al., 2004). In Wular lake, unlike lakes, no typical macrophytic zonation was distinguishable; instead various macrophytic species either grow intermixed with one another which result in the complex physiognomy of the wetland vegetation or grow in pure communities to form a characteristic type of vegetation which differs qualitatively and quantitatively from the lake vegetation. However, the distribution patterns of macrophytes depicted considerable spatial variations in Wular lake. This is possibly due to the significant spatial difference in the physical and
chemical properties of Wular lake waters (Toivonen and Huttunen, 1995; Sraj- Krzic et al., 2007).

Water depth is considered to be the major factor in affecting the distribution of macrophytes (Spence, 1982; Daniel et al., 2006). In the present study it also seems that water depth acts as a major factor in affecting distribution patterns of emergent and submerged macrophytes. This is because the maximum area under emergents was present at the shallowest Site I where large aggregations of emergents plant species are found distributed throughout. Moreover, this site also harbours lesser number of submerged macrophytic species. Among emergent macrophytes *Typha angustata* and *Phragmites australis* were the dominant ones and were widely distributed over the entire littoral zone of the wetland. *Myriophyllum verticillatum*, *Polygonum hydropiper* and *Polygonum amphibium* were also seen scattered all over the emergent zone. The dense population of emergent vegetation in the littoral zone seems to be linked with the decreased depth of the wetland caused by increased siltation carried from the catchment area by its inlets. It is in agreement with the findings of Wetzel (1983) and Tamire and Mengistou (2012) who reported that decreasing water level indicates a succession towards a marsh.

Rooted floating-leaf type macrophytes (*Nymphoides peltatum* and *Trapa natans*) also form widespread dense beds in Wular lake. This is due to the higher turbidity and fluctuations in water level that limits the distribution of macrophytes to mainly turbidity tolerant species, for example rooted floating-leaf types and emergents (Nurminen, 2003). Moreover, the increased water depth at certain portions of the Wular lake results in the establishment of rooted floating-leaf type macrophytes which is further corroborated by the studies of Spence (1967, 1982) who suggested an adaptive connection between deep waters and broad-leaf species. As the floating-leaf species are capable of growing under permanently inundated conditions in Wular lake, it appears that they are capable of anaerobic metabolism (Kaul et al., 1978).

It has been well emphasized that the distribution and growth of aquatic macrophytes is associated with nutrient rich environments particularly nitrate and phosphate which have been noted to favour macrophytes growth (Frankouich et al., 2006). Several studies have established that the nutrient enrichment can cause significant changes in the density, species composition and richness of aquatic vegetation in lakes (Lougheed et al., 2001; Rosset et al., 2010; Alahuhta, 2011).
Greater species richness at Site I in Wular lake can also be linked to the increase in the concentration of nutrients particularly nitrogen and phosphorus at this site. This is due to the fact that increase in the concentration of nutrients particularly nitrogen and phosphorus in freshwater ecosystems to a certain level would encourage infestation by macrophytes (Heegaard et al., 2001; Murphy, 2002). Further, emergent macrophytes have also been reported to be very efficient in the uptake of many plant nutrients from the sediments and thus helping in pollution abatement (Pandit, 1984, 1992). The strong positive correlation between density of macrophytes with ammonical-nitrogen (p<0.01, $r = 0.733$) and orthophosphate-phosphorus (p<0.01, $r = 0.765$) in the Wular lake suggests that nutrients can cause considerable changes in the density and distribution of macrophytes.

Among the varied environmental factors affecting the distribution of submerged macrophytes water depth and water transparency associated with light availability are of paramount importance (Spence, 1982; Chambers and Kalff, 1985; Daniel et al., 2006). It is well documented that the underwater light plays an important role in determining the depth distribution of different groups of aquatic macrophytes (Sculthorpe, 1971; Chambers and Kalff, 1985; Dale, 1986; Chambers and Prepas, 1988; Hrivnak et al., 2006). A number of reports indicate that certain species of aquatic macrophytes, mostly submerged ones, usually extend into the depths in order to maximize their absorption of the light and CO$_2$ needed for photosynthesis (Barko and Smart, 1981; Maberly and Madsen, 2002). Submerged macrophytes have also been reported to grow to a depth of two to three times the Secchi depth (Chambers and Kalff, 1985). In the present study it also seems that the distribution of submerged macrophytes is mainly dependent on water depth and transparency. This is because submerged macrophytes cover the maximum area at Site VII in Wular lake due to its greater depth and transparency. This observation is further confirmed by the significant positive correlation of density of submerged macrophytes with transparency (p<0.01, $r = 0.891$) and water depth (p<0.01, $r = 0.806$). In Wular lake, despite moderate depth, submerged forms except a few did not show luxuriant growth because of greater water turbidity (Gasith and Hoyer, 1998) and dense growth of rooted floating-leaf type macrophytes which limit light penetration. Data on physico-chemical parameters of Wular lake reveals lower
transparency in the lake resulting in the suppression of this life form. However, the dominance of *Ceratophyllum demersum* among submergeds seems to be linked with its adaptation to the low irradiation conditions which are practically prevalent in Wular lake (Vander Valk and Bliss, 1971). On the other hand, Hernández *et al.* (1999) and Foroughi *et al.* (2010) further opined that the dominance of *Ceratophyllum demersum* is due to its high vegetative propagation, lack of true roots, and high surface area: volume ratio, which makes it a strong competitor for nutrients. A number of studies indicate that nutrient enrichment is responsible for the changes that occur in the species richness, composition, and density of aquatic vegetation in lakes (Bini *et al.*, 1999; Magee *et al.*, 1999). Our results confirm that diversity of submerged macrophytes in Wular lake declines with deterioration in water quality. This is in consistent with the study of Lougheed *et al.* (2001) who also found reduced species richness of submerged macrophytes with the deterioration in water quality.

Temperature can influence plant performance, especially photosynthetic rates and is considered to be the single environmental variable profoundly influencing the propagule germination and shoot elongation in many aquatic plants over the whole range of their occurrence (Gorham, 1974; Madsen and Adams, 1988; Pilon and Santamaria, 2002). In the present study it also seems that temperature have profound influence on the diversity and distribution of macrophytes. The diverse growth of most of the macrophytes corresponds to the period of maximum atmospheric temperature. The strong positive correlation between density of free floating macrophytes and water temperature (p<0.05, r = 0.702) in the Wular lake also validate the fact that the temperature can cause significant changes in the density and distribution of macrophytes. This is in consistency with the findings of other studies (Vilbaste *et al.*, 2008; Hrivnak *et al.*, 2009b).

6.2.5. Diversity indices and cluster analysis

The diversity indices, being more reliable, incorporate species richness, commonness and rarity in an integrated manner (Washington, 1984). Various diversity indices pointed towards the heterogeneous species composition and complexity of Wular lake. In the present study the Shannon’s Diversity Index (H) showed high diversity of macrophytes at Site VII (3.06) and lowest at Site IX (2.38). The low diversity at Site IX may be related to high concentration of ammonia and low transparency (Kufel and Kufel, 2002). Gerritsen *et al.* (1998) reported that as the
number and distribution of taxa (biotic diversity) within the community increases, so does the value of “H”. Moreover, the reasons for high diversity at Site VII may be due to slightly lower nitrate and phosphate concentration and relatively high transparency (Oertli et al., 2000). The Simpson’s Diversity Index showed low variability with Site V recording the highest value of 0.989 while Site I recorded the lowest value of 0.939. According to Magurran (2004) Simpson Index is heavily weighted towards the most abundant species in the sample and being less sensitive to species richness. A greater value of Simpson Diversity Index at Site V is an indication of increase in the diversity and abundance of macrophytes at this site. The Sorenson’s similarity index based on species composition indicate that Site I had high degree of similarity with Site VI (81.3 %), which may be due to their littoral nature and similarity in their water characteristics as was observed during the present study. Moreover, these sites have almost similar dominance pattern of macrophytes which may also have resulted in high similarity between the sites. Further Bray-curtis cluster analysis also showed greater similarity between Site I and Site VI (78 %) which is also an indication of similar dominance pattern of macrophytes between the sites.

6.2.6. Primary productivity of macrophytes

The productivity of an ecosystem is vital and indispensable for ecosystem analysis as the same integrates the cumulative effects of the various physiological processes and interactions occurring simultaneously within the ecosystem (Jordan, 1985). According to Odum and Barrett (2008) the primary productivity of an ecological system is the rate at which radiant energy is converted to organic substances by the photosynthetic and chemosynthetic activity of the producer organisms. The aquatic resources have been till date the potential source of organic production for the entire living organisms. Many ecologists of the world have laid emphasis on the importance of the primary productivity as an important functional attribute of the biosphere because of its controlling effects on the rate of multiplication and growth of the living organisms of the ecosystem (Westlake, 1963). The productivity of a lake is often reflection of its nutrient status and trophic level. On the other hand, the productivity of aquatic macrophytes is often related with the growth form strategy of the species.

The present study reveals that the emergent macrophytes contribute more than 50 % of total macrophytic production in Wular lake. Though these macrophytes
occupy lesser area as compared to rooted- floating leaf types and submersed, they are unique in utilizing the available space and light with maximum efficiency and great economy because they are capable of regulating spatial patterns, particularly in leaf density and leaf inclinations, to distribute light evenly between the photosynthetic tissues and optimize light utilization efficiency as the terrestrials do (Wetzel, 2001). Besides, emergent macrophytes contain structural tissue whose cell walls are heavily thickened with cellulose, which is relatively refractory to rapid microbial decomposition (Atkinson and Cairns, 2001). The large underground stems and perennial roots and rhizomes of emergent macrophytes give them an edge over the other life-form classes in biomass accumulation (Wetzel, 1983, 2001). On the other hand, the other life-form classes, especially free-floating type and submersed, on account of the strong drag and pull force generated by the moving water, cannot maintain their well defined three dimensional structures, do not trap much of the solar radiations, thus depicting lower rates of primary productivity (Westlake, 1965).

During the present investigation, emergent species of *Typha angustata* and *Phragmites australis* dominated the production in Wular lake whereas free-floating species were least productive with submersed and rooted floating-leaf types as intermediates. Dominance of emergents in terms of productivity has also been reported by Westlake (1969), Dykyjova (1971), Wetzel (1975, 2001), Kumar (2009), Rather (2009), Atkinson *et al.* (2010) and Khan and Shah (2010). The annual primary production of emergent stands is sometimes the highest of all the populations in the temperate zone and it is generally accepted that helophyte coenoses are the most productive of plant communities (Westlake, 1963, 1965; Wetzel, 2001). Net primary productivity for temperate areas ranges from 900 to 5500 gdw. m$^{-2}$ yr$^{-1}$ (Mitsh and Gosselink, 1986). Shoot density also influences the primary production of aquatic macrophytes to a greater extent. The higher production of emergent macrophytes is directly related to highest shoot density. It is due to the fact that with the increasing water depth the shoot diversity decreases causing a decrease in productivity and most emergents also suffer significantly decreased growth in response to a large, sudden depth increase (Wetzel, 1983, 2001; Tamire and Mengistou, 2012). In accordance with the above mentioned attributes it is predictable that emergent macrophytes in Wular lake have greater shoot types for their greater productivity over others.
On the other hand, the macrophytes with floating leaves occupied an intermediate position between submergeds and emergents, being dependent on water for support and yet having some access to both gaseous as well as aqueous carbon dioxide sources (Kaul et al., 1978; Camargo and Florentino, 2000). The rooted floating-leaf type species such as Nymphoides peltata characterized by a long flowering period are often found to accumulate more biomass compared to the submergeds (Marion and Paillisson, 2003). The higher productivity of rooted floating leaf-type macrophytes compared to submergeds could also be attributed to the increased water depth of Wular lake that results in greater establishment of rooted floating-leaf type species (Kaul et al., 1978; Pandit, 2008). In addition to these factors, the biomass production dynamics is significantly affected by biotic factors such as the rate of colonization by epiphytic organisms, which is especially conspicuous in the case of species with large leaf area (Hopson and Zimba, 1993). The productivity values recorded in the present study for various rooted floating-leaf type species are somewhat similar to the values reported by Kaul et al. (1978), Brock et al. (1983) and Ravinder (2009). In Wular lake, Trapa natans, Nymphoides peltatum and Nymphaea mexicana were, however, the main constituent species of rooted floating-leaf zone and contributed a great deal towards annual production.

The production of submergded macrophytes is mainly determined by light penetration contrary to the rooted floating-leaf types which not only get direct radiation but also hinder the rays to reach deep to the submergeds (Chambers and Kalff, 1985; Pandit, 1992; Hrivnak et al., 2006). Therefore, transparency has a direct bearing on the production of submergeds. Submerged macrophytes usually extend into the depths in order to maximize their absorption of the light and CO₂ needed for photosynthesis (Barko and Smart, 1981; Maberly and Madsen, 2002). Light stress results in plants reallocating more resources towards shoots and leaves than to tubers (Madsen, 1991). Further, Pandit (2008) reported that in Wular lake, the growth of submergded vegetation is greatly restricted due to heavy turbidity brought about by the suspended silt, as is true for other wetlands of Kashmir also. Thus, in the present study the underwater light seems to play a major role in determining the production of submergded macrophytes.

In the present study, the free-floating macrophytes were found to be least productive. Which may be due to the fact that open water areas of the Wular lake are
exposed more to wind and wave action which are colonized mostly by rooted floating-leaf type and free-floating class of macrophytes and not by the dominant emergents. The findings of the present study corroborates with those of other studies (Kaul, 1970; Hudon et al., 2000; Rather, 2009; Kumar, 2009). But, the findings are in partial contrast to the findings of Thomaz and Bini (1998) who advocated that the open water areas lakes are rarely colonized by free-floating and emergent classes.

Temperature can influence plant performance, especially photosynthetic rates and is considered to be the single environmental variable profoundly influencing the standing crop of aquatic plants over the whole range of their occurrence (Gorham, 1974; Pilon and Santamaria, 2002). Temperature may also have an effect on propagule germination and shoot elongation in many aquatic plants (Madsen and Adams, 1988). Moreover, during periods of cooler temperatures plant production is generally less due to the lower photosynthetic rates (Scheffer, 1998). Numerous authors have emphasized that there is a direct relationship between the primary production dynamics of macrophytes and temperature (Hopson and Zimba, 1993; Vis et al., 2007; Shilla and Dativa, 2008). In the present study it also seems that temperature have profound influence on the standing crop values and biomass of macrophytes. The biomass peak for most of the macrophytes corresponds to the period of maximum atmospheric temperature. Further, the production values of macrophytes during the year 2012 were found to be lower as compared to the year 2011 which might be due to: (i) comparatively lower temperatures during the early growth and sprouting season of macrophytes, causing a delay in the flowering season of these plants, and (ii) early decomposition of macrophytes caused by rapid rise in temperature during the peak growth season. In the latter case it is likely that the higher temperature increased microbial activity and, therefore, oxygen consumption in the water, consequently affecting the pH and the rate of ion and nutrient liberation into the aquatic ecosystem and thus causing early decomposition of macrophytes (Carvalho et al., 2005). Esteves (1988) also advocated that in temperate regions, the seasonal variation of the biomass presented by aquatic macrophytes occurs mainly because of the seasonal variation of the temperature. The results of the present study corroborate with those of other studies (Esteves, 1998; Bini, 2001; Carvalho et al., 2005; Kumar, 2009).
6.2.7. Biochemical composition of macrophytes

In the present study, macrophytes of Wular lake, besides showing considerable temporal variations, were observed to exhibit interspecies and interclass variations in their biochemical compositions viz. total lipids, carbohydrate and protein contents. In most cases, proteins were found to make up the greatest proportions as compared to carbohydrates and lipids. However, there were only a few exceptions where carbohydrates made significant proportions. In all likelihood, lipids contributed relatively smallest proportions in all macrophytes.

From the present study, it is evident that the various biochemical constituents viz. total lipids, carbohydrate and protein content of macrophytes of Wular lake exhibited considerable seasonal variations. Numerous authors have emphasized that these variations may be due to the fact that the various biochemical constituents of macrophytes are primarily influenced by the environmental factors such as temperature, light available for photosynthesis, nutrient concentration in the ambient waters as well as the development stage of the macrophytes (Haroon et al., 2000; Kalesh, 2003; Ortiz et al., 2006).

6.2.7.1. Protein content

During the present investigation, total protein content of macrophytes varied from 3.2 to 23.8 % on fresh weight basis which is comparable with those of Pandit and Qadri, 1986 (6.87 to 21.8 %), Banerjee and Matai, 1990 (8.7 to 25.8 %) and Olele, 2012 (15.8 to 21.65 %) but lower than those reported by Boyd and Blackburn, 1970 (9.3 to 43.3 %) and Dewanjı et al., 1997 (32.9 to 62.7 %). Moreover, the comparative analysis of data showed significant interclass and interspecies variations in the protein content of macrophytes which may be attributed to the differential nutrient uptake potential of macrophytes especially that of nitrogen which in turn is influenced by various environmental and biological factors such as the type of tissue, the age of the plant part, its nutrient past history, interplant variability etc. (Lobban and Harrison, 1997; Kalesh, 2003). In the present study, it was observed that free floating-type macrophytes such as Azolla sp., Lemna minor and Salvinia natans contain more amounts of protein than other life-form classes. This is in consistency with the findings of other studies (NAS, 1984; Meyers, 1977; Edwards, 1980; Pandit, 1984; Pandit and Qadri, 1986; Banerjee and Matai, 1990; Dewanjı et al., 1997).
In general, on temporal scale, the maximum concentrations of proteins in various plant tissues were recorded during autumn, followed by summer and spring and decreasing to the minimum in winter. The higher concentration of proteins during autumn may be attributed to the fact that the accumulation and subsequent conversion of nitrogen into protein building in the mature tissues during the metabolic process is at its maximum during the peak growth of macrophytes (Sahyun, 2008; Ahmad et al., 2011). This observation is further confirmed by the significant negative correlation of protein content of macrophytes with ammonical-nitrogen (P< 0.05, r= -0.855). The dependence of protein level in aquatic plants on available nitrogen was also pointed out by Lapointe (1981), Dawes (1998) and Banerjee et al. (2009). Edwards (1980) advocated that the crude protein content increases as the nutrient content of the water in which the plant is grown increases.

6.2.7.2. Carbohydrate content

Data revealed that the concentration of carbohydrates in various macrophytes of Wular lake varied in the range 1.6 - 27.0 % on fresh weight basis. An earlier study on the biochemical composition of aquatic plants of Dal lake in Kashmir Himalaya revealed carbohydrates including fibre making 46.41 – 85.74 % on dry weight basis (Pandit and Qadri, 1986). However, the carbohydrate content registered during the present study remained within the reported values of Mishra and Jha (1996), Prasannakumari et al. (2000), Mini (2003) and Arathy (2004) in various aquatic and riparian vegetation. Comparatively higher values than those reported in the present study were recorded by FAO (1993) and Prasannakumari and Gangadevi (2012) in different aquatic plants. Significant differences were observed in the carbohydrate content of macrophytes with a distinct pattern between the seasons. This may be due to the variation in the nature of synthetic efficiency as well as the environmental factors such as temperature, nutrients etc. which influence carbohydrate synthesis (Kalesh, 2003; Prasannakumari and Gangadevi, 2012). It is also believed that the vegetative growth as well as development also influence the fluctuations in the carbohydrate concentration in the macrophytes. In general, maximum seasonal mean values of carbohydrate in most of the macrophytic species were recorded during summer whereas carbohydrate content attained least value during winter season. The observed increase in the carbohydrate content of macrophytes during summer may be due to an increase in the growth rate of macrophytes resulting from the favourable
environmental conditions (Jayasankar, 1999; Banerjee et al., 2009). The positive impact of temperature on the carbohydrate metabolism of aquatic plants has been supported by various authors (Rosenberg and Ramus, 1982; Rotem et al., 1986; Banerjee et al., 2009). This observation is further confirmed by the significant positive correlation of carbohydrate content of macrophytes with temperature (P<0.01, r=0.853). Thus, the active period of carbohydrate synthesis in macrophytes of Wular lake coincides with the increase in water temperature. On the other hand, the decrease in carbohydrate content during winter suggests that stored photosynthetic products are used for cold season maintenance (Terrados and Ros, 1992; Robledo and Freile-Pelegrin, 2005).

A perusal of data on the carbohydrate content of macrophytes in Wular lake revealed appreciable variations in the carbohydrate content among different groups of macrophytes which may be due to variation in the accumulation efficiency in terms of their phenology which is further corroborated by the studies of Mini (2003), Arathy (2004) and Prasannakumari and Gangadevi (2012) while working on aquatic and riparian vegetation. Among all the four life-form classes, the rooted floating-leaf type macrophytes registered the highest concentration of carbohydrates as evinced by Potamogeton natans (26.0 %), Marsilea quadrifolia (21.9 %), Nymphaea mexicana (20.4 %) and Hydrocharis dubia (17.8 %). The results of the present study also corroborate with those of other authors (Wikfort et al., 1992).

### 6.2.7.3. Lipid content

The lipid content of macrophytes in the present study varied in the range of 0.4-7.6 on % fresh weight basis. These values are in tune with those reported in literature for some aquatic macrophytes (Banerjee and Matai, 1990). However, they are lower than those reported by Rozentsvet et al. (1995). This variability in the chemical composition of macrophytes is believed to depend upon the differences in the species, season and location (Annon, 1984). In the present study also significant differences were observed in the total lipid content of macrophytes with a distinct pattern between the seasons. Fluctuations noticed in the concentration of lipid in the different genera may be due to the changes in the environmental factors that might have influenced the vegetative growth and development including availability of nutrients, allochthonous materials as well as variation in the efficiency of lipid
accumulation among the plants (Prasannakumari and Gangadevi, 2012; Yasser and Samir, 2014).

A perusal of data on the lipid content of macrophytes in Wular lake revealed that, like proteins, the maximum concentration of total lipids in various plant tissues were recorded during autumn, followed by summer and spring and decreasing to the minimum in winter. The higher concentration of total lipids during autumn may be because of the reduction in the levels of carbohydrates (Haroon et al., 2000; Nelson et al., 2002). Under this condition, more photosynthetic intermediates can be utilized in the synthesis of lipid molecule. During autumn, most of the macrophytes in Wular lake complete their life cycle and start drying up. As lipids are the end products of metabolic reactions in mature and aged tissues, they are naturally higher at this stage (Akingbade et al., 2001; Sahyun, 2008; Ahmad et al., 2011).

From the study it is clear that the concentration of lipids depicted highly significant variations among different groups of macrophytes. The concentration of lipids was generally higher in emergent macrophytes such as Myriophyllum verticillatum, Phragmites australis and Typha angustata which gains further support from the studies of Banerjee and Matai (1990) and Rozentsvet et al. (1995) who also reported higher lipid content in emergent aquatic plants. It is clear from the data that during the year 2011 the concentration of total lipids depicted greater variations in different periods, though significant increases for Ceratophyllum demersum and Potamogeton crispus (about 4 times each) were evinced in the early autumn season experiencing frequent rains. These differences indicate an acceleration of productive metabolic activity during this period and/or higher consumption of this organic compound during the dry period (Esteves and Suzuki, 2010). The significant increases in the lipid content (about 5 times) have also been reported for Ceratophyllum demersum in the rainy season (Esteves and Suzuki, 2010). The tendency to accumulate higher concentration of total lipids in the tissues of submerged macrophytes in this period suggests that this period presents better conditions to the development of these macrophytes.

6.2.7.4. Chlorophyll content

Macrophytes and their parts are vertically stratified in different positions in the water body. The productive structures i.e. parts rich in chlorophyll in different plants are concentrated at different levels. The chlorophyll content per unit weight of plant
parts is higher in leaf lamina than other green parts. The analysis of the data revealed distinct seasonal variations in the chlorophyll content of macrophytes during the two years of study period. In the present work, maximum pigment content of the macrophytes was obtained during summer season; the period characterized by optimum nutrient load and water temperature. Chlorophyll-a and chlorophyll-b contents were significantly lower in autumn. Total chlorophyll was the only exception. This trend may be attributed to the positive role of water temperature in promoting greater chlorophyll concentration and photosynthesis (Barko et al., 1982, 1986; Chambers, 1982; Nekrasova et al., 2003). The summer fall in the amounts of nutrients (ammonia, total phosphorus and dissolved silica) is attributed to the greater photosynthetic activity of macrophytes especially submerged leaving very small quantities of such nutrients in water (Rich et al., 1971; Xie, et al., 2004; Shilla et al., 2006). This is confirmed from the significant positive correlations between Chlorophyll-a, Chlorophyll -b and total chlorophyll and water temperature and negative correlations with nutrients (ammonia, total phosphorus and dissolved silica). Lower concentration of chlorophyll-a obtained in autumn may be attributed to the fact that the values of chlorophyll-a decreases when the light transmission increases (Atici and Alas, 2012). The strong negative correlation between transparency and chlorophyll-a in the submerged macrophytes also substantiate the fact that increased transparency decreases chlorophyll-a content by reducing photosynthetic input. A relative Chlorophyll-b enrichment in spring in submerged species suggests that these species exhibit a sun shade adaptation similar to higher plants and green algae (Robledo and Freile-Pelegrin, 2005). It has been advocated by Yokohama (1983) and Robledo and Freile-Pelegrin (2005) that under low light transmission the concentration of Chlorophyll-b is favourable for growth based on the fact that Chlorophyll-b absorbs shortwave light more efficiently than Chlorophyll-a. The lower quantity of chlorophyll pigment in macrophytes in other seasons reflects their adaptation to decreased water temperature (Dembitsky, 1996). The results of the present study corroborate with those of other studies (Kizevetter, 1981; Goncharova, 2004). Thus, the active period of pigment synthesis in macrophytes coincides with the increase in water temperature and decrease in nutrient load.

The macrophytes, as a whole, were characterized by low chlorophyll pigment content (mg/g on fresh weight basis) in comparison to the terrestrial plants.
The comparative analysis of data showed appreciable variations in the pigment content among different groups of macrophytes with different degree of leaf submergence (emergent, rooted floating, free floating and submerged). In emergent and rooted floating-leaf type macrophytes, the low chlorophyll pigment content might have been due to their existence at high irradiance (Ronzhina et al., 2004). In rooted floating-leaf type macrophytes the leaves are perpendicular to incident radiation. As a consequence of which they contain lower pigment content compared to submerged aquatic plants. In submerged macrophytes, the leaves are almost vertically oriented (Ronzhina et al., 2004). As a result of which they do not shade each other, enabling the plants to accumulate higher pigment content in them. Moreover, in the submerged leaves, in contrast to the emergent and floating ones, an increase in the photosynthetic rate of a single chloroplast as well as their existence in water under low light conditions results in an increase in the pigment content in their chloroplast. Further, it is believed that submerged aquatic plants are characterised by specific features of the pigment complex, ensuring plant adaptation to light conditions in water stratum (Ronzhina et al., 2004). Our results further gain support from the findings of Ronzhina et al. (2004) and Nikolic et al. (2009) who also reported higher pigment content in submerged aquatic plants. The free floating macrophytes represented in our study by Azolla sp., Salvinia natans and Lemna minor were characterised by slightly lower pigment levels. This might have been due to their existence at high irradiance and presence of homogenous type of mesophyll structure in their leaves (Ronzhina et al., 2004). Barko et al. (1986) advocated that within individual plants, total chlorophyll can vary significantly in response to light, with greatest chlorophyll concentration at the basal (darkest) portion of the plant. The normal life activity is ensured by low pigment content in plants adapted to high radiation. This is because lower pigment content prevents the danger of cell damage caused due to photooxidation (Popova et al., 1984).

Temperature is considered to be the single environmental variable profoundly influencing the photosynthetic rates and standing crop of aquatic plants over the whole range of their occurrence (Gorham, 1974; Pilon and Santamaria, 2002). Temperature may also have an effect on propagule germination and shoot elongation in many aquatic plants (Madsen and Adams, 1988). Moreover, during periods of cooler temperatures plant production is generally less due to the lower
photosynthetic rates (Scheffer, 1998). The positive impact of temperature on the photosynthetic rates of macrophytes has been supported by various authors (Hopson and Zimba, 1993; Vis et al., 2007; Shilla and Dativa, 2008). In the present study it also seems that temperature have profound influence on the photosynthetic pathway of macrophytes. The peak chlorophyll concentration for most of the macrophytes corresponds to the period of maximum atmospheric temperature. Further, the chlorophyll values of macrophytes during the year 2012 were found to be lower as compared to the year 2011 which might be due to: (i) comparatively lower temperatures during the early growth and sprouting season of macrophytes, causing a delay in the flowering season of these plants, and (ii) early decomposition of macrophytes caused by rapid rise in temperature during the peak growth season. In the latter case it is likely that the higher temperature increased microbial activity and, therefore, oxygen consumption in the water, consequently affecting the pH and the rate of ion and nutrient liberation into the aquatic ecosystem and thus causing early decomposition of macrophytes (Carvalho et al., 2005). The results of the present study corroborate with those of other studies (Barko et al., 1982, 1986; Chambers, 1982; Nekrasova et al., 2003).