CHAPTER 2
REVIEW OF LITERATURE

Algal composition, their diversity and seasonality in both lotic and lentic aquatic ecosystem had been extensively studied all over the world (Pfister, 1993; Biggs, 1995; Leukart, 1995; Gonulol & Obali, 1998; Sherwood & Sheath, 1999; Sherwood et al., 2000, Tas et al., 2002; Soylu & Gonulol, 2003; Hassan et al., 2010; Tian et al., 2012) and related the growth and development of algal communities to different abiotic factors such as the type of water bodies (lake, stream or river, light availability (water turbidity and clarity), types and depth of substrate, velocity of current, pH, alkalinity, hardness of water and the amount of nutrients, mainly phosphorus, nitrogen and carbon (McIntire, 1966; Moore, 1976; Goldman, 1979; Bothwell, 1985; Hill & Knight, 1988; Lohman et al., 1992; Pan & Lowe, 1994; Dodds et al., 1997; Winter & Duthie 2000; Mosisch et al., 2001; Stelzer & Lamberti, 2001; Notestein et al., 2003; Roberts et al., 2004). Phytoplankton abundance and species richness was negatively correlated to high turbidity and current velocity. Hynes, (1970); Crayton and Summerfield, (1979), Keithan and Lowe, (1985) reported that the change in water current changed the algal composition and abundance of algal communities in streams. In the hilly streams, water temperature, flow of water and substrate composition was considered as the major factors controlling the algal communities (Wetzel, 1983; Sharma et al., 2007). In addition, light, temperature and invertebrate grazing have been shown to possess potential effects in controlling
periphytic populations (Whitton, 1975; Biggs, 1996). Among the different factors, the amount of light reaching the surface of substrate played a significant role on the growth of algae (Stahl et al., 1994; Dodds et al., 1999; Glud et al., 1999; Guasch et al., 2003). A distinct seasonal pattern in the algal composition in streams and rivers and an increase in algal species diversity and richness with increase in temperature up to 25-30°C has been demonstrated in many studies. Squires et al., (1979) and Wilde and Tilly, (1981) reported a variations in periphyton diversity with seasonal changes mainly due to change in temperature. Patrick, (1971) examined changes in species composition on introduced glass slides in different seasons and reported that a small rise in temperature increased diatoms diversity in winter when ambient temperature was near the lower tolerance range for diatoms. When temperature was artificially raised at the upper end of the tolerance range (during summer), diversity of diatoms decreased as cyanobacterial species dominated.

The abundance, diversity and succession of different communities of algae in different rivers and its relation to water chemistry, mainly the fluctuations and changes in pH, temperature, conductivity and nutrients quality were reported by many workers (Reynolds, 1984; Sheath & Burkholder, 1985; Biggs & Close, 1989; Biggs & Gerbeaux, 1993; Mosisch & Bunn, 1997; Barinova et al., 2004; Atici & Caliskan, 2007; Zaloscar et al., 2007; Zabbay et al., 2008; Yang et al., 2009). A seasonal change in species composition was studied by Ismail, (2008) in Himreen Reservoir in Iraq. In Minichinda stream of Nigeria, Ezra and Nawankwo, (2001), Davies et al.,
(2009) also reported the seasonal variations in abundance and distribution of planktonic algae. Kobbia et al., (1991) investigated the effect of agricultural run-off on algal diversity and succession in river Nile, and concluded that members of Bacillariophyceae and Cyanophyceae were the dominant groups in nutrient rich water.

Hamed, (2008) reported that diatoms were the most diverse group followed by cyanobacteria in different water bodies of Egypt including river Nile. Similar findings were also reported by Hassan et al., (2010) in Euphrates river where Bacillariophyceae was the most dominant group. Recently, diatom diversity in rivers gained considerable attention in different parts of the globe (Rott, 1991; Round, 1991; Whitton et al., 1991; Coste et al., 1991; Whitton & Kelly, 1995; Rosen, 1995; Lim et al., 2001; Stevenson & Smol, 2003; Ector et al., 2004; Wang et al., 2005; Chessman et al., 2007; Taylor et al., 2007; Porter et al., 2008; Solak et al., 2012). A detailed work on diatom diversity in water systems in Northern and Northeast regions of Thailand was carried out by many workers and many novel diatom members were identified and recorded (Peerapornpisal et al., 2000; Pekthong & Peerapornpisal, 2001; Yana & Peerapornpisal, 2009; Leelahakriengkrai et al., 2009; Suphan & Peerapornpisal, 2010; Leelahakriengkrai & Peerapornpisal, 2010; 2011).

Diversity of desmids as indicator of water quality has been studied since long (Coesel, 1983; Gerrath, 1993; Ngearnpat & Peerapornpisal, 2007). Neostupa et al., (2009) studied desmids diversity in Central European peat lands. Extensive work on desmids diversity collected from various types of
wetlands was studied by Stastny, (2010) in Czech Republic. Distribution of
desmids and other green coccoid algae was reported by Coesel and Krienitz,
(2007). Fresh water filamentous green algae which belong to chlorophyceae
member were studied extensively in Pakistan by Leghari, (2001); Asghar et al., (2010).

Dissolved nutrients like nitrogen, phosphorus, calcium, sulfur,
silicon, presence of metals and trace metals, salinity, oxygen and carbon
dioxide were other factors that influenced the growth of algae (McCormick
& Cairns, 1994; Herbst & Blinn, 1998; Tang et al., 2003; Boivin et al., 2006;
Segal et al., 2006; Shun et al., 2009).

Based on the occurrence and diversity pattern, algae have been used
as an indicator species in aquatic environment (Stevenson, 1984; Jena et al.,
2005). Due to rapid response to a wide range of pollutants and also because
of their differential nutritional needs and their position at the base of aquatic
food webs, algal indicators provided relatively unique information
concerning ecosystem condition as compared to commonly used animal
indicators (Palmer, 1969; Round, 1991; McCormick & Cairns, 1994; Pan et al.,
1996; Stevenson et al., 2003; Potapova & Charles, 2007). Use of algae in
assessing water quality began in the mid 1970’s and since then different algal
communities have been used worldwide as a valuable tool in monitoring
water quality. (Schubert, 1984; Venkateswaralu & Reddy, 1985; Whitton et al.,
1991; Acs et al., 2004). Recently, diatoms have been used as an indicator
species for monitoring water quality (Palmer, 1969; Round, 1991; Agatz et al.,
1999; Belegratis & Economou-Amilli, 2000; Caput & Plenkovi-Moraj,
2000; Potapova & Charles, 2007; Ponander et al., 2007). Besides diatoms, other periphytons mostly some green algae were well recognized in the temperate countries as indicator species (Chessman et al., 1999; Potapova and Charles, 2002). Comparatively work in the tropical and sub-tropical countries using diatom or other periphytons as indicator of environmental changes were less (Lobo et al., 1996; Juttner et al., 2003).

Palmer, (1969) made the first major attempt to identify and prepared a list of genera and species of algae tolerant to organic pollution. Patrick, (1965) and Jafari and Gunale, (2005) reported that Oscillatoria, Euglena, Chlorella and Ankistrodesmus were typical inhabitants of polluted waters and highly pollution tolerant genera and, therefore, reliable indicators of eutrophication. The pollution tolerance of Stigeoclonium tenue, Schizomeris leibleinii, Cladophora glomerata, Spirogyra, Ulothrix were documented by Mclean, (1974); Gunale and Balakrishnan (1981). Euglenophytes, another algal group played an important role in determining water pollution and cleaning waste water (Soylu & Gonulol, 2003). It has been reported that their growth and distribution depended on the carrying capacity of the environment and on the nutrient concentrations, both intracellular and extracellular (Ezra & Nawankwo, 2001; Davies et al., 2009). In tropical regions, mainly in India, such studies has been reported by Venkateswarulu, (1981); Kannan and Krishnamurthy, (1985); Mohanty, (1985); Khan, (1991); Munn et al., (2002); Juttner et al., (2003); Rajakumari and Ritakumari, (2004); Narkhede and Raghothaman, (2007).
Algae, the predominant organisms in water bodies contribute mainly to primary production of an aquatic ecosystem. Productivity in any aquatic system is governed by diversity and abundance of different algal communities which in turn is controlled by nutrients, light and flow regimes (Lohman et al., 1992; Biggs, 2000; Dodds et al., 2002). Dodds et al., (2002) established a positive relation between production and nutrients availability where light was not a limiting factor. Light limitation was considered to be the controlling factor for primary productivity (Lehman, 2007). Toet et al., (2003) reported that light availability in the water column, higher availability of nutrients and less exposure to water current were the main factors that regulated the periphytons biomass. Ariyedej et al., (2008) reported that nitrogen, alkalinity and turbidity were the main factors that affected the variation of phytoplankton biomass as chlorophyll a in Banglang reservoir. Seasonal changes in periphyton production and nutrient content were controlled by physical, chemical and biological factors, mainly light (Sand-Jensen et al., 1988, 1989; Hansson, 1992), temperature (Davison, 1991), nutrients (Hansson, 1992), grazing (Cattaneo, 1983; Muller, 1994), current velocity (Biggs and Close, 1989; Sand-Jensen et al., 1989). Great seasonal biomass variability in tropical shallow reservoirs (Moschini et al., 2000; Fermino, 2006) and a great increase in periphytic biomass in dry period were reported (Moschini et al., 2000; Vercellino & Bicudo, 2006; Borduqui et al., 2008).

Agriculture, in particular, in the catchment area has been considered as the most-serious threat to the streams within the area (Squires & Saoud,
1986; Johnson et al., 1997; Wilby et al., 1998). A positive relationship between stream nutrient concentrations and the area under agriculture was reported by Leland and Porter, (2000); Rhodes et al., (2001); Kuo and Chiu, (2004); Inwood et al., (2005). Nutrient loading from agricultural land was 10-20 times higher than the load from forested land (Rekolainen, 1989; Pekarova and Pekar, 1996). Agricultural runoff could lead to higher nutrient concentrations in nearby streams (Chetelat et al., 1999; Pan et al., 1999; Dodds et al., 2002). Increased amount of nutrients (phosphorus, nitrogen, potassium), entering a stream from agricultural runoff increased the growth of algae and other organisms (Jones and Knowlton, 1993; Daniel et al., 1994).

Yu and Lin, (2009) reported that algal productivity in the subtropical mountain streams of Wuling area in Taiwan varied significantly with the extent of agriculture in the catchment. Algal biomass was correlated directly with dissolved phosphorus and inversely with depth (Allyson et al., 2005) and was also positively correlated with the urban activities (Lilian et al., 2006). Mosisch et al., (2001) reported that nitrogen alone stimulated periphytic algal production in subtropical streams with sufficient light. Direct relationship between chlorophyll a and the variations in phytoplankton biomass and productivity were reported by Danielkutty and Sobha, (2006) in two freshwater rocky pools of Kollam District of Kerala.

Ferragut et al., (2010) reported that the periphyton biomass and nutrient content was controlled primarily by the seasonal scale. In Brazilian lentic ecosystems, phosphorus was reported to be the most limited nutrient for algal growth (Huszar’s et al., 2005). Studies on the increase in primary
productivity and algal biomass accumulation due to elevated nutrient concentrations in naturally flowing water systems have been carried out by many workers (Hill & Knight, 1988; Hill et al., 1992; Dodds et al., 1997; Biggs, 2000; Tank and Dodd, 2003). Increased biomass of periphytic algae due to addition of phosphorus in phosphorus deficient streams was reported by Peterson et al., (1983); Perrin et al., (1987); Bothwell (1989). Addition of nitrogen and phosphorus in combination doubled the growth of periphytons and tremendously increased the chlorophyll a production in flowing river (Stanley et al., 1990; Burton et al., 1991; Lohman et al., 1992; Perrin & Richardson, 1997). Relative growth rate of periphytic algae was directly related to soluble reactive phosphorus in artificial stream (Bothwell, 1985). According to Carey et al., (2007), periphyton chlorophyll a production in periphytic algae did not increase well only with nutrients enhancement but increased with modification of physical factor like light intensity. Lewis and McCutchan, (2010) reported that the nutrient response of periphyton biomass was suppressed by other controlling factors at low nutrient concentration in streams and rivers of the Colorado Mountains. Ghosh and Gaur, (1990) reported that phosphorus deficiency limited the algal productivity in the streams of Shillong.

In the lotic systems, current velocity was one of the significant physical factors affecting distribution and inducing heterogeneity to the algal communities within a habitat (Stevenson et al., 1996). Wendker, (1992) studied the influence of current velocity on diatoms of small soft water streams and showed that there were slight increase in diversity values when...
current velocity increased. Soininen, (2004) reported that in a clear river, diversity of diatom communities at the highest velocity level was low while in turbid river, it was more similar, at all velocities. Todd and Poff, (2006) reported that chlorophyll \( a \) and AFDM (ash free dry mass) were best predicted by interactions between current velocity, grazing duration and regrowth time. Poff et al., (1990) reported that current velocity and flow pattern directly influenced the algal assemblages and composition in streams. Ghosh and Gaur, (1991, 1998) reported that in an unshaded stream, the periphytic biomass and algal colonization were negatively correlated to flow rate. The periphytic algal species of riffles and pool were markedly different from each other in diversity, cell counts and species composition. Lamb and Lowe, (1987) reported that at different current velocities, there was a similarity in the diatom composition in Maumee river in Ohio but the cell densities in the slow current were three times more in the water system with faster current. Humphrey and Stevenson, (1992) reported that rise in water current stimulated algal growth in nutrient-rich water but inhibited algal growth in nutrient-poor streams. An increased species richness and chlorophyll content in algae was reported in upper Colorado river when algal grazers were removed (Ronald et al., 2003).

Periphytic algae absorbed and sequestered inorganic nutrients (Tushman & Stevenson, 1991; Mulholland, 1992) and thereby helped in purifying stream water. Algae require carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, magnesium, iron, potassium, various other cations, and a number of trace elements to carry out the metabolic processes necessary for
their growth. Compared with higher plants, most algae contained high concentrations of essential nutrients and low concentrations of structural compounds and phenols that resisted and inhibited digestion respectively (Hill et al., 2011). Macroalgae are known to possess good biosorptive properties and has been used in waste water management (Davis et al., 2000). Rosell and Srivastava, (1985) reported that the total nitrogen, potassium and phosphorus content in *Macrocystis integrifolia* and *Nereocystis leutkeana* were high during fall-winter and low during spring summer. Micro and macro element of some fresh water algae collected from Hanna and Urak valley of Quetta was studied by Mudassir and Mansoor, (1999). Singh and Gupta, (2011) reported that the nutrient content of the same species of Lemanea fresh water filamentous red algae collected from different rivers in Manipur differed in different sites. The sequestration of metals by filamentous algae has been studied in both field and laboratory (Lawrence et al., 1998; McHardy and George, 1990; Whitton et al., 1989). Rai et al., (1981); Stevens et al., (2001); Das and Ramanujam, (2011) reported that the metal contents sequestered by *Klebsormidium* species was more in the algal biomass than in the ambient water. Mulbry and Wilkie, (2001) reported that the benthic freshwater algae growing on dairy manures contained approximately 1.5–2% phosphorus and 5–7% nitrogen. Stelzer and Lamberti, (2001) studied the effect of N: P ratio and total nutrient concentration in periphyton community structure, biomass and chemical composition in stream, and reported that nitrogen and phosphorus percentage
in periphyton increased with the increase in those two nutrients in stream water.

Substantial contributions have been made on diversity of algae from Indian sub continent by many algologists of the country. Most of the studies concentrated on the phytoplanktons of lakes, pond and large rivers. Anand, (1998); Tejaswini and Vijaya, (2004); Vishnoi and Srivastava, (2004); Misra et al., 2005; Jena et al., 2006; Kumar, (2006); Sridhar et al., (2006); Tiwari and Chauhan, (2006); Muthukumar et al., (2007); Senthilkumar and Sivakumar, (2008); Kumar and Chaudhary, (2009); Makandar and Bhatnagar, (2010). In several river systems, the studies on algal communities have been reported by Sheeba and Ramanujan, (2005) on Ithikkara river in Kerala. Another study was reported by Nivedita and Hema, (2010) in Kosi river in Almora District, Baba et al., (2011) on the periphytic algal community of Himalayan river Sindh, Selvin-Sameul et al., (2012) in Tamraparani river in Tamil Nadu. Some other studies included algal diversity in Panzara river, Maharashtra (More & Nandan 2000), phytoplankton diversity in the hilly streams of Garhwal Himalaya (Sharma et al., 2007), algal biodiversity and succession in Periyar river at Aluva, Kerala (Zacharias & Joy, 2007). An extensive study on the chlorococcales from Eastern and North-Eastern states of India has been carried out by Jena and Adhikary, (2007).

Among all the groups, blue green algae attained maximum attention by algologists all over the world including India due to its high practical importance and therefore most of the available works on algal communities
were centered on this group. Presence of high number of blue green algae characterizes eutrophic water bodies with high nutrient inputs (Sankaran, 2006; Gomathi et al., 2011; Khare & Patil, 2011). Comparatively very less work has been carried out on desmids which were predominant in oligotrophic water (Vidyavati, 2007). A Few studies on this group were reported by Suxena and Venkateswaralu, (1968); Jena et al., (2006); Panikkar et al., (2012).

Literature on Indian diatoms are scanty. Major works on this group were contributed by Gandhi, (1998) and Desikachary, (1987, 1988). Juttner et al., (2003) recorded the diversity and richness of diatoms from the streams of Eastern Himalaya. Jena et al., (2006) recorded from Orissa and North East regions. From Tapti river, it was reported by Kavitha and Balasingh, (2007).

In North East India, reports on algal diversity are still meager. The literature available from this region included algal diversity in a few lakes and ponds. Besides, it included algae from rice fields of Tripura. Sharma, (2004), on the phytoplankton communities of a floodplain lake of Brahmaputra river basin in Upper Assam, Kumar and Rai, (2005), on Cyanophycean and Chlorophycean flora of Sikkim Himalayas, Saha et al., (2007), on cyanobacterial species from freshwater streams of Kakoijana reserve forest, Assam; Das et al., (2010), on algal taxa from different water bodies of Tripura, Sharma, (2009), on the composition, abundance and ecology of phytoplankton communities of Loktak Lake, Manipur and Yasmin et al., (2011) from North East India lying in south of Eastern Himalaya are the other contributors.
Meghalaya is rich in aquatic resources but literature regarding the algal diversity is scanty. The literature available from the state are that of Biswas (1934); Alfred (1975); Ghosh, (1991); Rout, (1991); Sharma and Lyngdoh, (2003); Jena et al., (2006) and Khumanthem et al., (2007). Most recent works on this context were that of Ramanujam and Siangbood, (2009); Das et al., (2009); Das and Ramanujam, (2010); Das and Ramanujam, (2011); Siangbood and Ramanujam (2011) and Ramanujam et al., (2012).