2 REVIEW OF LITERATURE

2.1 Studies on Water quality of freshwater reservoirs

India, the seventh largest country in the world, is blessed with rich hydrological resources encompassing perennial and seasonal; freshwater, marine and coastal lagoons as well as glaciers and aquifers. However, the momentum in the area of hydrological research suffered a huge setback post the Indian independence era. The major scientific contributions were in the field of taxonomy and distribution, biology and population ecology, community dynamics, floral and faunal diversity, nutrient dynamics and toxicity studies, to name a few. Moreover, after the Stockholm Conference and realization of amplified issues pertaining to water pollution, there was a rapid increase in the research work carried out in the field of hydrobiology (Gopal and Zutshi, 1998).

The characteristic of each of the water body in a different geological environment has its quality governed by the local factors. The water quality is also affected by the type of boundary around the water body, type of human activity, the catchment area and its related properties. The issues mainly arise due to the factors acting in the direct vicinity. In some of the underdeveloped and developing countries, poor sewage treatment and management systems also cause substantial deterioration of freshwater reservoirs. The already grave issue is further aggravated by illegal dumping of solid waste; especially in the urban areas with dwindling water bodies. Such wetlands are often characterized by higher organic load as well as presence of faecal coliforms, imposing a serious threat to public health when the water is used by adjoining population for various purpose (Safari *et al.,* 2012; Shaikh *et al.,* 2013).

In certain cases, besides being the source of fresh-water, the lakes also act as a place of recreation, leading to higher tourism. In case of Periyar Lake, Kerala; the investigation on the water quality and probable causes affirm larger influence of anthropogenic activities on water quality (Krishnan, 2008). Moreover, at the place of the reservoirs with restricted human activity, the integrity of the system is maintained in its natural state. The above author has put great emphasis on holistic management of such system rather than giving importance to a particular component of the system.

Apart from anthropogenic pressure from residential area, the industrial activities also alter the water quality (Farshad and Venkataramana, 2012). It's a matter of fact that the

type of contaminants influencing the water quality differ depending upon the activities. Season driven thermal stratification affects the distribution of plankton and productivity of an aquatic system. A study was conducted to understand the relationship between the thermal stratification and chemical stratification in Japan where the lake had a mean depth of 30 m and surface area of 23 km^2 (Yu *et al.,* 2010). They inferred that the volume of the lake and hydraulic conditions has influence on the chemical and thermal stratification of the water body both horizontally and vertically.

The vertical distribution and the density of phytoplankton cells vary with light availability provided the nutrients do not act as limiting factors. The productivity often remains high in summers and decreases as the temperature drops during the winters (El-Monem, 2008). In addition to this, the lotic systems have lower primary productivity in comparison to the lentic systems. A study on seasonal variation of phytoplankton community was conducted by Yilmaz and Aykulu (2010) in a freshwater lake Sapanca, Turkey between the years 1991 and 2001. The samples were collected from spatially distinct stations and sub sites. The study indicated presence of a total of 54 phytoplankton species with dominance of Bacillariophyta, Chlorophyta and Cyanophyta. The researchers compared the results with the previous studies and found that the surface phytoplankton were less than the previous studies, however the chlorophyll–a content was found to be relatively higher. It is noteworthy, that the researchers have not provided the information about the time when samples were collected.

It is well established fact that excess of Nitrogen if discharged in the environment may lead to eutrophication in the surface water bodies (Cheng *et al.,* 2002). In the lakes of temperate regions, the problem of eutrophication can be very dangerous. A study indicates that rapid eutrophication can accelerate the aging of lakes and also lead to conversion of an aquatic system to a terrestrial system through succession (Nędzarek *et al.,* 2010). Eutrophication at any particular point of time also limits the oxygen availability and affects the health of aquatic organisms, especially the fishes. Even though eutrophication is a major issue in lentic systems such as lakes and reservoirs; often the studies pertaining to the less polluted systems are not given much attention. Nonetheless, such systems are equally influenced by complex cycles of biogeochemical transformations, conversion of organic nutrients to inorganic forms, sedimental fluxes

and their rates etc. (Robson, 2014). This is not merely restricted to lentic water bodies, holding true even for the lotic systems such as rivers, their tributaries and streams.

The number of phytoplankton and zooplankton are prominent bio-indicators to measure the extent of water quality. Due to their diversity, minimum requirements and sensitive tolerance limits, such organisms survive only in specific types of conditions and therefore their presence or absence can provide a fair idea about the condition of the system (Shaikh *et al.,* 2013). In fact, even within the phytoplankton community, different populations have varied responses to the different contaminants (Jing *et al.,* 2011). For instance, some species of phytoplankton have shown increased biomass to heavy metal contamination which is indicative of their resistivity towards elevated concentration. Whereas in the same study area, some of the phytoplankton populations showed deprived growth conditions. This demonstrates the potential to use phytoplankton as indicators of heavy metal contamination as some specific phytoplankton are indicative of specific water quality scenario. Such as presence of *Oscillatoria* in freshwater systems indicate heavy Nitrogen and Phosphorous loading whereas Spirogyra, epiphytic diatoms and other higher plants in the water are indicative of cleaner water with respect to nutrient loading (Tao, 2011).

The water quality also affects the zooplankton as demonstrated in a study of Ramgarh lake of Jaipur, Rajasthan (Paulose and Maheshwari, 2008). The study was designed to understand the seasonal variation in the zooplankton community and their relation with the water quality parameters of certain interest. The rotifers showed significant positive relation with nitrate (a plant nutrient) whereas Ostracoda showed positive correlation with Nitrate and Phosphate both. COD and BOD being indicators of organic loads were found to be negatively affecting the diversity of zooplankton in general. In previous studies designed to study the growth of *Microcystis aeruginosa* in relation to the availability of Nitrogen and Phosphorous, researchers observed varied growth in numerous different combinations of situations. They concluded that even if Nitrogen and Phosphorous both are important nutrients for algal growth in an aquatic system, Nitrogen acts as limiting factor in larger number of instances. They also cited this to be important for control of algal blooms just by controlling the Nitrogen loading or Nitrogen removal from the aquatic systems (Gerloff and Skoog, 1957). Above that, if excess of ammonium is added to the ground water, it results in nitrate formation, apart from

variability in the nutrient loading as regulatory factor, there are a number of other influencing factors such as temperature, pH, suspended solids etc. (Glibert *et al.,* 2013). Moreover, even climate change and increased CO_2 levels impose major implications on aquatic systems. Several models have been developed but considering the complexities of the systems, novice investigations and more inclusive models are need of the hour. It is also generally observed that some of the parameters are in high concentration during a particular period of the year during specific season (Parikh and Mankodi, 2012).

There are a number of methods to mitigate the highlighted issues with water bodies but the measures should be locally designed and implemented for effective results. Due to huge global diversity of lakes, every issue is to be handled by understanding the local condition and thus, there cannot be a global common solution for managing such water bodies (Drabkova, 2007). In addition to this, the seasonal variation must be incorporated in the study prior to deciding the management plan; since the water quality largely varies with changing seasons (Agarwal and Rajwar, 2010). The phytoplankton, especially the cyanobacteria are important aspect of lake management since they drastically affect the stability of the system with their periodical blooms (Imai *et al.,* 2009). There are multiple factors affecting the growth and distribution of such organism such as nutrient availability, light penetration, removal by grazing, temperature (most influencing factor) etc. However, by managing the nutrient load into the system, growth of such algal species can be controlled; since controlling ambient air temperature and water temperature is not a feasible option (Gilbert, 2012). This could be an important lake management strategy. While designing the management strategy, a synergistic approach towards the limiting factors such as Nitrogen and Phosphorous should be incorporated. This is particularly important to maintain the relative balance of such elements so that the stability of the lake system is not compromised and the system doesn't undergo trophic cascade. This is of prime importance in shallow lakes where the nutrient availability is higher than the deeper lake and the interdependencies of the nutrients would be more complex (Jeppesen, 1998; Nirmal Kumar *et al.,* 2008).

In a study involving the use of *Lemna minor* (duckweed) for removal of Nitrogen and Phosphorous, the researchers inferred about the higher rates of nutrient uptake by the plant (Cheng *et al.,* 2002). They have also suggested the controlled growth of these plants in artificial impoundments for treatment of waste water having excess of such nutrients.

Despite having higher rates of nutrient uptake, the duckweed was only useful when the nutrient concentration in the waste water to be treated was low. At higher concentrations, the nutrient removal was not much significant. In addition to this, higher light intensity and warmer ambient temperature leads to accelerated growth of duckweed. *Lemna minor L.* was also assessed with respect to its performance on different types of waste water treatment and was able to remove 73 – 84 % of COD, 83 – 87 % of Total Nitrogen, 70 – 85 % Total Phosphorous as well as 83 – 95 % of Organic Phosphorous (Ozengin and Elmaci, 2007). They have demonstrated duckweed to be a promising wetland plant for nutrient removal.

The soil and sediment system of an aquatic system along with the existing biota act as a source of dissolved organic matter (DOM) in the water column. DOM has direct influence on water quality since it controls the nutrient availability, geo-chemical cycling, energy supply as well as it affects the amount of solar radiation distribution in the water column thereby ultimately affecting productivity (Williamson *et al.,* 1999). Some of the naturally found metal ions such as Ca^{2+}, Mg^{2+}, Ni^{2+}, Zn^{+}, Mn^{2+} etc. are known to have an effect on DOM, nevertheless, their absolute or relative influence is non predictable (Cârstea *et al.,* 2012). There also is a need to incorporate the nutrient – DOM relationship for preparing the management plan of such systems. With further research, control of DOM might be possible with manipulation of metal ion concentration in water bodies, especially for a lake system used for drinking water supply, agriculture, as well as aquaculture.

In Indian context, the research on wetland, lake or reservoir water quality; has grown at a rapid rate and various dimensions of limnology have been explored. Some of the indicative studies are improvement of water quality through macrophytes where role of vascular plants in clarifying polluted waters have been studied (Dhote and Dixit, 2007). A study of freshwater lake in Bhopal was aimed at assessing the pathways of nutrition loading in the aquatic system (Dixit *et al.,* 2005; Dhote and Dixit, 2007). The authors strongly recommended water quality management and conservation strategies to be implemented along with continuous monitoring. One of the studies also involved the use of remote sensing in mapping and monitoring of a wetland system for conservation purpose (Chopra *et al.,* 2001). The study emphasized on the database generation in terms of landuse/ landcover study and variability of the same. Parameters such as aquatic vegetation and turbidity levels were studied using multi-date satellite data to identify the

threats to the wetland, on the basis of the same findings; appropriate conservation and management strategies have been suggested as an applicable outcome.

Gujarat is blessed with numerous coastal and inland wetlands. Moreover, the state enjoys huge number of colleges and universities, research institutes, NGOs as well as other organizations which are working on water quality research and allied topics. With special emphasis to wetland water quality, much of the research is done in the parts of central Gujarat where a number of small, medium and large wetlands are located. Surface water quality of a tropical pilgrimage wetland was assessed by measuring physical and chemical parameters of the water. The objective of the study was to carry out preliminary investigation of the water quality so that the status can be known which would further help in conservation and maintenance of the wetland (Soni and Thomas, 2013). Similar studies were also carried out for Dakor Sacred Wetland, Thol wetland, Timbi reservoir, Wadhwana reservoir, Javla reservoir, Check dams and other surface water resources in Gir, Saurashtra (Nirmal Kumar *et al.,* 2005; Vachhrajani and Mankodi, 2008; Kumar and Oommen, 2009; Nirmal Kumar *et al.,* 2011; Parikh and Mankodi, 2011; Parikh and Mankodi, 2012; Goswami and Mankodi, 2012; Pathak and Mankodi, 2013; Tailor and Mankodi, 2013; Soni and Thomas, 2014).

Studies pertaining to the physico-chemical status and its variability were not studied for two of the reservoirs under investigation. For one of the reservoir, the study was conducted to assess the water quality and the same was correlated with the avian diversity. Thus, the study would add value to the existing database of the water quality of reservoirs in Vadodara district.

2.2 Studies on Sediment Quality

Soil and sediment systems also act as a source of a number of plant nutrients and the release of the same is governed by a number of factors viz., seasonal variation, saturation in water column, temperature and productivity as well (Edmondson and Lehman, 1981). This directs that the lake management practices should take into consideration not only the water quality but also the sediment quality. Wherever the lakes and reservoirs are surrounded by agricultural fields, there are often instances of nutrient enrichment of the same especially during the monsoon period (Fillos and Swanson, 1975). The water flows from above the agricultural fields and enters into the lakes and/or reservoirs. The fertilizers used travel in dissolved form along with the surface runoff and reach such

bodies. Intensive agricultural practices may add nutrients at a very high rate and may convert the system into an eutrophicated one. Diversion of waters entering into such systems from the agricultural field is considered to be a tedious but viable option since the agricultural fields are non-point sources of the nutrients. Long term addition of organic sewage and the constituents therein, when unutilized by the trophic structure, often become a part of sediments where they ultimately settle. If the addition of such constituents including nutrients becomes surplus than its utilization/removal, there is a continual increase in their concentration in the sediments (Wenchuan *et al.,* 2001). It is having an important ecological and environmental implication that even if the addition of nutrients is restricted by regulating sewage or wastewater flow into the reservoir, the sediment deposits of nutrients will be available for quite a long time. If the concentration of such elements is very high, the curative process to combat eutrophication may fail since the nutrients are already deposited in the sediments.

Nutrient availability from the sediments are affected by the geo-chemistry and native properties of sediments. This in addition to the overall limnological conditions decides if the sediments will be acting as a sink or a source for nutrient (Syers *et al.,* 1973). The deposited nutrients in the lake bottom can again be liberated in the above lying water columns by various bio-geo-chemical processes. The deposition and re-suspension of nutrients are dependent upon the biological activity, depth of the bottom, faunal and floral diversity, temperature of water and sediment and dissolved oxygen; to name a few. One of the study report that the submerged macrophytes are important as they link the sediments with the water columns. It is speculated that their biological role may alter the quality of sediments as well as water but the complexity of such interactions have led to very little information on the same (Barko and James, 1998). Apart from the processes within the lake system, external force such as wind is demonstrated to be playing an important role in an in situ investigation of nutrient re-suspension especially in shallow lake system. Study indicate that when the sediments are disturbed by the currents driven by strong winds, the nutrients present in the pore waters of the sediments get released near the sediment layer and mixes with the above lying water (Qin *et al.,* 2004). This study adds another important component for consideration to broaden the understanding of lake systems and associated processes. The effects of lake sediments are not only restricted to the lake ecosystem but are extended to the ground water quality too. Interactions of lake sediments with surrounding is often too complex and difficult as well

as tedious to study (Jones and Bowser, 1978). This might be one of the reasons that the lake sediments are generally considered as sinks of nutrients and other solids and less study is carried out on the same as compared to the above lying water. A study was carried out to assess the growth of macrophytes in varied sediment nutrient concentration (Barko and Smart, 1986). The study indicates that in freshwater systems, there can be more than one limiting factors for the growth of aquatic plants and sediment nutrient concentration play a major role for promoting and maintaining the growth of the same. The study also indicates that not only the chemical constituents but also the physical properties such as texture of the sediments play a considerable role on growth of such vegetation.

Out of all the nutrients required for a healthy aquatic ecosystem, the Nitrogen, Phosphorous and Carbon are most important as they largely affect the status of these systems (Forsberg, 1989). The carbon deposited in the sediments may change the DO concentrations at and near the sediment–water interface provided microbial decomposition is occurring in the sediments, which ultimately affect the fish and other aerobic fauna of the lakes and reservoirs. Nitrogen and Phosphorous on the other hand act as limiting factors as well as can cause higher level of eutrophication and in extremes of cases may lead to death of the water body, too. Thus, understanding the interactions and processes in lake sediments are very important. A team of researchers studied the spatio – temporal distribution of Total N and Total P in a shallow eutrophic lake in China and found that higher concentration of both the nutrients was found during the summers and autumn seasons (Xu *et al.,* 2003). They also found higher concentration of nutrients near the mouth of various rivers which is indicative of enrichment of lake by external sources. Considering other physical and chemical properties, the results indicate that Total N and Total P concentrations are positively correlated to pH and negatively related to sediment size diameter and SiO_2 concentrations.

The Phosphorous deposited in the sediments is largely affected by the redox potential and pH of the water and/or sediments. In a study the researchers demonstrated higher Phosphorous release rates when the sediments were exposed to higher redox potential and higher pH, there is an increased release of P from the lake sediments (Christophoridis and Fytianos, 2006). In such conditions the sediments acts as a source of P for the above waters. The study also revealed that in an oxic condition the oxidized surface micro-layer

in the sediment acts as a barrier restricting the release of P in the water. One of the study also implies that the nutrient availability near the sediment surfaces cannot only be attributed to the decomposition of matter from the sediments but the influx also plays a major role (Matisoff *et al.,* 1981). Such multiple studies clearly point at the complexities of bio-geo-chemical transformations in the sediment systems of lakes and reservoirs. One of the studies on the release of phosphate from sediment encompassed the components such as aerobic conditions, anaerobic conditions, sterile conditions and non-sterile conditions. In this laboratory experiment, the results indicate that there was higher release of phosphate from the sediments when exposed to anaerobic conditions in comparison to aerobic conditions in most of the instances (Bates and Neafus, 1980). This may imply that if anaerobic conditions prevail near the sediment surface, it may lead to higher phosphate release accelerating the eutrophication processes. Thus, for lake restoration/maintenance purposes, monitoring DO levels near the sediments can be considered an important factor.

In India, the lake sediment studies are focused to the subjects such as heavy metal composition in sediments and associated ecological risk, pesticides in sediments, effect of weathering and anthropogenic influence on sediment chemistry, geo-chemical characteristics of lake sediments, variation in sediment quality, physical properties etc. (Rao and Pillala, 2001; Jumbe and Nandini, 2009; Selvam *et al.,* 2012; Suresh *et al.,* 2012). Whereas in Gujarat, little work is done on the sediment quality with respect to nutrient status as well as organic carbon deposits especially in the case of wetland habitat of the selected study area (Kumar *et al.,* 2008; Patel and Vediya, 2012; Upadhyaya *et al.,* 2012). This was one of the governing factors for considering the sediment quality with respect to the nutrients for the current study.

The specific study pertaining to the nutrients and allied parameters were scarce in the Vadodara district. Also, the previous studies had little direct emphasis on the pre – monsoon and post – monsoon concentration of the nutrients in wetland sediments. Thus, the sediment quality was identified as one of the objective of the study.

2.3 Phytoplankton studies of freshwater reservoirs

Plankton are organisms, both plants and animals which depend upon the currents of aquatic system for their movement and lack active locomotion. The term is derived from the Greek work *plankton* which means “drifter” or “wanderer”. On the basis of mode of

nutrition, they are classified as Phytoplankton (plants) and Zooplankton (animals). They form the bottom most trophic levels in aquatic ecosystems and are of much importance as far as aquatic food webs are concerned. They are widespread in distribution in aquatic systems such as marine, estuaries, rivers, streams, ponds and lakes.

Phytoplankton are the photosynthetic organisms and especially in aquatic systems, the dissolved nutrients often play a significant role in deciding the productivity of the system. Phytoplankton serve as a food source for zooplankton and other aquatic forms. To understand the relation between phytoplankton and zooplankton biomass, statistical analysis of the biomass data was carried out (McCauley and Kalff, 1981). The study revealed that the zooplankton biomass was positively related to the phytoplankton biomass. The researchers specifically considered crustacean zooplankton biomass and thus the results may be useful for economic aspects of plankton ecology. The type of phytoplankton community existing in the system is largely affected by the dissolved nutrients. At the optimum concentration i.e. in mesotrophic state higher phytoplankton diversity is observed whereas at extreme low concentration and extremely high concentration there are fewer species which dominate due to their adaptability towards the situation. In one study, phytoplankton growth was observed against various concentrations of Nitrogen and Phosphorous (Morris and Lewis Jr, 1988). The study indicates that Nitrogen, most frequently, was a limiting nutrient. The results of the study are important from the lake management perspective. For instance, excess of algal blooms can be controlled by regulating the entry of Nitrogen in such system and in case of aquaculture practices, Nitrogen can be supplied if higher phytoplankton growth is desired. In a more specific analysis of the effect of Phosphorous and Nitrogen on phytoplankton growth and distribution, an experiment was designed to check the seasonal distribution pattern with varied supply of Nitrogen and Phosphorous. Out of the two forms of Nitrogen supplied to the system, the phytoplankton growth rate in response to ammonium was slightly better than the nitrate (Maberly *et al.,* 2002). At times the nitrogen is added through atmospheric deposition as demonstrated in the study of unproductive Swedish lakes. The investigation has resulted into development of the theory that atmospheric Nitrogen deposition is also an important source as far as external loading of nutrients is concerned (Bergström *et al.,* 2005)

Since the wetland systems are quite diverse and complex yet interesting systems, a number of different cause-effect relationships can be observed. In one such study, with an objective to assess the effect of macrophytes on phytoplankton, three shallow lakes were studied by Takamura *et al,* (2003). All the three lakes had different levels of vegetation cover and varied ranges of nutrient levels. The study demonstrates that the lakes having presence of submerged macrophytes showed significantly low levels of nutrients and Chlorophyll *a* concentrations. As Chlorophyll-a concentrations are attributed to the phytoplankton biomass, the results indicate negative effects of submerged macrophytes on growth of phytoplankton.

Multiple studies have been carried out in understanding the ecological importance of plankton with respect to diversity and distribution, factors affecting their biomass, relationships between phytoplankton and zooplankton biomass, their seasonal dynamics, productivity, effects of greenhouse gases, plankton as aquatic food resources etc (Mullin and Brooks, 1976; Durbin and Durbin, 1981; Stockwell *et al.,* 2001; Irigoien *et al.,* 2004; Murrell and Lores, 2004; Strecker *et al.,* 2004; Vachhrajani and Mankodi, 2008; Goswami and Mankodi, 2012; Karia *et al.,* 2013). Depending upon the types of habitat, the studies are carried out globally with local, regional as well as global perspectives. In India, less number of studies are done on phytoplankton with respect to freshwater lentic systems; as majority of the studies involved investigation of coastal, estuarine or riverine systems (Madhav and Kondalarao, 2004; Rajasekar *et al.,* 2005; Roy *et al.,* 2006; Sridhar *et al.,* 2006; Rajkumar *et al.,* 2009; Acharyya *et al.,* 2012; Sahu *et al.,* 2012). In some of the studies pertaining to the phytoplankton with respect to freshwater lakes and wetlands, greater emphasis is put on the relation of the community with physico-chemical structure of the systems (Senthilkumar and Sivakumar, 2008; Panigrahi *et al.,* 2009; Patil Shilpa *et al.,* 2012; Abdar, 2013).

The floodplains of rivers are also unique type of wetlands. In one such wetland of Barak valley, Assam in North–East India, the study aimed at investigating phytoplankton diversity as well as a number of environmental variables such as water temperature, transparency, rainfall as well as forms of nitrogen (Laskar and Gupta, 2013). They found that the plytoplankton community had a species richness of 53 taxa, where *Chlorophceae* were the dominant ones. It is also stated that the aforementioned environmental parameters are very important and are the driving factors deciding the phytoplankton

diversity and density in that system. Phytoplankton diversity and its relationship with physico–chemical properties were studied for Bhoj wetland, Bhopal, India (Bhat *et al.,* 2012). Here also, *Chlorphyceae* were the most abundant phytoplankton class. They also claim that the water quality is good at the upper lake of the wetland, but continuous monitoring is needed so that any damage done to the wetland can immediately be identified and necessary corrective actions can be taken.

In Gujarat, there are several studies carried out on freshwater wetlands. Ratheshwar lake in Central Gujarat was studied to assess the eutrophication with reference to plant diversity. The detailed study provides information about the important elements responsible for eutrophication, the phytoplankton diversity and density in relation to the trophic status as well as seasonal variation in the density of various phytoplankton classes (Nirmal Kumar *et al.,* 2005). Another study was carried out for a community wetland at Kanewal, where physico–chemical investigation of water body and its correlation with the phytoplankton community was done. Absence of *Euglenophyceae* in the water was indicative of lesser degree of organic pollution (Kumar and Oommen, 2011).

In an interesting study, attempts were made to assess the environmental status of the wetland on the basis of phytoplankton and macrophytes. 'Palmer's Index', 'Nygaard's Index' and 'Macrophyte index' were determined from the data and interdependencies among these biotic components were established (Soni and Thomas, 2014). This would be helpful in further development and conservation of the Gomti Reservoir of Gujarat. In another study, a sacred palustrine habitat was investigated for phytoplankton diversity where a total of 39 genera and 48 species of phytoplankton were found. Here *Bacillariophyceae* were abundant followed by *Chlorophyceae, Cyanophyceae* and *Euglenophyceae* (Soni and Thomas, 2013). Many other studies have encompassed the investigation of phytoplankton community structure, limiting factors in relation to phytoplankton, seasonal variability of phytoplankton community, pollution status and allied topics incorporating the study of phytoplankton as one of the component (Nirmal Kumar *et al.,* 2011; Verma *et al.,* 2012; Chavda, 2013; Thomas, 2013).

There were no previous record of phytoplankton communities of the reservoirs under investigation. The study will add value to the existing database of such kinds of studies. Moreover, some of the species of phytoplankton indicate specific set of ecological

conditions. This information can be helpful in assessing the reservoirs for their status of nutrient enrichments.

2.4 Avifaunal diversity

Small ponds and lakes are often characterized by higher diversity of macrophytes; especially the submerged plants. It is generally assumed that the overall diversity of such water bodies is generally low but they form a unique system; characterized by higher vegetation abundance and lower fish density. Nevertheless, they usually harbour higher diversity of birds, amphibians and other invertebrates (Scheffer *et al.,* 2006). With local ecological importance point of view, such habitats are equally important as unique systems. Multiple researchers have worked on avifaunal diversity in and around wetlands with respect to multiple parameters such as water quality, sediment quality, season of the year, weather and climatic conditions, macrophytes and plankton, molluscs and macro and micro invertebrates, fish diversity, human interferences, habitat fragmentation and land - use change etc. (Stanley, 2004; Kumar and Gupta, 2009; Pandya and Padate, 2009; Sandilyan, 2009; Pawar, 2011; Rajashekara and Venkatesha, 2011; Balachandran, 2012; Karia, 2012; Gandhi, 2013; Kumar and Gupta, 2013; Koladiya *et al.,* 2014; Koladiya *et al.,* 2014; Prasad *et al.,* 2014; Chatterjee *et al.,* 2015; Harisha, 2016).

A study of Lake Erie, Ontario demonstrates the effects of human intervention on biological diversity (Schummer *et al.,* 2012). To assess the effects of dredging on birds, aquatic macro-invertebrates and plant communities, they assessed varying properties of the habitat after dredging. They found that the area that was dredged for diversifying the habitat promoted the growth of cattail – reed plants and has been beneficial to the marsh – nesting birds by increasing as well as fish and other wildlife. Direct and indirect effects of human activities on avifaunal diversity were studied by Datta (2011) in two wetlands of Jalpaiguri, West Bengal, India. A total of 86 birds species including exclusive wetland birds as well shore birds were recorded out of which some were permanent residents, some were migrants (both winter migrants and summer migrants) and some were local migrants. The larger wetland harboured 80 species whereas the smaller one supported 42 species of birds. Apart from the size, both the wetlands were almost identical with respect to its ecological character as well as direct human interaction. However, due to local awareness and interventions from the local authority has resulted in least direct encounters of birds with humans. The author claims that even if there was negligible

direct human interference, the agricultural activity in the surrounding has caused Phosphorous enrichment of both the wetlands. If it continues for long, the ecological character and bird diversity both, may face threat. Bird diversity and probable threats to the same were studied in Ousteri Wetland, Puducherry, India for December, 2009 and January, 2010 (Padmavathy *et al.,* 2010). The authors recorded 109 avian species including migratory and local species. Threats such as reduced water levels, hunting and poaching, predation, weed infestation, food availability, cultivation practices etc. were identified as factors leading to loss of bird diversity.

Study of bird diversity and density in India is not standardized and the methodology is largely dependent upon the scope and perspective of the study. It is a general observation, that majority of the studies revolve around the birds that have higher conservation value whereas the bird species which are common and high in abundance are often neglected as they do not enjoy specific conservation status. Such studies are largely inclined towards the water – fowls and majority of the terrestrial birds are side tracked (Urfi *et al.,* 2005). The authors emphasize on widening the scope and adoption of standardized methodology across the country for the study of avifaunal diversity.

Importance of shallow and small wetlands is also indicated by a study carried out in Chhilchhila Wildlife Sanctuary of Haryana, where the area of the wetland is merely 0.3 km^2 and depths of 4.5 to 1.8-2.7 m in monsoon and summer seasons respectively (Kumar and Gupta, 2013). 57 species of wetland avian fauna were recorded during the study conducted over a period of 3 years. Out of the total, 33 were winter migrants, 2 were summer migrants and 22 were resident wetland birds. They also report that anthropogenic pressures such as fuel wood collection, cattle grazing and improper management of the wetland, the integrity of the system was at risk. Another study of a small wetland having an area of approximately 0.1 km^2 carried out in Karnataka, India demonstrates importance of such ecosystems for avian diversity (Bhat and Hosetti, 2009). Anekere wetland was investigated for bird diversity by using point count and direct count methods and the inventory was prepared. A total of 44 were listed during the study period at two sites of the wetland where highest density and diversity were recorded during the winter season from December to February. Out of the two sites, the one which had lesser disturbance, higher water retention and abundance of food showed greater abundance of birds in comparison to the other site. The study also indicates that

change in ecological character may lead to the decrease in bird diversity for which the authors recommended restoration measures to bring the wetland back to its original ecological status.

In a study of 28 agricultural wetlands in parts of Uttar Pradesh, India, the authors found justifiably good bird diversity in relatively smaller wetlands (Sundar and Kittur, 2013). They also report that majority of agricultural wetlands were experiencing intensive human interference which has relatively less effects on the bird diversity. It is opined in the study that conservation of avian diversity cannot be done merely by conserving larger and famous wetlands with few of the focal taxa. For overall conservation of bird diversity, a more holistic and ecological approach is needed for which untested assumptions need to be discarded. In a case study of Keoladeo Ghana National Part, Bharatpur and Lake Kolleru Wetland, East coast of India (Gopal, 1991), the author investigated the role of traditional knowledge of wetland management and management practices by the authorities. It is claimed in the study that merely keeping the local individuals out of such systems and preventing their interaction with such system is a mechanical solution which may not fit to the probable issues faced by both the wetlands. Author stressed upon utilization of age old traditional knowledge in policy preparation and management strategies.

Nal lake is a well-known bird sanctuary of Gujarat often referred to as "Nal Sarovar". Seasonal patterns of diversity and abundance of wetland bird were studied during the period March 2004 to February 2005 where monthly observations were taken (Kumar *et al.,* 2007). There were a total of 109 wetland birds encountered during the study out of which 42 were resident and 67 were seasonal visitors or migrants. Higher densities of wetland birds were observed where emergent macrophytes were in abundance and showed low human interference. The wetland birds prefer this type of habitat as it provides shelter as well as safety from the predators. It is noteworthy that the Nal Lake enjoys conservation status of a Bird Sanctuary and the notified area of the same is approximately 120 km^2 which is enormously huge in comparison to marginal wetlands.

Ecological conditions of a wetland can be assessed considering the bird communities as indicators. With objective to identifying the technique to evaluate the ecological status of wetlands, Nal Sarovar Bird Sanctuary and Thol Lake Bird Sanctuary were studied (Patel and Dharaiya, 2007). The authors used 'Marsh Bird Community Index' of 'Biotic Integrity'

and revealed that the index is positively correlated with the wetland bird species richness and negatively correlated with the disturbances to the systems. The study paves a path of using avifaunal diversity as an indicator of wetland quality and encourages the use of such indices on larger scale encompassing more number of wetlands. In a three years long study from 2008 to 2010 pertaining to wetland bird diversity in arid area of Kachchh (Gajera *et al.,* 2012), the researchers identified 152 species of birds out of which 26 species were migrant, 90 were resident breeding and the rest were local or resident migrants. Considering the huge area and mammoth bird diversity, the authors have considered the area to be very rich which warrants conservation attention.

A study in semi–arid zone of Central Gujarat demonstrates importance of smaller village ponds as wetlands supporting biodiversity (Deshkar, 2008). The research encompasses diversity study of birds, molluscs, and plankton as well as study anthropogenic activities around these wetlands. It is concluded that such wetlands are also important ecological units supporting biodiversity and should be maintained by providing them specific conservation status. Importance of small village pond as bird diversity area has been demonstrated in a study of Masar Village pond of Vadodara District (Sonal *et al.,* 2010). The authors recorded the bird diversity as well as assessed the water quality and concluded that the water quality and seasonal variation have significant effect on the bird diversity of the pond. Moreover, they also claimed that human activities in the vicinity also has a considerable influence on bird diversity since the birds very often prefer habitats with least disturbances.

Birds are the best indicators of ecological conditions. They are highly mobile and immediately respond to the disturbances. A deteriorated habitat would show least bird diversity and an ecologically affluent system would harbour higher bird diversity. Presence of higher bird diversity is also indicative of plentiful resources, favourable climatic conditions. Thus, study of avifaunal diversity was considered an important aspect of the study.

Water and sediment quality, phytoplankton and avifaunal diversity are closely related components of a wetland system. The holistic approach in this study was made so that it would help in thematic understanding of the existing ecological condition. The attempts were also made to view these components in relation to the other components under investigation.