3. REVIEW OF THE LITERATURE
3. Review of the literature:

3.1. Hydrology of the lagoon:

The hydrology of a lagoon mainly depends on its water balance. Basso (2000) suggested water balance equation of the lake that may be written as $Q_a - Q_c = Q_r$, where $Q_a$ is the inflow of the lake, $Q_c$ is the outflow of the lake and $Q_r$ is the flow corresponding to change in the lake level. The inflow to the lagoon is controlled by direct precipitation, discharge from the rivers, inflow of the sea water and nonmeasured area like surface runoff, head water etc. and ground water discharge. The outflow to the lake is controlled by evaporation from water surface, outflow to the sea and ground water recharge. Bandhyapadhyya and Gopal (1991) suggested that hydrology of Chilka lagoon was primarily determined by the precipitation pattern and drainage basin, the volume of freshwater discharge into various sectors and the evaporation determined by surface water temperature. Ramanadham (1967) calculated the daily evaporation rate of Chilka was around 0.60 cm/day and Murty (1988) also studied this in Central sector with an observation 0.65 cm/day.

Water depth is a major physical parameter in the lake, which varies, in different sectors and different seasons. Patnaik (1971) observed that the lake level of Chilka was lowest during April to June and highest during July to September showing 50 cm depth. Asthana (1979) measured the average water depth of Outer channel area, which was one meter and not exceeding two meter during monsoon. Bandhyapadhyya and Gopal (1991) suggested that the water level decreased gradually during October to March and southern sector was quite deep compared to Northern and Central sectors. Siddiqi & Rao (1995) stated that the lake depth varied widely between 0.40-4.9 m. Bhatta & Patnaik (1998) mentioned the water depth varies from 41.0 cm to 448.0 cm.

Wetzel (1983) stated that the salinity of the surface water of the world was highly variable depending upon ionic influences of drainage and exchange from the surrounding land, atmospheric sources derived from the land, ocean, human activity and exchange with sediments with in the water body. He also mentioned that the global mean salinity of river water was 120 mg/l. Gibbs (1971), Feth (1971), Kilham (1975) were of opinion that the three major mechanisms controlling the salinity of world surface water were rock dominance,
atmospheric precipitation and the evaporation-precipitation process. Eugster and Hardie (1978) opined that saline lakes formed and persist when (1) outflow of water is restricted as in hydrologically closed basin (2) evaporation exceeds inflow and (3) the inflow is sufficient to sustain a standing body of water. Hutchinson (1957) stated that the salinity of Lake Waters of closed drainage basin was governed not only by inputs of dissolved ions from runoff, but by the fate of these materials upon evaporation. Bandhyapadhyya and Gopal (1991) were of opinion that the mixing of lagoon water was determined by salinity gradients, wind speed and lake morphometry. They also suggested that wind is the major driving force for the water currents and mixing patterns which also had the role for changing local and transient changes of salinity. Silias Ebanezar and Parameswaran Pillai (1993) reported that the salinity of the lagoon environment was found to be influenced by the freshwater inflow, seawater incursion and circulation during northeast monsoon period. Their observation on the Pillaimadam lagoon revealed that salinity value was below 3 ppt during October-December and during summer (April–August) it was hyper saline. Abdul Aziz and Balakrishnarn Nair (1980) recorded maximum 20.3 ppt in May and minimum of 0.75 ppt during monsoon from Paravur lagoon. Banerjee and Roychowdhuri (1966) observed that the water of the Chilka lake was mixohaline except during September-October, the highest salinity during April with 36 ppt and lowest during October with 0.29 ppt. Ramanadham et al (1964) while studying the limnology of Chilka lagoon observed that the salinity gradient was maximum at Mugarmukh in summer and the entire lake showed slight increase in salinity with depth during monsoons. Mohanty (1975) observed that the salinity of Outer channel region of Chilka Lake was around 34-35 ppt and it exhibited double oscillations during the neap and spring tides. Bandhyapadhyya and Gopal (1991) mentioned that the overall salinity of the lake was influenced by the annual precipitation in the lake and its drainage basin as well as the inflow of freshwater by various rivers and rivulets draining into it. Siddiqi & Rao (1995) found that the salinity of surface and bottom water were not too pronounced in most of the sectors of Chilka lake and in general vertical distribution of salinity was characterised by top to bottom homogenesity at most of the places. The surface-bottom difference in salinity was noticeable in outer channel during summer ranging 7-13 ppt. Their observation in surface salinity profile in Chilka
lake was Southern sector 7-17 ppt, Central sector 1.73-18 ppt, Northern sector 0-
observed the salinity range in Chilka lake was 0.0 to 31.1 ppt.

According to Wetzel (1983) temperature and density stratification in the
lakes are dominant regulators of nearly all physico-chemical cycles and
consequent of lake metabolism and productivity. Silas Ebenezar and
Parameswaran Pillai (1993) suggested that the water temperature was mainly
dependent on the temperature of atmosphere and the level of water. Abdul Aziz
and Balakrishnan Nair (1980) observed in Paravur lagoon that the water
temperature was maximum during premonsoon and minimum during monsoon
and post-monsoon period. Ramanadham et al (1964) and Banerjee 
Roychowdhuri (1966) found the range of water temperature in chilka lake from
19°C during January to 32°C during June. Ramanadham et al (1964) suggested
that the variation in water temperature over different years were generally
associated with the variations in wind force, inland water flow, influx of the
inshore waters and atmospheric temperature. Mohanty (1975) opined that the air
temperature and water temperatures were not closely related in Outer channel due
to effect of both flood and seawater. The observation of Misra (1988) revealed
that the difference between the surface and bottom water temperature of Chilka
lake were mostly less than 1°C due to shallowness of the lake. Siddiqi 
Rao (1995) observed the range of both surface and bottom water temperature in
Chilka Lake. They suggested that both season wise and sector wise the average
differences between the average sub surface and average bottom water
temperature were less than a degree Celsius. The bottom water temperature
varied in winter 22.7-27°C in summer 25.2-34.2 °C and in monsoon 28.0-34.8 °C.
They are also in opinion that the water of Chilka Lake tends towards vertical
homothermy. Bhatta & Patnaik (1998) mentioned that the water temperature
range was 24.0°C to 32.0°C in Chilka lake.

Banerjee and Roychowdhuri (1966) found that the lake water of Chilka
in the northern sector was quite turbid during the summer mainly due to strong
southerly winds which caused mixing of sediments from shallow bottom and
during monsoon due to silted rainwater, wind mixing and probably rising
phytoplankton growth. Transparency increased during winter due to settling up
the silts. Misra (1988) observed higher transparency found in Chilka Lake during
summer in Central and Southern sectors with maximum about 100 cm in Southern sector. Patnaik (1971) reported in the Outer channel of Chilka Lake that the transparency was low during October-December due to passage of floodwater and also in January – March due to high growth of phytoplankton. Siddiqi & Rao (1995) stated from their study of chilka lake water that the southern sector with higher transparency with 0.9040m than the other regions, whereas the northern sector with low transparency with 0.3138m, the central sector recorded transparency with 0.6671 m and outer channel with 0.4567 m.

The dissolved oxygen content profile in estuaries and coastal lakes are regulated among others by turbulence/wave action, current, biotic activities, salinity and temperature effect. Mohapatra et al (1988) observed that in Chilka Lake the dissolved oxygen content varies from 1.3-13.4mg/l. Banerjee and Roychowdhuri (1966) found that D.O. values was higher during winter with 11.4 mg/l and downward trend during summer and monsoon with 3.3 mg/l. He also stated that northern sector had the lower D.O. content during summer and early part of the monsoon due to higher water temperature, salinity and B.O.D due to decomposition of organic detritus. Misra (1988) from his observation stated that in Chilka Lake during summer D.O. (6.42-6.62mg/l) was high due to high rate of photosynthesis and in October it was high mainly for phytoplankton bloom where as D.O. was low during winter (3.3 mg/l possibly due to the mixing of oxygen depleted bottom water with the surface water. Mohanty (1975) observed in the outer channel of Chilka Lake that D.O. content was higher during July-October due to flow of highly oxygenated flood water. Asthana (1979) reported similar D.O. content in Chilka lake in different sectors of the lake and higher D.O. content in northern sector due to phytoplankton production. Siddiqi & Rao (1995) investigated in Chilka lake that the D.O. concentration of subsurface water were higher than the bottom water due to higher phytoplankton production in the highly irradiated upper euphotic layer of subsurface water than the bottom water. The seasonal subsurface D.O. content varied in winter 7.0-11.2mg/l, in summer 4.8-14.6 mg/l, in monsoon 3.0-14 mg/l. and the sectorial range of D.O. was: Southern 2.7-14.4 mg/l, Central 3.1-15.8 mg/l, Northern 4.4-14.8mg/l, Outer channel 7.8-14.6mg/l. Bhatta & Patnaik (1988) observed the D.O. content varied from 0.8-14.3 mg/l.
Wetzel (1983) stated that the pH of natural water ranged from <2 to 12 and its value was dependent on the amount of dissolved material in the water and suggested that the lethal effects began to appear near pH 4.5 and near pH 9.5. Abdul Aziz and Balakrishnan Nair (1980) found the pH of Paravar lagoon with maximum 8.40 during late July and minimum 6.70 during late December. Banerjee and Roychowdhuri (1966) and Misra (1988) observed that the pH of Chilka lake water ranged from 8.0 to 9.6 and lower values found during rainy season and comparatively higher values during summer and winter. Roy (1954) found that the range of pH in Chilka lake water during 1950 & 1951 were 8.0-9.5 and 7-10 respectively. Mohanty (1975) stated that pH of Outer channel water of Chilka Lake was lower compared to the other areas of the lake mainly due to higher buffering capacity of that area. Siddiqi & Rao (1995) investigated that the pH values of subsurface water of Chilka lake varied widely from 7.0 (Southern sector) to 10.66 (Northern sector), and in general the lake water showed alkaline in nature. They also stated that the subsurface waters in the Southern and Northern sectors as well as Outer channel with lower and higher ranges of pH where as in Central sector it showed only higher pH value. Bhatta & Patnaik (1988) found the range of pH value in chilka water from 7.1-9.6.

Nitrite, nitrate, phosphate and ammonium are the major ionic states in the lagoon water. Chapin and Uttormark (1973) observed the north-central and eastern regions, especially bordering the southern great lakes received the largest input of nitrogen from precipitation. Wetzel (1983) stated that the source of organic and inorganic nitrogen to the lakes from surface land drainage and groundwater sources. Regarding the phosphorus contents in the lakes he also stated that total phosphorus concentrations in non-polluted natural lake extended over a very wide range from less than 1 mg/l to more than 200 mg/l in some closed saline lakes. According to him lakes rich in organic matter tend to exhibit high total phosphorus concentrations and the lakes with drainage from sedimentary coastal areas also have high phosphorus levels. Abdul Aziz and Balakrishnan Nair (1980) observed that in Paravur lagoon the highest concentration of phosphate during January and nitrate during September. Banerjee and Roychowdhuri (1966) calculated the average phosphate content value in Chilka water ranged from trace to 0.18 ppm and the maximum value noted at Kaluparaghat. Regarding nitrogen content in Chilka water he observed
the range from trace to 0.19 ppm and generally the summer months and winter months showed a slight rise in nitrate nitrogen content. Patnaik & Sarkar (1976) observed in Chilka lake that the nitrate concentration varied from traces to 0.19 mg/l. During February and August-September in the northern sector it was slightly increased where as it was higher in Outer channel during May and August. Misra (1988) reported in central and southern sectors that nitrate concentration was higher during September – November. Regarding the phosphate content in chilka water Misra (1988) stated that the annual variation in phosphate concentration exhibited a bimodal pattern with a high peak in September – October. Bhatta and Patnaik (1998) found the nitrate range in Chilka lake from 0.01 to 0.8 ppm.

Sediments in the lake plays an important for maintaining the nutrient budget of the lake. According to Jones and Bowser (1978) and Kelts & Hsiil (1978) sediment consists of three primary components (1) Organic matter in various stages of decomposition (2) Particulate mineral matter including clays, carbonates and non-clay silicates and (3) an inorganic component of biogenic origin eg. Diatom frustules or certain forms of Calcium carbonate. Murthy and Veerayya (1972a & 1972b) have recorded four major sediment units from Vembanad lagoon i.e. sands, silty sands, clayey silts and silty clays. He also observed that the organic matter content was ranging 0.10 to 6.0%. Veerayya and Murthy (1974) studied on the bottom sediments of Vembanad lagoon and suggested that the sediments in the estuarine region were the deposition of suspended load by flocculation during the post monsoon and pre-monsoon months supply of five materials from the sea through tidal current during these months. Sajan and Damodaran (1981) while studied the sediments of Ashtamudi lagoon recorded that the river mouth area composed of fine sediments like clay, silt clay with high concentration of organic matter and in the mouth region especially in the tidal channel area the sediment was composed of fine to medium sands with low organic matter content. They also observed a gradual increase in grain size of the sediments from the river mouth towards the tidal channel. Roy George et al (1993) studied the sediments of Ettikulam lagoon and stated that sediment distribution was affected by the river deposition and various geomorphic features such as barriers and islands in this region. Sahoo et al (1991) studied the sediments of Talapady lagoon near Mangalor and revealed that
the organic carbon, nitrogen and phosphorus in sediment varied from 0.09 to 4.15%, 0.04 to 1.59 mg/gm and from trees to 19.06 mg/gm respectively. He also stated that most of the months were sandy or silty sand and phosphorus and nitrogen concentrations also were greater in fine-grained sediments. Shankaranarayana and Gupta (1973) reported that the Lakshadweep lagoon area of biogenic sedimentation looked pure white owing to the high concentration of river discharge from the mainland which were resulted in the contamination of sediment silt, clay etc. Chandramohan et al (1994) were of opinion that distribution of sediments along the lagoon beach during monsoon and fair weather season was predominantly controlled by wave activity and current circulation pattern of the lagoon and during high tide the current induced by part of wave energy passing over the barrier reef and the tidal inflow stirred up the sediment and carried them parallel to the shore. As the wave action was intense during southwest monsoon, considerable quantity of water would flow over the reef due to waves and tides. Sahu et al (1990) studied the sediments of the outer channel of Chilka lagoon and stated that the sediments were sandy and uniform in distribution. Asthana (1979) investigated in detail the sediments of Chilka lagoon with the observation that sandy-clayey nature of sediments in the fringe areas or the lake bordering the hilly country and rolling plane. He also stated that due to shorter distance or transport and negligible velocity of the transport medium the sediments were course grained in nature and confined to the marginal areas. He also performed the textural analysis of Chilka sediments with sand content varied from less than 0.25% to 99.52%, silt varied from 0.25% to 60.02%, clay varied from 0.21% to 93%, organic matter content varied from 0.15% to 14.9%. Natarajan (1988) opined that in chilka lake clay formed an elongated stretch throughout the central region of the lake. He mentioned that the clay was dual in origin: the autochthonous clay and organic particles originate from the plankton community of the Northern shallow part and the allochthonous input was via gradual sorting of the sediments along the fringes and the sediment load of the rivers Daya and Bhargavi. Mohanty (1993) studied the mineralisation of organic nitrogen at different salinity levels of brackish water fishpond soil of chilka lagoon upon addition of cowdung under laboratory condition at ambient temperature (28.8-30.6°C) over 120 days. He observed upon aeration percentage gained in mineralized nitrogen at 0.5, 10, 20 and 30 ppt salinity ranged between

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26.1 and 28.5 ppt and was not significantly different. He stated finally that the mineralisation was slower at higher salinities.

3.2. Phytoplankton and seaweed:

The major works done on the phytoplankton and seaweed ecology of lagoon water other than India are summerised as follows-

Marinho et al (1993) investigated on the phytoplankton community of Lagoa guarnaiaba, Araruama, Brazil with an observation that after rising the water level the Chrysophycean species arises and Cyanophycean species are replaced by flagellates. They also suggested that reduction of biomass, community structure, change and reduction of pH and dissolved oxygen may have played a role in decreasing the lagoon’s trophic level.

Greenwald and Stuart (1993) observed that the effects of salinity on the coastal lagoon phytoplankton assemblages with an observation that at more than salinity 17 ppt most of the phytoplankton taxa showed marked effects. They also indicated that Pyrophytes were most abundant at 51 ppt and least abundant at 8.5 ppt or 17 ppt, Cryophytes increased with increased salinity, Euglenophytes exhibited no salinity effect and Bacillariophytes were abundant at 8.5-34 ppt and least abundant at 51 ppt.

Fong and Zedler (1993) from their study on temperature and light effects on the seasonal succession of algal communities in shallow coastal lagoon found that the biomass of phytoplankton and benthic mats were highest at 25°C, while macroalgae attained the maximum biomass at 18°C-22°C, reduced light and short days favoured the accumulation of phytoplankton and attached macroalgal biomass where as high light and longer days favoured floating macroalgae and Cyanobacterial mats. They also observed that attached macroalgae dominated in early spring, floating macroalgae in summer, Cyanobacterial mats in late summer and phytoplankton in late fall.

Philips & Badylak (1996) investigated on the blue green algal blooms in Florida Bay and reported that blue green algal bloom have the implication in fish kills, sponge die-offs, reduction in seagrass communities and potential alteration of food webs.

Charpy et al (1997) during the study of particulate matter in Tnamotee atoll lagoon (French Polynesia) found that the phytoplankton biomass
(Chlorophyll) concentration was inversely related to the water exchange between lagoon and ocean.

**Collos et al** (1997) studied the variability in nitrate uptake kinetics of phytoplankton communities in a Mediterranean coastal lagoon with the inference that in low nitrate containing water the saturation kinetics shown by the bloom of *Chaetoceros* sp, biphasic kinetics shown by the bloom of *Skeotonema coastatum* and flagellates at transition point between 10 & 50 μM while the unsaturated kinetics shown by *Thalassiosira* bloom and flagellates up to 100 μM nitrate condition.

**Perej et al** (1999) studied the ecological condition of *Nudularia* sp. with an observation that this bloom occurred in water with the pH 8.3 and temperature 23°C.

Major ecological studies on the phytoplankton and seaweeds in Indian lagoon water other than Chilka Lake are summarised as follows:

**Srinivasan** (1969 & 1973) collected and identified 120 species of seaweeds from Indian coastal water.

**Abdul Aziz & Balakrishnan Nair** (1980) investigated on the seasonal distribution and biomass of phytoplankton in Paravur lagoon and reported that highest and lowest volume of phytoplankton recorded during early September and early October respectively.

**Mathew and Balakrishnan Nair** (1981) made qualitative and quantitative studies of phytoplankton of Veli lagoon indicating 53 genera of algae distributed in that lagoon and Chlorophyceae was the dominated class.


Studies on the phytoplankton, several other attached algae and seaweed in Chilka lagoon till date are as follows:

**Srinivasan** (1969 & 1973) collected and reported 4 seaweeds from chilka lake.

**Biswas** (1924) and **Biswas** (1932) reported the algal flora of Chilka Lake comprising of 22 species. **Roy** (1954) recorded more than fourty species of diatoms over nineteen genera in Chilka Lake with majority of them are marine.
origin and the rest is brackish water type. Devasundaram and Roy (1954) observed that *Chaetoceros* sp. and *Asterionella japonica* are the dominant components among the diatoms in Chilka Lake.

**Patnaik & Sarkar (1976)** from their study on the distribution and seasonal fluctuation of phytoplankton in relation to salinity, phosphate and nitrate observed that three peaks of total phytoplankton in northern and Central sectors, four peaks in Southern sector and two peaks in Outer channel sectors. They also reported that on an annual average the Diatoms were dominant (67.3%) followed by Blue green algae (25.9%) Dinoflagellates (3.5%), Green algae (2.3%) and miscellaneous (1.0%). Their study reveals that the salinity operates as a factor determining and composition of phytoplankton rather than showing any uniform correlation with the phytoplankton peaks.

**Patnaik (1973 & 1978)** investigated the qualitative and quantitative distribution of dominant algal forms in relation to some physicochemical parameters. He recorded that *Chaetomorpha* was the dominant and most widely distributed alga in the lake followed by *Lyngbia* and *Enteromorpha*. He also pointed out that southern sector had comparatively high algal density probably due to least fluctuation in salinity, higher transparency and an abundance of sheltered areas due to a number of islands and hillocks where as the northern sector had low algal density due to wide fluctuation of salinity and transparency.

**Panigrahy and Misra (1985)** studied biogeography of the diatoms.

Based on salinity and phytoplankton distribution **Raman et al (1990)** divided the lagoon into five ecological zones i.e. Zone-I corresponding to Rambha bay with high salinity and Dinoflagellates are the principal dominants; Zone-II central sector & Zone-III intermediate between central and northern sector with reduced salinity and Cyanophyceans as major dominants; zone-IV northern sector with maximum dilution in salinity dominated by Diatoms and certain Chlorophyceans; Zone-V, Channel area with more or less marine environment have the phytoplankton inhabitant of marine origin. They reported 97 phytoplankters from which 13 were of Cyanophyceae, 4 of Euglenophyceae, 16 of Chlorophyceae and 60 of Bacillariophyceae.

**Samanta Roy & Padhi (1999)** from their study on the water chemistry and seasonal pattern of algal blooms of Chilka Lake observed that increased eutrophication caused the algal bloom. They also observed the maximum algal
bloom at all sites in summer and Cyanobacteria were the permanent bloom components. They reported *Oscillatoria* and *Lyngbia* bloom occurs in all seasons and *Trichodesmium erythraeum* and *Anabaena circinalis* blooms developed only for short period mainly in the summer and rainy seasons.

3.3. Seagrasses, aquatic macrophytes, flora & vegetation:

Interference competition between seagrass and seaweeds was studied by Paul & Fenical (1987), Lemmee et al (1993), Villele and Varlaque (1995) with an inference that the invasion of seaweed in seagrass beds declined the seagrass community structure due to rapid vegetative growth, increased organic matters deposition and secondary metabolites.

Disturbance in seagrass habitat and the influence in changing biomass of seagrass community were studied by Camp et al (1973), Cambridge et al (1986) and Williams (1988). According to their view the major disturbances on seagrasses are partial and total harbivory, bioturbation from animal burrows and nests, boat anchors and propeller scar, dredge-n-fill operations and storms. Succession in seagrasses in west Australia was studied by Kirkman (1985) who concluded that the succession in seagrasses in west Australia was controlled by species specific dispersal capabilities and that species diversity was higher in disturbed communities due to different species occupying different spatio-temporal niches. Williams (1990) and Fourquerean et al (1995) hold the opinion that the direction and rate of succession are dependent on the resource availability, species specific dispersal capabilities and proximity to bare areas. Long et al (1996) observed dredging effect on the seagrass community in Deception bay, Australia and found that *Halophila ovalis* (R. Br.) Hook. f. persisted up to 14 months after dredging. Agawin et al (1996) after studying some seagrasses suggested that seagrass species dominance is dependent on the specific nutrient gradients. On the other hand Cambridge (1996) suggested that the seagrass species distribution patterns might be determined by resistance to water movement and competition for light.

Byonton et al (1996) studied the relationship of some physicochemical parameters to the aquatic vegetation of coastal lagoon Maryland with the view
that water clarity supports to survive the extensive growth of seagrass community.


Some works on the aquatic macrophytes of Chilka Lake were done by several workers. Haines (1921-25) collected and mentioned some plants that are collected from Chilka lagoon and its vicinity. Mooney (1950) in his supplement to the Botany of Bihar and Orissa also mentioned some plants which were distributed in Chilka and its vicinity. Patnaik (1973b) while studying the aquatic plants of Chilka lake considered the extension of the vegetation in the northern sector up to 8 km from the western shore, 2 km from the eastern shore; in the central sector, 3 km from western shore and in the southern sector up to 2 km from the shore and outer channel. Panda and Patnaik (1985,1988) studied the Flora & vegetation of Chilka lake reporting 352 angiospermic species belonging to 272 genera under 96 families. Panda et al (1986) collected *Macrotyloma* (Wt. & Arn.) Verdc. from Chilka lake and reported as new to Orissa. Panigrahi (1988) studied the Flora and vegetation of Chilka lake indicating 150 species of vascular plants and briefly discussed the vegetation of the water body and landmass mainly on Barkuda island in comparison to other islands and headlands of Chilka lake.