International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Studies on Water Quality and Macrophyte Composition in Dal Lake of Kashmir J&K

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Abstract: ***The accelerated sedimentation, settling of plant biomass and siltation have rendered lake basins shallow and continuous dry summers have resulted in low water level and high summer temperatures. All these factors have been responsible for high macrophyte vegetation in the lake which not only looks unaesthetic but create many hindrances. Vegetation stands have become mono-species, biomass per unit area has increased appreciably and the carbon dioxide content in water has decreased in response to vigorous photosynthesis. The amount of organicproduction by macrophytes in Dal Lake has been calculated for the entire year taking into consideration the extent of growing period. For this purpose various species have been considered under their respective life-forms. The area has been calculated for each life form separately. The data show that more than 41 thousand tons of organic matter is added to the lake each year by macrophytes which add to the sediment pool and also result in sedimentation.***

Keywords: sedimentation, dal lake, macrophyte, biomass

1. Introduction

Dal Lake supports a rich and varied growth of macrovegetation which in some areas has become so thick as to form an almost impenetrable mass. The most extensive coverage is of submerged species and floating forms which have reached nuisance levels. Our studies show that the richness of macrophyte vegetation in Dal lake is not only due to constant supply of nutrients from the catchment but also because of many other favourable conditions such as shallow depth of basin and its gradual slope, nutrient rich sediments, optimum light and temperature conditions during growth period, minimum wave effect and the presence of numerous perennial species which are adapted to an efficient utilization of the existing environmental conditions. It is well known that aquatic macrophyte communities are “habitat opportunists” and hence it is difficult to dislodge a community once it is established in a particular lake or a part of it.

Past Studies

Studies on macrophyte vegetation of Dal Lake was started as early as 1920 by Prof. S. K. Mukerjee but because of his untimely death most of the data got lost and only a few abstracts have appeared on the species composition, successional trends and light conditions of the lakes. The Yale North India Expedition visited the valley in 1932 and for the first time reported not only on the presence but dominance of Potamogeton lucens and Potamogeton crispus from Dal lake. It is interesting to find that both these species are not now dominant. Two species, Polygonum amphbium and Nymphoides peltata were found to be the main floating forms in 1932 and now we find the former species virtually having disappeared from the lake. Koul (1946) reported profuse growth of Myriophyllum verticillatum in side channels of Dal. Even now this species is abundantly growing in silted regions of Hazratbal basin. Koul also observed dominance of Myriophyllum spicatum and this species continues to occupy its prominent position in the submerged community of Dal Lake. The other species during mid-forties were Nymphaea Alba, Nymphoides peltata, Hydrocharis morsus-ranae and Lemna sp. Euryale ferox was dominant in Hazratbal basin but it is not now present in this basin but in isolated patches in side channels. A comprehensive listing of macrophyte species from Dal and other lakes of Srinagar was carried out by Kaul and Zutshi (1967) who included data on phenology and general distribution of various species. Zutshi and Vass (1982) investigated coverage and primary production of some dominant macrophyte forms.

The studies undertaken so far clearly establishes the fact that even in the past aquatic vegetation was quite abundant in Dal Lake and perhaps because of traditional management comprising of periodic removal of weed manually for laying floating gardens and for animal feed kept its growth under check. Also because of lesser impact of human population on the lake ecosystem the vegetation never assumed nuisance levels as is the case today. In recent years the amount of nutrient inputs has registered manifold increase and as a consequence the sediments have become much enriched. The accelerated sedimentation, settling of plant biomass and siltation have rendered lake basins shallow and continuous dry summers have resulted in low water level and high summer temperatures. All these factors have been responsible for high macrophyte vegetation in the lake which not only looks unaesthetic but create many hindrances. Vegetation stands have become mono-species, biomass per unit area has increased appreciably and the carbon dioxide content in water has decreased in response to vigorous photosynthesis.

Vegetation Types

Dal Lake supports a complete constellation of life-forms of aquatic macrophytes. These are:

1) Emergent communities (Helophytes) represented by following species, Typha angustata, Phragmites communis, and species of Cyperus, Carex and Scirpus.
2) Floating-leaf (Ephydates) species which comprise of Lemnids (L. minor, L. gibba, Spirodella polyrhiza), Nymphaeids (Nymphoides peltata etc.).
3) Submerged (Hyphydates) like elodeids, plants with long shoots e.g., Hydrilla verticillata, Myriophyllum spicatum, Ceratophyllum demersum, etc.

The distribution and presence of dominant macrophyte species is not the same in different basins of Dal Lake e. g., in Gagribal area and Bod dal basin, Myriophllum spicatum is the most common species followed by Potamogeton lucens and P. pectinatus. Among the floating forms the most dominant species are Nelumbo nucifera, Nymphoides peltata and Nymphaea stellata. In Hazratbal basin the most dominant community is Myriophyllum spicatum-Ceratophyllum demersum. Emergent species are Typha angustata and Phragmites communis. These species are well established on silted regions. In Nagin, Ceratophyllum demersum is the most dominant form but in side channels of the lake it is Salvinia natans which constitutes bulk of the vegetation. The distribution of most common macrophyte species is shown in Table 1.

Table 1: Distribution and coverage of dominant macrophytes in Dal Lake

Species	Gagribal	Bod dal	Hazratbal	Nagin	Side channels
Certophyllum demersum	p	p	++	+++	+
Hydrilla verticillata	p	p	+	+	+
Hydrocharis morsus-ranae	+	p	p	p	++
Lemna sp.	+	p	+	p	+
Myriophyllum spicatum	++	+	+	p	p
Nelumbo nucifera	+	++	++	+	
Nymphaea stellata	+	++	+	+	++
Salvinia natans	+	p	++	+	+++
Phragmites communis	p	p	+	p	+
Typha angustata	p	p	+	+	+

p: present + 5-25% cover, ++ 25-50%, +++ > 50%

The amount of organic productionby macrophytes in Dal Lake has been calculated for the entire year taking into consideration the extent of growing period. For this purpose various species have been considered under their respective life-forms. The area has been calculated for each life form separately. The data show that more than 41 thousand tons of organic matter is added to the lake each year by macrophytes which add to the sediment pool and also result in sedimentation. The data is presented in Table 2.

Table 2: Primary production data on macrophyte vegetation

Life-form	Area covered		Organic matter production	
	ha	%	g/m2/day	t/ha/year
Emergent species	50	3-5	10.5-15.0	27.6
Floating forms	280	25-30	1.24-5.4	8.8
Submerged	680	55-65	0.77-2.4	4.62
Total	1010		12.51-22.8	41.03

Source: LAWDA

Accumulation of nutrients by macrophytes

Kaul et al. (1980) reported that in Dal Lake the emergent vegetation comprising mainly of Typha and Phragmites is able to lock as much as 57% of different nutrients within their tissues. In comparison, the submerged vegetation retained only 14 to 38% of nutrients and the floating vegetation as little as 4 – 7%. Among the main elements nitrogen concentration was maximum in the plant tissues followed by calcium, potassium and sodium in that order. The least accumulation was of phosphorus. The concentration of various minerals followed a definite seasonal trend showing maximum concentration during June and July when light and temperature conditions are most favourable for growth and reproduction. As winter approaches the concentration falls rapidly and same is the case with the onset of spring when growth is initiated. Generally four months i.e., May to August is the period when maximum mineral concentration is recorded within the macrophyte tissues. Three elements, nitrogen, potassium and calcium are in maximum concentration in the plant tissues and phosphorus and sodium in the least concentration as is shown in Table 3.

Table 3: Monthly variations in mineral content (g/m2) of macrophyte species

Mineral constituent	Mar	Apr	May	June	July	Aug	Sept.	Oct.
N	2.42	4.52	10.79	14.91	14.83	10.99	5.90	2.18
P	0.12	0.23	0.56	0.78	0.77	0.55	0.240	0.09
K	1.9	3.49	8.35	11.96	9.7	8.59	4.13	1.58
Na	0.23	0.43	1.01	1.54	1.60	0.99	0.56	0.24
Ca	2.29	4.27	10.11	14.58	14.78	10.88	4.98	1.75
Mg	0.61	1.24	3.0	4.42	4.28	3.18	1.48	0.58

Source: LAWDA

Data on the extent of mineral accumulation by different life-forms of macrophytes in Dal Lake show that as much as 86 metric tonnes of nitrogen followed by 58.12 metric tonnes of calcium, 41.45 m/t of potassium and 27.06 m/t of magnesium are locked up. The amount of phosphorus was only 3.64 metric tonnes. The data is presented in Table 4.

Table 4: Mineral accumulation (metric/tonnes) by macrophyte vegetation

Life-form	N	P	K	Na	Ca	Mg
Emergent	64.06 (74)	2.94 (80)	23.39 (56)	6.74 (80)	35.81 (61)	20.08 (74)
Rooted floating	3.91 (5.0)	0.07 (1.9)	2.06 (4.5)	0.54 (5.3)	4.0 (7.0)	1.55 (6.0)
Submerged	18.04 (20.0)	0.63 (17.0)	61.0 (38.0)	1.17 (14.0)	18.31 (31.0)	5.43 (2.0)
Total	86.01	3.64	41.45	8.36	58.12	27.06

The values in the parenthesis are % mineral content for the entire lake.

Weed Harvesting: Advantages and disadvantages:

In order to permit use of Dal Lake for aquatic sport, navigation and other desired use a case has been made for removal of excessive biomass of macrophytes by mechanical harvesting. There is no denying that in some areas of the lake weed growth is excessive which presents a degrade view of the ecosystem. Unfortunately while advocating the use of machines for weed cutting the role of macrophytes as an integral part of the freshwater ecosystem playing numerous and diverse functions have been completely overlooked. Further it should be noted that the most sound and reasonable management approach would be control of macrophyte vegetation in Dal lake rather then its eradication. It is well known that macrophytes are bio-indicators of pollution, they effectively remove mineral from the sediment nutrient pool and thus help in pollution abatement by acting as nutrient pumps and serve as biological sinks. The local population of Dal use macrophytes in many ways which include food, fodder and medicinal plants. The macrophytes also form the basic source of food in aquatic food chain and provide the most suitable breeding, resting and sheltering place for macrofauna, including fish and other organisms including waterfowl, besides supporting substantial quantities of periphyton on which depend a large number of aquatic animals. Prevention of sediment resuspension and oxygenation of water through photosynthesis are other functions of macrophytes. But it is also a fact that excessive growth of macro vegetation in a lake impedes transport, hinder irrigation, increase sedimentation by trapping silt particles and affect recreation. What is therefore needed is to assess both the advantages and disadvantages of using mechanical harvesting for control of aquatic vegetation and then select the approach which is most beneficial to the system without creating undesirable changes which may be more harmful and difficult to control.

Advantages

1) The harvesting of weed is safer in comparison to use of weedicides especially when the lake is used for recreation and drinking water supply.
2) Harvesting removes biomass and also plant nutrients contained within the tissues.
3) Harvesting of macrophytes does not normally interfere with the desired use of the lake except when macrophytes are harvested by local farmer for green fodder.
4) There is a certain degree of selectivity in mechanical harvesting. It is possible to remove weed from specified areas in a short period of time.
5) Harvesting has little impact on the non-target organisms other than those removed with the cut vegetation.
6) Harvested vegetation may be used as green manure, animal feed and for production of biogas.

Disadvantages

1) During deweeding the vegetative fragmentation results in more rapid growth of target species.
2) A large number of fish especially juvenile gets killed as it gets entangled within the harvested weed.
3) Mechanical harvesting involves high capital cost.
4) The machines used for weed cutting require constant maintenance which at times becomes difficult because these are imported.
5) The depth of water limits the use of machines.
6) Harvested vegetation may become a waste material and difficult to dispose off.
7) Different types of machines need to be used for controlling different type of aquatic vegetation e. g., the machine that can be used for harvesting submerged vegetation cannot be used for floating leaf vegetation.
8) Harvesting is a slow process and regrowth is quite rapid and therefore it can create public dissatisfaction.
9) The machines are not suitable in shallow and narrow waterways and side channels.

Opinions grossly differ on the usefulness and efficacy of mechanical weed harvesting as a tool for controlling nuisance weed growth. Since the trophic interactions among different biotic components of lakes are not only very much intricate and somewhat site specific it is not exactly known as to how the system will respond once it is exposed to intensive weed harvesting. Wile (1975) is of the opinion that mechanical harvesting provides immediate relief from nuisance conditions without addition of foreign substances. According to Carpenter and Gasith (1978) the immediate consequences of mechanical cutting of submerged macrophyte may include suspension of sediments and *aufwuchs* and exudation from damaged tissues which can potentially alter water chemistry and metabolism. Bartell and Breck (1978) are of the view that reduction in macrophyte abundance could change the structure and functioning of the lake subjected to harvesting.

Manual deweeding in Dal Lake

Removal of macrophyte vegetation is a common practice in Dal Lake and has been in vogue since 15th century or so. The local farmer removes submerged vegetation manually making the use of long wooden poles. In this process a small quantity of sediment is also removed. The mix of plants and sediment is used for laying floating gardens. The most common species that are removed manually are Myriophyllum spicatum, Potamogeton lucens, P. pectinatus and Ceratophyllun demersum. Some other submerged species may also get uprooted in this operation but these are rarely encountered. In the past, this type of weed removal acted as a traditional management for the lake. The weeds were kept under check, but in recent years the ecology of the system has changed so much that manual deweeding does not keep pace with prolific growth of vegetation. In addition, large quantities of floating-leaf vegetation is also removed by local population especially women folk and used as fodder during summer when other type of fodder is scarce. The plants which are removed by hands include Nymphoides peltata, Nymphaea stellata and Potamogeton natans. At present manual deweeding in dal lake continues at two levels; one is the traditional way as described above and other is being carried out under the control of Lakes and Water Ways Development Authority. Many local farmers are engaged on daily basis to remove weed from the lake using local contraptions and boats. The weed instead of being used for floating gardens is dumped along the shores till that time when trucks carry it to the disposal sites. No data is available on the impact of this operation and its usefulness.

Mechanical weed harvesting in Dal Lake

As a follow up to the recommendations of Enex (1978), the Government of Jammu and Kashmir imported two weed harvesters of Rolba Aquamarine type from Switzerland in 1984 and started weed removal from Dal Lake. The main purpose as spelled out in the report was to use weed harvesting as a means to nutrient removal instead of improvement of lake aesthetics. It was suggested that weeds should be removed at a controlled rate and maximum up to 75% of submerged vegetation should be harvested. According to some estimates weed harvesting would remove only 13 tonnes of phosphorus and 91.5 tonnes of nitrogen annually from the ecosystem. The emphasis that time was not on removal of impediments that excessive weed creates in transport, fishery and recreation but nutrient removal. In 1986 two more harvesters of pick-up type were purchased and harvesting continued till 1989 when militancy broke out in Kashmir. This interrupted the operation of the harvesters. An Impact assessment study was undertaken during 1988-89 to find out the changes in water chemistry and biotic populations as a result of mechanical weed harvesting (Zutshi and Ticku 1990, Ticku and Zutshi 1991, 1993). The authors reported following results:

1) The visibility of water decreased by nearly 47% after weed harvesting. The impact was due to resuspension of sediments which created turbid conditions. Although the effect was short lived, repeated use of machines could result in impairment of photosynthetic process.
2) The dissolved oxygen concentration of lake water decreased after deweeding.
3) There was increase in specific conductivity values by as much as 30%.
4) Both nitrogen and phosphorus values increased but the increase was on short term basis. It is most probable that stirring of sediments by harvesters release nutrients from sediments.
5) There was significant increase in the chlorophyll a concentration (up to 50%) as a response to deweeding.
6) Mechanical harvesting of plants has profound impact on the species number, composition and on the community structure of plankton population. The diatom population increased by as much as 50%. There was also increase in cyanobacterial population. Decrease in competition by removal of macrovegetation could trigger increase in algae population. Zooplankton population also registered significant increases especially rotifera.
7) Weed harvesting had major impacts on fish population of Dal Lake. Nearly 8 tonnes of fish was lost annually from the lake if it was presumed that 1600 tonnes of weed are removed per year. The maximum loss was of indigenous species such as Nemachilus latius and Barbus conchonius.
8) It is suggested that excessive macrophyte removal can have extensive secondary effects on fish and their prey, and these effects may ripple down the food chain throughout the system.

Although weed harvesting continued for more than three years during pre-1990 period there was no visible improvement in the overall proliferation rate of the weeds and no significant reduction in their coverage. The plant beds in the cut area got restored within three to four weeks after harvesting. The submerged species whose apical portions were cut by the machine developed a large number of secondary branches thereby increasing the canopy which gave fan like appearance. The inter-nodal distance in some macrophytes increased in response to harvesting. Blooms of filamentous algae appeared in lake areas subjected to frequent harvesting.

Deweeding in Dal Lake: Possibilities and constraints

Among many in-lake restoration measures, biomass removal using weed harvesters has been carried out in Europe and the USA with some degree of success. In many cases, harvesting of weeds has been followed by chemical applications. In Dal Lake use of chemical control is not at all desirable because of its multiple use. One has to keep in mind that Dal Lake restoration is not a simple task, and requires sound scientific understanding of structure and functioning of the biological communities. An essential pre-requisite in the formation of a restoration project is to set up restoration objectives for the lake. Arguments for carrying through the programme of restoration are to be clearly spelled out in terms of the designated use of the water body. Once restored to a desired level no further extensive management programme should be necessary.

It is a common experience that in Dal Lake overabundance of macrophyte vegetation is interfering with boating, sometimes with fishing, with swimming and above all is aesthetically displeasing. There are no quantitative data to show the extent of increase in macrophyte vegetation during the last few years. We have no information which species has increased in its cover and biomass production and which species has shown decreasing trends. In the absence of such data it is purely on visual observations that statements are made in support of excessive vegetation development in the lake. There are no recent vegetation maps which could be compared with earlier maps, nor any quantitative data on biomass production. Assuming that macrophyte vegetation has been increasing in Dal Lake it is recommended that a physical control measure which includes manual and use of mechanical harvesters should be continued keeping in view the following aspects:

1) It should be noted that aquatic plant control, rather than eradication is the most sound management approach.
2) Total removal of plant cover and large scale harvesting should be avoided at all costs.
3) Shallow lakes like Dal Lake are very prone to shift from stable vegetative state to non-vegetative state where cyanobacteria blooms occur which are very difficult to control and harmful to aquatic sport. The vegetative state is more robust to disturbances but excessive weed removal can offset their stability and cause turbid waters with algal blooms.
4) Weed harvesting has be selective i.e., limited to certain areas only. Lake areas which are useful for fish, fodder and food plants should not be exposed to repeated harvesting.
5) Harvesting should be carried out before flowering and fruiting and formation of propagules in plants.
6) Time and season of harvesting is the most important factor. It has profound impact on regrowth of vegetation. In Dal Lake one cutting should be done in late spring and second during late summer. Extra cutting should be carried out only in some selected areas and that too when it is absolutely necessary.
7) It is very important that only 40% to 50% weed is removed and rest is left untouched. Deweeding operations in which 30% to 50% of the vegetation remains after treatment is taken as normal.
8) Removal of nutrients through weed harvesting is not high in Dal Lake as most of the nutrients get concentrated in emergent vegetation which is not harvested by machines (data given in tables) and it does not create any environmental problems. Manual removal of emergent vegetation by local farmers keeps it under check.
9) Harvesting of ~ 50% submerged vegetation would remove not more than 13 tonnes of phosphorus and 75 tonnes of nitrogen annually. Data presented in tables show clearly that maximum nutrient concentration is achieved during summer.
10) In Dal Lake it is the internal nutrient load that supports the rich vegetation growth. Sediments act as a nutrient trap and supply phosphorus and nitrogen to growing macrophyte vegetation. Even when these nutrients are reduced from catchment through various rehabilitation measures macrophytes would continue to grow for many years in the system.
11) Macrophyte removal must consider the desirability of leaving some selected areas undisturbed for fish spawning and waterfowl feeding.
12) Time frame should be prepared for weed harvesting and strictly followed.
13) Major effort should be directed towards harvesting undesirable plant species such as Ceratophyllum demersum, Nymphaea stellata, Salvinia natans and Hydrocharis morsus-ranae.
14) It should be ensured that all cut parts of the plants are removed from the lake. Regeneration in case of some species is very rapid which helps in quick establishment of the stand.
15) Harvested plants should be immediately removed from the lake shore to avoid leaching of nutrients into the lake water.
16) Machines should be used in open lake area and manual deweeding in back waters.
17) Special contraptions need to be used for removing Salvinia natans. Sieves made of non-corrosive material with three sides covered and one side open can be locally made and used for removing Salvinia. This operation should be started before the water fern starts fruiting in autumn.

2. Conclusions

Harvesting of aquatic vegetation has been used in many lakes, which are maintained for multiple uses. The main objective behind harvesting is to remove unwanted plants or plant parts to permit the desired use of the water body. Manual methods continue to be used to control excessive growth of macrophytes, which are both economically and environmentally appropriate. Harvesting of aquatic vegetation can be done by using machines which cut submerged and rooted vegetation at a particular height from substratum. Harvesting could be integrated with other biological control methods which need to be investigated properly.

In Dal Lake removal of vegetation is being carried out both manually and using imported harvesters. Mechanical harvesting has both the positive impacts and also negative aspects. Harvesting is a temporary measure to keep vegetation under some degree of check, it is not a permanent solution. It is desirable to have some quantity of macrophyte vegetation (> 50%) in lake to keep algal blooms under check, which otherwise would be extremely difficult to control. We do not support the use of large number of machines; two fully functional Rolba harvesters should be good enough to undertake selective deweeding of the lake. One machine is already fully functional and in use.

A continuous monitoring should be to be undertaken during harvesting operations covering the following aspects:

1) Vegetation maps to be prepared for comparing changes in cover and density of various species. A comparison can be made with earlier vegetation maps. Aerial photographs and satellite imageries will be very useful.
2) Efficiency of machines and men need to be recorded periodically.

3) Re-establishment of vegetation and changes in the community structure to be monitored.
4) Phenology of various aquatic plants to be recorded.
5) Any changes in dominant species after deweeding to be noted regularly.
6) List of species that escape harvesting to be noted.
7) Records of species which would escape weed control to be noted
8) Alternative possibilities of weed control to be assessed
9) Weed cutting to be carried out during peak biomass development.
10) Some species not present before harvesting can appear as they are able to exploit the changes in habitat. These species need to be regularly monitored.

In our opinion, harvesting should be limited to the following areas.

- Backwaters
- Areas where exotic water fern and water lilly abound.
- Additional areas being brought under lotus.
- Parts of Gagribal and Nagin basin which are used for swimming and other recreational activities. (Fig 14.1)

It is further recommended that the Scientific Advisory Committee, as proposed in Section 18.1.3 of Chapter 18, should be associated with the above and make suitable recommendations for additions/alternations periodically.

Catchment

The catchment area of Dal Lake is 337.17 sq. km which is about twenty times more than the lake area. The catchment consists of Himalayan mountain ranges on its north and northeastern sides, on its western side the lake is enclosed by flat arable land and expanding urban human settlements. The main geological formations are panjal trap, agglomerate slate, Triassic limestone and clayey material. In some parts of the catchment freshly deposited alluvium is also present. The adjoining mountains have little vegetation cover. The denudation of forest cover is probably the outcome of human activity in the past. It is most likely that natural causes might have also contributed towards reduction of vegetal cover (Zutshi 1987). Nearly 60% of the catchment is under various degrees of erosion with some compartments experiencing moderate to severe erosion. The top soil and other eroded material from the catchment finally drains into the Dal lake through many streams and channels. It is estimated that from Telbal nallah alone as much as 60, 877 tons of silt is drained into the Hazratbal basin every year. As a result the lake has filled up in many places. **Peripheral Areas**

During sixties and seventies many peripheral parts of Dal Lake in the east and northeast were filled up to create small patches of built area for floriculture. During subsequent years these patches were further extended with the result that a large portion of lake periphery was converted into built land which was subsequently used by local people for willow cultivation. Near Nishat garden the reclaimed part of the lake is used for commercial activity. Silted up areas favoured invasion of emergent macrophyte vegetation and resulted in further shallowing of the basin. During the construction of northern foreshore road huge quantities of earth was used a part of which flowed into the lake bed in the northern part of Hazratbal basin. This activity created further built areas along the road. Once the road was opened to traffic these unattractive patches of land, shoals and silted up vegetated islands became clearly visible to general public. The lake in this part was looking like a filled up marsh with hardly any open water area meeting the eye.

Nature of sediments

The surface sediments of Dal Lake comprise non-stratified loamy clays interspersed with carbonaceous bands. These overlay pale yellow laminated marls and silt and bands of interbedded medium to coarse grained greenish sands, marl stones, calcareous grits and clays of lacustrine origin. Below this, glaciofluvial sediments of gravel sands and beds of resorted glacial moraines occur over basal boulder conglomerates.

The rate of sedimentation is highly variable in different basins of Dal Lake and can be assumed to be greatest in Hazratbal basin which receives inflow from Telbal nallah. According to de Terra and Patterson (1939) the silt supply was evidently checked and counter balanced in past ages by erosion through lake currents, for otherwise the lake would have silted up more rapidly. The distribution of mineral grain in three basins of Dal lake is shown in Table 5.

Table 5: Distribution of mineral grain in Dal Lake (Percent volume)

Basin	Depth (m)	Coarse detritus	Fine detritus	Mineral grain	Diatoms
Gagribal	1.2	54	33	2	1
Hazratbal	4.0	54	6.8	29	3
Nagin	5.0	23	56	10	5

Source: LAWDA

It is seen from the above table that Hazratbal has highest per cent mineral grain in comparison to two other basins. This is quite understandable in view of high silt deposition in this part of the lake. Enex (1978) stated that in 1976 the total volume of settled silt in Dal Lake coming through the inflow channel was of the order of 36 million cu m. This would mean that each year if the shedding of the silt from the catchment continues at the same rate it would fill an area of 3.6 ha of lake up to one meter of depth.

Trisal and Kaul (1983) provided data on granulometric composition of four basins of Dal Lake and classified the Dal Lake sediment as silty loam (Table 6).

Table 6: Per cent granulometric composition of sediments

Basin	Coarse sand	Clay	Silt	Fine sand
Hazratbal	0.28	33.50	45.0	21.22
Bod dal	1.42	29.20	54.50	14.88
Gagribal	1.10	25.0	35.0	38.90
Nagin	1.70	37.50	32.50	28.30

Source: LAWDA

Data on particle size distribution, elemental composition and mineralogy of Dal lake sediments have been obtained by Kango et al. (1987 a). The samples were collected mainly from Hazratbal basin starting from mouth of inflow channel

Paper ID: SR22831224102 DOI: 10.21275/SR22831224102

towards the center of the basin. The size of the particle ranged from clay to coarse sand. The finer particles were mainly distributed along the offshore region and in deeper parts of the lake. The large sized particles were quite extensive in their distribution within the macrophyte stand and heavier particles were deposited near the entrance of Telbal into the lake. The smaller particles were carried by turbulence towards the open water areas. The coarse silt was 57% near the inflow and in the center clay content was 32%. Near human settlements sand content was 40% and coarse silt 49%. The particle size distribution is given in Table 7.

Table 7: Particle size distribution in Hazratbal basin

Distance from Shore (m)	Near size	Sorting	Skewness	Kurtosis
0	6015	1.58	2.58	1.53
425	4.98	1.23	1.66	4.74
554	6.66	1.15	3.05	2.13
725	5.78	1.32	1.07	2.43
875	5.94	1.46	1.25	2.77

Source: Kango et al.

Using X-ray diffraction and thermal analysis the clay mineral content of Dal Lake was seen to contain 72% illite and 28% chlorite. No calcite was detected in the sediment. Both the minerals present in the lake are stated to be the products of weathering and erosion processes (Kango et al.1987 b).

Chemical composition of lake sediments shows maximum presence of organic carbon which in case of Hazratbal basin was more than 18%. Aluminum was also high in the sediments. The phosphorus concentration was lower than nitrogen and calcium but higher than magnesium. Seasonal fluctuations in mineral composition were well marked e. g., Phosphorus decreased during spring –summer as plants utilized it for their growth. From August onwards the concentration of phosphorus increased in sediment which was maintained until next spring. This clearly shows the role of sediment nutrient pool towards the growth of vegetation. Organic carbon increased from July onwards as plant material started getting decomposed and settled in lake bottom. The change in sediment organic carbon closely paralleled the change in total phosphorus. Potassium depicted a decreasing trend in its concentration with the approach of summer and this was the case with all the basins. The calcium content showed a slight tendency to decrease during March-June in the entire lake. The per cent mineral composition is shown in Table 8.

Table 8: Mineral composition of Dal Lake sediments (%)

Parameter	Hazratbal	Bod dal	Gagribal	Nagin
N	1.88-2.92	1.05-2.16	1.60-2.05	1.62-2.21
P	0.09-0.25	0.09-0.29	0.08-0.19	0.08-0.20
Org. C	9.75-18.56	9.41-12.65	9.28-12.60	10.20-14.10
K	0.70-1.15	0.76-0.94	0.66-0.92	0.64-1.30
Na	0.11-0.31	0.06-0.19	0.09-0.13	0.12-0.13
Ca	2.75-3.95	3.15-3.86	2.40-3.50	2.10-3.15
Mg	0.46-0.61	0.52-0.74	0.50-0.61	0.54-0.62
Al	8.15-9.0	7.93-9.02	7.85-8.75	8.25-9.28
Fe	2.02-2.53	2.15-3.16	2.41-2.87	3.0-3.76
pH	6.8-7.2	6.9-7.2	7.0-7.2	6.6-7.1

Source: LAWDA

In Dal Lake, sediment phosphorus pool in the top 10 cm layer was found to be very large being more than 700 thousand kg which accounted for about 99% of the total pool. This shows that most of the phosphorus remains trapped in sediments, which are generally known to be long term phosphorus sinks. The average reserve of phosphorus in the sediment can be attributed to the sedimentation of this mineral after its precipitation (Ishaq and Kaul 1988).

Concentrations of some important heavy metals from Dal Lake sediments show presence of Manganese and Zinc in appreciable quantities (Table 9). However, the concentrations varied in different sites.

Table 9: Trace metal concentration in sediments (ug/g)

Site	Mn	Zn	Co	Ni	Cu	Pb
Inflow	588	130	9	10	36	14
Macrophyte Stand	576	147	7	10	54	1
Open water	1070	218	15	1	63	25
Close to human Habitations	817	177	9	20	117	21

Source: LAWDA

The results reported in Chapter 5 confirm the earlier observations of high rates of sedimentation in Hazratbal basin because of large quantities of silt flowing into this basin. The pattern of sedimentation changed significantly as the distance from inflow channel increased. In the vicinity of Telbal nallah organic matter was only 10% and it increased towards the lake center. Along the eastern part of the lake where macrophyte vegetation is very prolific organic matter content of sediment was as high as 63%. On an average the sediment organic content varied between 25-30% which indicated dominant role of macrophyte vegetation in the rate of sedimentation of the lake and also functioning of the ecosystem.

Chemical analysis of cores collected in the present study was carried out to estimate the concentration of phosphorus and nitrogen in various strata of the sediment. For this purpose composite core samples of 0 to 20 cm depth and of more than 20 cm depth were analyzed. The data clearly shows that both phosphorus and nitrogen concentrate in surface sediments (up to 20 cm depth) and not in deep sediments. The results are given in Table 10.

Table 10: Chemical analysis of sediment cores on Dal Lake (μg/g)

Site	Depth of Core (cm)	Total phosphorus	Total Nitrogen
Hazratbal (Near inflow)	0-20	300	4490
	21-54	84	4000
Nagin-Hazratbal (Connecting channel)	0-20	237	2200
	21-44	170	1980
Nagin	0-20	568	9540
	21-44	473	6130
Bod dal	0-20	793	12990
	21-56	275	9480
Gagribal	0-20	187	4830
	21-42	102	4570

Source: LAWDA

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