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Assessment of Trophic State of Nagin Lake Based on Limnological and Bacteriological Studies

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ABSTRACT

The present study was carried out to evaluate the trophic condition of Nagin Lake, Kashmir, based on its limnological features and bacterial load. A total of 15 limnological parameters were analysed, besides the bacterial load. The average values recorded were: air temperature (16.19±1.23°C), water temperature (12.40±0.92°C), depth (3.14±0.14 m), transparency (1.93±0.07m), TDS (149.52±5.66 $mg.L^{-1}$), TSS (95.63±3.27 $mg.L^{-1}$), pH (8.42±0.07), conductivity (260.61±12.16 μScm^{-1}), dissolved oxygen (6.96±0.13 $mg.L^{-1}$), free carbon-dioxide (0.55±0.20 $mg.L^{-1}$), ammonia (199.6±10.34 $\mu g.L^{-1}$), nitrate (399.94±203$\mu g.L^{-1}$), total phosphorus (492.12±21.79$\mu g.L^{-1}$), orthophosphate (50.06± 2.83$\mu g.L^{-1}$) and chlorophyll-*a* (13.43±0.86$\mu g.L^{-1}$). Most of the parameters recorded higher values during the warmer seasons of summer and autumn. The bacterial load showed an increasing trend from winter to summer, showing its direct relation with temperature and inverse relation with the dissolved oxygen content. Carlson's Trophic State Index was used to calculate the trophic state of the lake which showed higher values, suggesting the deteriorating condition of the lake water.

INTRODUCTION

The valley of Kashmir is blessed with a number of lakes with different hydrological settings such as Dal lake, Wular lake, Manasbal lake, Nagin Lake, Anchar lake, etc. (Sarah et al. 2011). The origin of the lakes in Kashmir is either tectonic or fluviatile, as all the lakes lie on the flood plain of river Jhelum. Nagin Lake, also considered as one of the basins of Dal Lake, is one of the important tourist attractions of the valley of Jammu & Kashmir. The lake water has considerable impact on social and economic status of the local population as it provides potable water and fish, besides being used for recreation and irrigation of the agricultural land. However, this freshwater lake, like most of the other water bodies in the Valley, is also under anthropogenic pressure, due to which its water quality has deteriorated during the past 50 years. Although the increased fertility of lakes with aging is a natural phenomenon, but the pace at which the lakes of this part of the Himalayas have shown this phenomenon, clearly indicates that human interference in the catchment areas as well as within the basins of the aquatic system has greatly increased. The inhabitation in and around the lake has resulted in the continuous inputs of sewage and other domestic wastes into the lake, leading to the increased rate of eutrophication. Keeping in mind the economic and aesthetic importance of this lake, a study was carried out to understand its present trophic condition using limnological and bacteriological parameters as tools for interpretation.

MATERIALS AND METHODS

Study area: The present investigation was carried out for a period of one year, from December 2013 to November 2014 at three different sites on the Nagin Lake. The sites selected were littoral, limnetic and near the outlet of the lake in order to get an idea about the trophic state of the lake as a whole.

***Nagin littoral*:** It is located on the banks of Nigeen club, which is a famous place for public gatherings and national and international conferences.

***Nagin limnetic*:** This site is located in the central part of the lake and has maximum depth. Here the macrophytic associations comprise of *Ceratophyllum demersum, Nymphaea alba, Nymphoides peltatum, Nelumbo nucifera, Potamogeton natans, P. crispus, Hydrilla* sp. etc.

***Nagin outlet*:** This area marks the outlet of the lake which is close to the famous Badamwari park. This part of the lake is marked by *Potamogeton natans, Hydrilla verticillata, Ceratophyllum demersum,* etc.

Sample analysis: The water samples were collected monthly for a period of one year (December 2013-November 2014) and kept in polyethylene plastic bottles. The parameters like pH, temperature, depth and transparency were checked on the spot while for other parameters, the water samples were carefully transferred to the laboratory on the same day and stored at 4°C until processing and analysis (APHA 2005). All the limnological parameters were analysed using standard procedures of APHA (2005). For bacteriological analysis, the water samples were collected in separate sterile Corning bottles, which were brought to the laboratory within one hour of sampling. The total viable bacterial counts of the samples were determined by standard procedures of APHA (2005) under sterile conditions.

RESULTS

The limnological parameters and bacterial counts analysed from different sites of Nagin Lake are presented in Tables 1 and 2 respectively. The overall mean air and water temperatures recorded during the four seasons at different sites were 16.19±1.23 and 12.40±0.92°C respectively. Both, air as well as water showed maximum mean temperatures during summer (24.61±0.86°C and 17.88±0.35°C respectively), while minimum mean temperatures were recorded in winter season (6.0±0.28°C and 4.14±0.34°C). The mean depth recorded in the Nagin Lake was 3.14±0.14 m. The maximum depth was recorded during autumn (3.30±0.31 m), while minimum was observed in winter (2.95±0.24 m). Among the sites, the littoral one showed the maximum depth of 4.35 m during autumn. The seasonal comparison of the transparency showed that the maximum values were obtained in winter (2.04±0.15 m) followed by autumn (2.0±0.15 m), spring (1.92±0.15 m) and summer (1.76±0.16 m) seasons respectively. The total dissolved solids (TDS) and total suspended solids (TSS) showed similar seasonal trend, both being significantly (P<0.05) higher during autumn and lower in winter seasons. The overall mean TDS value obtained was 149.52±5.66 mg.L^{-1} and showed an increasing trend from winter to autumn season. The suspended solids recorded an overall mean of 95.63±3.27 mg.L^{-1}, being maximum at the littoral site (127 mg.L^{-1}) during autumn season. Nagin Lake showed an alkaline pH throughout the study. Significantly higher (P<0.05) mean pH was recorded during spring (8.61±0.14) and summer (8.78±0.10) as compared to autumn (8.08±0.06) and winter (8.23±0.13) seasons. The overall seasonwise mean pH at different sites was observed as 8.42±0.07. Mean conductivity of the lake was observed as 312.11±24.28 µScm^{-1}, being highest in spring (312.11±24.28 µScm^{-1}) followed by winter (294.22±11.36 µScm^{-1}), autumn (266.0±18.61 µScm^{-1}) and summer (170.11±5.0 µScm^{-1}) respectively. The dissolved oxygen (D.O.) content of the lake recorded an overall concentration of 6.96±0.13 mg.L^{-1}. D.O concentration showed an inverse relation with temperature, being highest in winter (7.6± 0.25 mg.L^{-1}) and significantly (P<0.05) lower in summer (6.15± 0.23 mg.L^{-1}) season. The sitewise comparison showed that the highest D.O concentration (8.13 mg.L^{-1}) was present at the Nagin outlet during winter, whereas the lowest concentration (5.9 mg.L^{-1}) was recorded at Nagin limnetic during summer. Mean free carbon dioxide recorded an overall low concentration of 0.55±0.20 mg.L^{-1}. Highest mean concentration was recorded during autumn as 1.16±0.57 mg.L^{-1} while free carbon dioxide was absent from the Nagin waters during summer season. Seasonal comparison of ammonia concentrations in Nagin Lake revealed that significantly (P<0.05) higher concentration was present during winter (235.03±29.44 µg.L^{-1}) as compared to spring (205.37±21.27 µg.L^{-1}), summer (190.32±15.28 µg.L^{-1}) and autumn (167.67±4.49 µg.L^{-1}) seasons. The overall mean concentration of nitrate-nitrogen at different sites of Nagin Lake during different seasons was recorded as 399.94±20.3 µg.L^{-1}. Autumn season showed the maximum mean concentration of 443.4±37.8 µg.L^{-1} while spring showed the minimum mean concentration of 360.72±39.20 µg.L^{-1}. The sitewise comparison of total phosphorus concentration in the Lake revealed that outlet site showed maximum (6646.47 µg.L^{-1}) value during winter while the limnetic site recorded minimum (326.87 µg.L^{-1}) value during summer. The mean orthophosphate concentration in Nagin Lake recorded during different seasons was 50.06± 2.83 µg.L^{-1}, highest being recorded in autumn (52.22± 5.87 µg.L^{-1}) and lowest in winter (47.94±5.51 µg.L^{-1}). Mean chlorophyll-*a* concentration in the lake was recorded as 13.43±0.86 µg.L^{-1}. A significant (P<0.05) difference was seen in the chl-*a* values of winter spring and summer seasons. The highest value (22.02 µg.L^{-1}) among the sites was observed at limnetic site during spring.

The average seasonal total viable count recorded during the study was 6.33±0.11 cfu log_{10}/mL, with a significant (P<0.05) difference between TVC of winter, spring and summer seasons. The highest (7.29 cfu log_{10}/mL) TVC count was observed at littoral site while the lowest (5.47 cfu log_{10}/mL) was recorded at the limnetic site.

Carlson's trophic state index: The TSI values of chlorophyll-*a,* depth and total phosphorus were used to calculate the Trophic State Index (Table 3) at different sites of Nagin Lake. The obtained TSI values were compared with Carlson's trophic state classification criteria (Carlson 1977). The results indicated that the lake was in a eutrophic state at all sites, during the entire period of the study.

DISCUSSION

The changes in air temperature are closely proportional to that of water temperature (Sharma et al. 2014), and hence simultaneous measurements of both are important in determining the status of a water body. The air and water temperature showed an increasing trend from winter to summer in the present investigation, however air temperature was found to be higher than the surface water temperature which may be due to the fact that water molecules are held together with strong hydrogen bonds and therefore can absorb huge amounts of heat without much increase in temperature. Both air and water temperatures were lower in winter season during the study. The lower water temperature in winter has been attributed to cold, low ambient temperature and shorter photoperiods (Ganai & Parveen 2014).

No seasonal variation was recorded in the mean depths at different sites of the lake. Winter showed minimum values of depth which could be the result of low inflow to the lake as the feeder canals are considerably dry during winter. These findings are in agreement with the findings of Bhat & Yousuf (2004) and Krishnan (2008). The highest depth was observed during the month of autumn owing to the floods which hit the valley in the early autumn. The higher mean transparency during autumn and winter seasons as compared to spring and summer seasons was observed in the study. These findings are in agreement with the findings of Balkhi et al. (1987), Pawar & Pulle (2005), Husen & Dhakkal (2009), Harney et al. (2013). The lower water transparency recorded during summer season might be partly due to higher inflow of tourists in summer months, the peak tourist season, causing an inflow of waste discharges into the lake.

Estimation of total dissolved solids (TDS) in water bodies has been employed to denote various kinds of minerals like salts, metals, cations, anions etc. present in the water. The increasing trend in the concentration of TDS and TSS from winter to autumn in the present study may be suggestive of contamination with domestic wastewater, garbage, fertilizer, etc. as has also been observed by some workers (Tiwari 2005). Higher TDS and TSS values were recorded in autumn than other seasons owing to the heavy rains and devastating floods of early September 2014 in the valley. Heavy rains washed away higher regions of the city and caused tremendous inflow of human, animal and agricultural wastes into the lake resulting in elevated TDS and TSS concentrations in the lake water. The higher values of TSS in summer and autumn seasons may also be linked to the accumulation of different salts in water as a result of higher evaporation rates in the warmer months (Pedge & Ahirrao 2013).

The overall mean pH of water was found to be high (8.42±0.07) depicting an alkaline nature of Nagin waters. This has been linked to an imbalance in carbon-dioxide, carbonate-bicarbonate equilibrium, more so due to alterations in physico-chemical conditions (Trivedi et al. 2009, Singh et al. 2015). The higher pH values of during summer (8.78±0.10) may be partly due to increased photosynthetic assimilation of dissolved inorganic carbon by the planktons. A similar effect could also be produced by water evaporation through loss of half bound CO_2 and precipitation of mono-carbonate (Khan & Choudhary 1994). The higher pH levels may also be partly due to an inflow of pollutants from the surrounding areas, especially during summer when the tourist influx is more to the valley.

The present study revealed low conductivity values in summer season which might be due to locking up of nutrients in the macrophytes. Lower electrical conductivity in summer may also be due to diminution in the dissolved ions caused by the precipitation of calcium carbonate and other minerals carried out under high pH as a result of high productivity (Adnan 2010). Spring season on the other hand showed maximum levels of conductivity which could be partly due to constant entry of runoffs brought about by the rainfall into the lake as has been reported by many workers previously (Garg & Singla 2002, Kumar et al. 2002, Radhika et al. 2004, Adnan 2010).

The dissolved oxygen concentration was highest in winter and the lowest in summer season, suggesting an inverse relation between dissolved oxygen and the temperature. Similar seasonal variations were also reported by Balkhi et al. (1984), Bushati et al. (2010) and Kumar & Jha (2015). Lower dissolved oxygen in summer may be due to the presence of sewage and other wastes of human and animal origin getting decomposed at a faster rate at higher ambient temperature thereby reducing the oxygen levels of water. The higher dissolved oxygen in winter, on the other hand, may be as a result of increased solubility of oxygen at lower ambient temperature as has been suggested by Umerfaruq & Solanki (2015). The overall mean dissolved oxygen content of water was low (6.96± 0.13 mg.L-1) mirroring the intensity of pollution due to anthropogenic intervention into the domain of the lake.

In the study, complete absence of free carbon-dioxide was recorded at many sites which could be due to its complete utilization in photosynthetic activity or as a result of its inhibition by the presence of appreciable amount of calcium carbonate in water as also reported by Kumar et al. (2010). An overall low concentration of free carbon-dioxide may be due to the fact that Nagin Lake is heavily infested by macrophytes which may be completely consuming the available free carbon-dioxide.

An overall high ammonia concentration (199.6±10.34 $\mu g.L^{-1}$) in the lake can be linked to the deterioration in the water quality. Shrivastava et al. (2015) reported higher concentration of ammonia in areas where untreated domestic and public toilets had direct access to the river Patalganga in Maharashtra. Another reason for high levels of ammonia in the lake may be due to its release from the sediments under low oxygen levels at which nitrification of ammonia ceases and the absorptive capacity of the sediments is re-

Table 1: Seasonal limnological profile of different sites of Nagin Lake.

Season	Site	Air Temp. (ºC)	Water Temp. (ºC)	Depth (m)	Transparency (m)	TDS ($mg.L^{-1}$)	TSS ($mg.L^{-1}$)	pH
Winter	Littoral	6.0	3.8	2.03	1.63	106.67	78.67	8.17
	Limnetic	6.0	4.3	3.70	2.63	94.00	76.33	8.17
	Outlet	6.0	4.2	3.13	1.87	109.00	81.00	8.37
	MEAN±SE	6.0±0.28	4.14±0.34	2.95±0.24	2.04±0.15	103.22±4.13	78.66±1.60	8.23±0.13
Spring	Littoral	18.2	15.6	2.03	1.40	147.33	83.67	8.80
	Limnetic	18.2	14.2	4.03	2.40	146.67	77.33	8.40
	Outlet	18.2	13.5	3.43	1.97	155.67	75.67	8.63
	MEAN±SE	18.16±1.52	14.44±0.97	3.16±0.29	1.92±0.15	149.88±2.43	78.88±3.11	8.61±0.14
Summer	Littoral	24.5	18.6	2.03	1.10	171.00	109.33	8.67
	Limnetic	24.6	17.6	4.17	2.03	158.33	100.67	8.77
	Outlet	24.6	17.3	3.23	2.17	172.67	105.00	8.93
	MEAN±SE	24.61±0.86	17.88±0.35	3.14±0.30	1.76±0.16	167.33±2.72	105.0±3.17	8.78±0.10
Autumn	Littoral	16	13.7	2.2	1.6	170.5	127	8.15
	Limnetic	16	12.4	4.35	2.6	150	116	8.05
	Outlet	16	13.2	3.35	1.8	212.5	117	8.05
	MEAN±SE	16.0±1.15	13.15±0.98	3.30±0.31	2.0±0.15	177.67±11.19	120.0±3.09	8.08±0.06
Overall	MEAN±SE	16.19±1.23	12.40±0.92	3.14±0.14	1.93±0.07	149.52±5.66	95.63±3.27	8.42±0.07

Season	Site	Conductivity (μScm^{-1})	Dissolved oxygen ($mg.L^{-1}$)	Free CO_2 ($mg.L^{-1}$)	Ammonia-N ($\mu g.L^{-1}$)	Nitrate-N ($\mu g.L^{-1}$)	Total P ($\mu g.L^{-1}$)	Orthro-P ($\mu g.L^{-1}$)	Chl-*a* ($\mu g.L^{-1}$)
Winter	Littoral	311.33	7.83	0.50	274.90	434.43	544.53	59.74	8.25
	Limnetic	297.00	6.83	1.33	134.83	224.77	327.67	26.13	7.20
	Outlet	274.33	8.13	0.67	295.37	547.10	646.47	57.97	11.58
	MEAN±SE	294.22± 11.36	7.6± 0.25	0.83± 0.47	235.03± 29.44	402.10± 48.87	506.22± 47.83	47.94± 5.51	9.01± 1.6
Spring	Littoral	324.33	7.47	0.00	248.67	392.93	491.40	57.84	15.19
	Limnetic	281.00	6.27	0.67	135.80	226.27	345.23	29.43	22.02
	Outlet	331.00	7.67	0.00	231.67	462.97	616.60	57.73	19.53
	MEAN±SE	312.11± 24.28	7.13± 0.25	0.22± 0.22	205.37± 21.27	360.72± 39.2	484.41 ± 43.61	48.33± 4.75	18.91± 1.15
Summer	Littoral	155.67	5.97	0.00	230.50	441.67	514.60	69.23	17.29
	Limnetic	171.00	5.9	0.00	132.00	254.67	326.87	25.13	12.93
	Outlet	183.67	6.6	0.00	208.47	484.37	616.00	60.83	11.36
	MEAN±SE	170.11± 5.0	6.15± 0.23	0.00± 0.00	190.32± 15.28	393.56± 37.8	485.82 ± 48.76	51.73± 7.13	13.86± 1.18
Autumn	Littoral	290	7.45	0.00	168.35	496.15	552.35	63.975	13.10
	Limnetic	252	6.9	2.5	164.85	294.65	329.35	29	7.71
	Outlet	256	6.6	1	169.8	539.4	594.5	63.7	15.04
	MEAN±SE	266.0± 18.61	6.98± 0.13	1.16± 0.57	167.67± 4.49	443.4± 37.8	492.06± 41.28	52.22± 5.87	11.95± 1.16
Overall	MEAN±SE	260.61± 12.16	6.96± 0.13	0.55± 0.20	199.6± 10.34	399.94± 20.3	492.12± 21.79	50.06± 2.83	13.43± 0.86

duced (Wetzel 2001).

Nitrate levels in the lake were higher in the autumn season which might be due to inflow of pollutants from the surrounding areas of the lake following extensive floods during September 2014. High nitrate levels recorded during spring could be a result of high rainfall during which the surface runoff carrying fertilizers and other waste materials directly got access to the lake water. Similar observations have been made previously by many workers (Tamot & Sharma 2006, Pedge & Ahirrao 2013). However lower nitrate values in winter months might be due to low ambient temperature, wherein the rate of decomposition declines leading to an uptake of nitrate by higher density of algal bloom.

Presence of phosphorus in excess of 30 $\mu g.L^{-1}$ in water bodies is regarded as a major nutrient triggering

Table 2: Seasonal total bacterial count in Nagin Lake.

Season	Site	Parameter Total Viable Count (Cfu log_{10}/mL)
Winter	Littoral	5.87
	Limnetic	5.47
	Outlet	5.55
	Mean±SE	5.62±0.12
Spring	Littoral	6.59
	Limnetic	6.18
	Outlet	6.24
	Mean±SE	6.33±0.16
Summer	Littoral	7.29
	Limnetic	6.69
	Outlet	7.18
	Mean±SE	7.05±0.14
Autumn	Littoral	6.71
	Limnetic	6.08
	Outlet	6.15
	Mean±SE	6.31±0.15
Overall	MEAN±SE	6.33±0.11

eutrophication (Welch 1980). Higher total phosphorus levels in water have been taken as indicative of pollution (Pathak & Mankodi 2013, Abir 2014) and thus our findings strongly suggest highly eutrophic status of Nagin waters needing extensive remedial measures. The high mean total phosphorus (492.12±21.79 $\mu g.L^{-1}$) of Nagin Lake may be explained by an improper sewage disposal system in this area. Sharma et al. (2015) linked the higher phosphorus values of Nagin basin to the direct discharge of untreated human wastes from houseboats and illegal settlements adjoining the lake. Orthophosphate showed the similar trend of non significant variation among the various seasons during the study. Higher orthophosphate concentrations may be linked to the use of detergents and dyes in the nearby areas which find their way into the waters.

In the present study, the mean chlorophyll-*a* was recorded as 13.43±0.86 $\mu g.L^{-1}$. According to Wetzel (1983), lakes having chlorophyll-*a* values in the range of 3.0 and 78.0 $\mu g.L^{-1}$ are classified as eutrophic. High values have also been linked to the greater abundance of phytoplankton in water bodies (Banita et al. 2013). Chlorophyll-*a* concentration was significantly higher (13.86±1.18 $\mu g.L^{-1}$) in summer and spring (18.91±1.15 $\mu g.L^{-1}$) while lowest (9.01±1.6 $\mu g.L^{-1}$) in the winter season. This can be explained by the fact that photosynthetic activities are pronounced in summer months due to higher ambient temperature, supply of nutrients and enhanced photoperiod which are conducive for the growth of algae, hence increasing the algal biomass. Lower values in winter, on the contrary, are suggestive of lower productivity during cold weather conditions.

Carlson's Trophic State Index (TSI) has been used as an authentic measure for determining the eutrophic status of water bodies based on three independent variables viz., chlorophyll-*a* pigment, Secchi depth and phosphorus. In the present investigation, TSI values at all the sites were found to be over sixty, thus indicating high trophic condition of the lake. These high values of all the variables may be the result of constant inflow of nutrients and pollutants into the lake through the catchment areas leading to accelerated growth of phytoplankton biomass.

The bacterial load of the lake ranged between 5.62±0.12 and 7.05±0.1 (cfu log_{10}/mL) during the different seasons. Such high bacterial numbers may be due to increased tourist activities in the valley during last few years following political stability. Extension of tourist season as a goal to improve the tourist industry by the State Government may partly be responsible for higher bacterial counts since the latter is directly related to contamination with human and animal wastes. A highly significant difference was seen in the bacterial loads of summer and winter seasons, with lower values having been recorded in winter. Similar observations have been made by Chandra et al. (2006), Khalifa & Sabae (2012). With increase in the atmospheric temperature, human activities increase in and around the lake due to inflow of tourists for obvious reasons of higher number of hotels, restaurants, houseboats and the street vendors. A negative association was, however, recorded between the total viable bacterial counts and the dissolved oxygen which could be explained by the fact that most of the bacterial species utilize oxygen for growth and multiplication thereby causing reduction in the concentration of dissolved oxygen. Thus reduction in the concentration of dissolved oxygen is concomitant to the increase in the free carbon dioxide, as was observed in the present study. These observations are in agreement with the reports of Yousuf et al. (1984), Siraj et al. (2006) and Haroon et al. (2010).

CONCLUSION

In the present study, most of the limnological parameters of Nagin Lake showed higher values than the normal range, suggesting its eutrophic state. The study reveals high input of nutrients and organic biomass into the lake's basin, resulting in increased levels of productivity. Major cause for this nutrient enrichment is the human interference in and around the lake which reduces the quality of lake water in addition to causing constant stress on its aquatic flora and fauna. Further, the altered physico-chemical parameters render the water unfit for growth and development of the native fish which thrive well in clear waters. There is a need for proper management and monitoring of this lake so as to

Table 3: Carlson's Trophic State Index at different sites of Nagin Lake.

Sr. No	Sites	TSI for Chl-*a*	TSI for Depth	TSI for Total Phosphorus	Carlson's TSI
1.	Nagin Littoral	56.12	49.58	94.42	66.70
2.	Nagin Limnetic	55.68	39.88	87.88	61.14
3.	Nagin Outlet	56.71	42.88	96.87	65.48

conserve this natural resource, which is not only a source of recreation in the valley, but is also an important contributor to the fisheries sector of the State.

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