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Review Article
Physico-chemical Limnology of Lakes in Kashmir Himalaya, India

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Abstract

Kashmir Himalayan lakes are of diverse types, majority of which are shallow in nature and are situated in the flood plain of river Jhelum. In the present review we scanned all the reliable literature for the lakes and wetlands of Kashmir Himalaya to document the historical review of these ecologically important systems. Till date no published review is available at global level, therefore, an attempt was made to have an insight of the previous work to trace the major changes in Kashmir lakes. It seems evident from the existing literature, that the years between 1970-1990 laid foundation stone for the limnological research in Kashmir Himalaya. The water quality of Kashmir Himalayan lakes is degrading at an accelerated speed due the un-checked pollution by the human interference causing cultural eutrophication particularly for the shallow lakes and wetlands. Internal nutrient loading appears to be the major cause of eutrophication particularly in the shallow wetlands of Kashmir. The major threat to Kashmir lakes is the excessive nitrogen influx in general and phosphorus in particular from the vast catchment area which is of agricultural type. Sound management practices should be adopted to save these ecologically important zones for further deterioration.

Key words: Limnology, lake-typology, eutrophication, nutrient loading, phosphorus, nitrogen, management practices, Kashmir

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INTRODUCTION

The word limnology was derived from the two Greek words limne meaning lake and logos meaning study and is considered as a part of ecology. It covers the biological, chemical, physical, geological and other attributes of all inland waters, both lotic as well as lentic ecosystems. It was Francois A. Forel (1841-1912) a professor in the University of Lausanne, Switzerland who coined the term Limnology. Henri LeBlanc (1912) listed Forel's publications on Lake Geneva monograph Le Leman: Monographie Limnologique, published in three volumes in 1882, 1895 and 1904, with a total of 14 chapters is considered the first book on limnology. It continued to work until a few months before his death in 1912, producing about 35% of his publications after the appearance of the last volume of the monograph in 1904. Edmondson[1] considers its 14 chapters as the main supporting fields of modern lake limnology. The limnological contributions of Forbes were diverse. It was among the first to study north American inland lakes (other than the Great Lakes). His studies on several lakes in the Rocky Mountains, published in 1893, represented the sole of biological information on lakes for a number of years in the western United States. Forbes was an early and notable contributor to limnology of running waters as well; under his direction, the Illinois State Laboratory of Natural History established a floating laboratory on the Illinois River and conducted an extensive, 50 years long study of the river. Progress in the limnological survey has been so rapid that in 1918, it became completely and integrated, lucid branch of science. Different workers have made remarkable contributions in the proposed field of lakes and wetlands. Among them Birge and Juday[2] are included among the founders of limnology. Their research contributed substantially to the basic understanding of a broad range of physical, chemical and biological characteristics of lakes. They also assisted the development of the field through their roles in initiating a strong educational program and communications networks linking professional limnologists. In 1907, C. A. Weber introduced the German terms for eutrophic (nährstoffreichere), mesotrophic (mittelreich) and oligotrophic (zuletzt nährstoffarme) regarding the chemical nature of the soil solution in German bogs. In 1920s August Thienemann and Einar Naumann classified lakes according to their trophic state (nutritional status). According to them, a physical measure (transparency), chemical concentrations (of nutrients) and biological characteristics (species types and abundance and primary production) can be used to classify lakes. Naumann became a leading limnologist who introduced Weber's concept, but with different terminology ("eutrophic" and "oligotrophic") into limnology to indicate poor or rich phytoplankton communities. In 1921, Thienemann accepted Naumann's terms but applied them to clear lakes rather than phytoplankton and added "dystrophic" for lakes with brown, humic waters with little lime. In 1922 International Association for Theoretical and Applied Limnology was founded in Germany by Thienemann and Naumann. North American limnology was initiated by G. Evelyn Hutchinson (1903-1991), who spent most of his career at Yale University, was a dominant figure development of ecology in general. Howard Thomas Odum (1924), student of G. E. Hutchinson, at Yale University while working on the energetics of Silver springs, Florida (Odum, 1957), is said to be a landmark in the limnological work by refining the diurnal oxygen method for measuring primary production. Various classifications schemes on the basis of water parameters were proposed from time to time to categories the lakes. The most commonly used classification till date regarding the alkalinity ranges was proposed by Moyle[3] who classified the lakes into soft, medium and hard on the basis of alkalinity ranges. According to this classification, waters having alkalinity up to 40 mg L^{-1} are soft, with 40-90 mg L^{-1} are medium and above 90 mg L^{-1} are hard. Further, Spence[4] has also classified Scottish lakes into three major categories based on the value of alkalinity. They are: (i) nutrient poor (1-15mg L^{-1}), (ii) moderately rich nutrient (16 mg L^{-1} to 60 mg L^{-1} and (iii) nutrient rich (>60.00 mg L^{-1}).

LIMNOLOGICAL SURVEY IN INDIA

The limnological investigations in India were initiated by Prasad[5] in Punjab (on ponds) and were followed by Philipose[6] on ecology and seasonal succession in a permanent pool at Madras city. The beginning of systematic limnological studies in India was made by Ganpathi[7-9] and his associates made investigation on the river Godavari and examined the effects of paper mill pollution at Rajahmundry. Chacko and Srinivasan[10] studied the hydrobiology of major rivers of Madras state of south India. Alikunhi[11] studied limnological relations of Indian inland waters with special reference to algal blooms. Chakrabarty *et al.*[12] made a survey on physico-chemical conditions of Jamuna River at Allahabad. Rao and Govind[13] carried out the hydrobiology of Tungabhadra reservoir. Sreenivasan[14] studied hydrology of tropical impoundment, Bhavanisagar Reservoir, Madras state for the years 1956-1961. Banerjee and Roychoudhury[15] worked out the physico-chemical nature of Chilka lake of Orissa. Saxena *et al.*[16] observed pollution of the river Ganga near Kanpur. Khan and Siddiqui[17-18] investigated the diurnal

and seasonal variation in the limnological features of a perennial fish of Aligarh, Uttar Pradesh . Since then, there has been notable proliferation of studies on different aspects of ecology from diversified freshwater biotopes of India, resulting in voluminous literature.

Research scenario in Kashmir Himalaya: The ground-breaking work on limnology of Kashmir lakes with regard to general ecology, lake succession and morphometry dates back to Mukherjee[19-20] besides, there are some ecologically important early research works[21-22]. Hutchinson[22] reported in the course of Yale North India expedition, reported on some zooplankton of Indian Tibet, but his by and large were confined to fish rather than to any other limnological aspects[23].

More intensive studies on Kashmir lakes were, however, initiated in 1964-65 and number of publications have since then appeared in press[24-40]. That could be used as the baseline for the current and future limnological research. There have been complaints during the last few years about the fast environmental deterioration of some of the lakes, particularly the valley lakes, being subjected to fast urbanization impacts, besides other anthropogenic pressures including tourism.

Lake typology of Kashmir: The lakes of Kashmir are categorized into three different types (i) Glacial mountain lakes, (ii) Pine forest lakes and (iii) Valley lakes based on their origin, altitudinal situation and nature of biota they contain. Basically all are high altitude lakes (alt. 1583-4000 m above sea level) as compared to the lakes situated in plains of India (alt.<500 m). The first series of lakes (Alipather, Tarsar, Marsar, Sheshnag, Kousernag, Toulian, Gangabal, Nundkhol Vishansar, Kishansar) are classified as upper mountain lakes. Pine forest lake include Nilnag and the valley lakes include Dal, Anchar, Wular, Manasbal, Naranbagh, Khanpur, Tigam, Tilwan, Pashakuri[41].

Valley lakes reveal richness in calcium and magnesium fall within the category of Hard water type. Kaul and Handoo[42] depicted that Nagin basin and Nilnag showed a positive heterograde along with a clinograde type, no such condition was obtained for Manasbal lake. Vass[43] and Kaul and Handoo[31] categorized the positive heterograde oxygen curve as biogenic. In all these lakes the depletion of oxygen in the lower layers near the bottom is an indication of eutrophication. They further applied Hutchinson[44] concept of correlating the rate of hypolimnetic oxygen deficit with lake typology, to Nagin basin of the Dal lake and Nilnag lake would be categorized with the oligotrophic series while Manasbal lake with the series of eutrophic lakes. The average ionic composition of the valley lakes indicate their medium hard water nature with divalent cations exceeding monovalents. The usual cation progression is Ca>Mg>Na>K for majority of Kashmir valley lakes[45] and can be classified as calcium rich using the criteria of Ohle[46].

The pine forest lakes (Nilnag) depict similar trends in regard physico-chemical characteristics as observed for the valley lakes. The lake, however, has two circulation periods one in March and other in October. The oxygen profile in the lake also depict clinograde oxygen curve as depicted by the Nagin basin and the Manasbal lake[47]. The concentration of other parameters like alkalinity, calcium, magnesium, sodium, potassium, phosphate, phosphorus and nitrate nitrogen of these elements were lower as compared to the valley lakes which were attributed to little human habitation. However, allochthonous material which gets into the lake along with the run-off from the pine forest and the varied patches of arable land has resulted in its considerable enrichment[48]. Anion levels depicting a carbonate-bicarbonate system (HCO_3>SO_4>Cl) also are similar to other valley lakes.

Contrary to the valley and forest lakes the upper mountain lakes of Kashmir are poor in ion content with conductivity as low as 11 µS in case of Alipather lake. The authors categorized the upper mountain lakes on the basis of conductance into two types: (i) ultra-oligotrophic having conductance values less than 50 µS (ii) oligotrophic having conductance values more than 50 µS. They opined that mountain lakes fall within the category of ultra-oligotrophic. The increased salt concentration in some of these lakes is perhaps the result of frequent cattle grazing on their shores.

GENERAL WATER CHEMISTRY OF KASHMIR LAKES

Over the past four decades, voluminous literature is available regarding the lakes of Kashmir Himalaya. But the problem being that the maximum literature is locally available. Therefore, an attempt was made to have an insight of these research papers to make it globally available for the future research. The lakes of the Kashmir valley are generally shallow and situated in the flood plains of river Jhelum. Thermal stratification is fairly uncommon and stable stratification occur in deeper lakes (Manasbal lake).

Vass *et al.*[49] advocated that high dissolved oxygen concentration during winter can be attributed to low biological activity. Zutshi *et al.*[50] studied the limnology of a manmade lake, Sarban lake, Kashmir and pointed out that during low water level, there is increase in primary production, chloride, iron and nitrogen contents. In another study, Zutshi *et al.*[51] studied the nutrient status and plankton

dynamics of a perennial pond and found a positive correlation between temperature, total phyto- and zooplankton.

Yousuf *et al.*[52] while studying some limnological aspects of Mirgund wetland and maintained that total alkalinity as well as hardness showed large seasonal fluctuations and was related to the water level variations. Balkhi *et al.*[53] studied the hydrobiology of Anchar lake, Kashmir and reported that the water chemistry of the lake was influenced by the inflow pattern from the catchment. Trisal[54] reviewed the physico-chemical characteristics of water and sediments, biological features and nutrient dynamics as carried out by various investigators while suggesting strategies for the conservation of Dal lake. The observations further indicated that the direct discharge of sewage from houseboats, reduction of plant cover in the catchment area, interruption to the flow of water, human encroachments, increase in population within the catchment area etc., have lead to in the deterioration of water quality, growth of aquatic macrophytes and siltation. Based on the data available some measures for conservation of lake ecosystem were also proposed by the author.

Ishaq and Kaul[55] studied the water renewal in relation to runoff in a Himalayan lake and revealed that the lake catchment had high annual watershed efficiency. They also calculated Ca and Mg budgets for Dal lake. The physico-chemical aspects of pollution of River Jhelum were studied and it was concluded that the water quality of river, in general, has deteriorated over the years. Yousuf and Shah[56] recorded low values of many nutrients in spring waters and attributed this condition to lower biological activities in such water bodies. An attempt was made by Zutshi and Wanganeo[57] to apply nutrient load model to access the trophic status of some lakes of Kashmir. They have observed much higher balance for phosphorus and nitrogen in urban lakes than in rural lakes. Phosphorus load in Dal lake as observed by Ishaq and Kaul[58] revealed that 99% of the total phosphorus is locked up within the sediments whereas remaining 1% is distributed in and being utilized by aquatic organisms. Pandit and Qadri[59] have found that the floods were quite detrimental for wetlands in general and its biotic setup in particular. They have also recommended a number of management strategies to be adopted for overcoming such an eventuality. Khanpursar was found to be deeper and poorer in nutrients than Trigamsar. Ammoniacal nitrogen was the only parameter which was reported in higher concentration in Khanpursar and was attributed to agricultural run-off. Sarwar *et al.*[60] while studying the abiotic environment of Wular lake, observed that the lake water remained well mixed throughout the period of investigation, without depicting either summer or winter stratification. Accordingly, they placed the lake under the category of moderately eutrophic, mainly on the basis of specific conductance values. The equivalency order of various cations was: Ca>Mg>K>Na>NH and HCO>Cl>SiO(OH)>SO_4^2. Yousuf *et al.*[61] and Yousuf[62] that the waters were alkaline and always hard due to the presence of carbonates and bicarbonates of calcium and magnesium, with calcium ions being the dominant cation in Manasbal lake . Dissolved oxygen and free carbon dioxide recorded an increase in their concentrations that are closely related to the productivity of the system and concluded the lake to be gradually passing through eutrophication Pandit[63] attributed the winter high and summer low in the conductivity values to the uptake of ions by plants during the growing season. Bhat *et al.*[64] studied the impact of effluents of Sheri-Kashmir Institute of Medical Sciences (SKIMS) Soura, on Anchar lake. They have attributed that the fluctuations in pH of the lake are due to the draining of hospital wastes into the lake. Rather *et al.*[65] while studying physico-chemical characteristics of Hokarsar wetland reported lower values for the depth, alkalinity and pH and attributed high concentration of various other nutrients like Ca, Mg, Na K, N and P to the eutrophic status of the wetland. Pandit,[45] and Pandit *et al.*[66] while working on the Dal lake opined that during last four decades the lake is undergoing accelerated eutrophication.

Pandit and Yousuf[67] in their studies on 6 Kashmir Himalaya lakes revealed that the best chemical indicators for knowing the trophic status of these aquatic systems were the total phosphorus and total dissolved inorganic nitrogen in the epilimnetic layers. They placed the two mountain lakes, viz., Gangabal and Nundkol under oligotrophic, two rural lakes Manasbal and Malpursar, under mesotrophic while semi-urban Anchar lake under eutrophic and urban Khushalsar lake under hypertrophic category. Kundangar and Abubakar[68] while comparing the past limnological data with the present, observed a progressive increase in various chemical parameters like specific conductivity, total alkalinity, sodium and potassium while considerable increase was noticed in silicate, nitrate- nitrogen, ammoniacal nitrogen and that of total phosphorus, but gradual decrease in dissolved oxygen and no major shift in pH values was recorded in the Dal lake. Siraj *et al.*[69] while studying the impact of floating gardens on the water quality and Cladocera population in Nigeen lake revealed that there was no significant correlation between water temperature and pH. They further inferred that conductivity values were significantly higher near the floating gardens and it was contributed to significantly higher values of chloride. Higher

values of these parameters were attributed to leaching of the fertilizers concentration in the close vicinity of the floating gardens.

In yet another survey by Siraj *et al.*[70] on the Shalbug wetland revealed that all the three forms of nitrogen (nitrate, ammonia and nitrite) recorded lower values. However, Phosphate-phosphorus and total phosphorus were recorded in appreciable quantities throughout their study. Studies made by Reyaz and Yousuf[71] on the ecology of macrozoobenthic community in the Wular lake observed high values of bicarbonates of calcium and magnesium, total inorganic nitrogen and total phosphorus, thus giving it the status of typical hard water type.

Kumar and Pandit[72], while studying the physico-chemical features of water in Hokersar wetland in Kashmir Himalaya, revealed that the wetland is calcium rich and hard water type with alkaline waters and placed the wetland in β-mesotrophic type of Olson[73] on the basis of specific conductance (200-250 μS cm^{-1}). Pandit[74], while discussing the wetland biodiversity of wetlands in detail, highlighted the most important areas of concern including the overall deterioration of wetlands due to diverse and intense anthropogenic pressures leading not only to the eutrophication but also reducing the wetland area and subsequently the loss of biodiversity. Shah and Pandit[75] observed higher values of transparency, dissolved oxygen and free carbon dioxide in winter. However, lower values of alkalinity and total phosphorus were recorded in summer. They however, further opined that the waterbody belonging to the hypertrophic category of Wetzel[76] as depicted by the average concentration of both total phosphorus and orthophosphate phosphorus. Shah and Pandit[77] while studying the relationship between physico-chemical limnology and crustacean community in Wular lake observed positive correlation of crustaceans with temperature, depth and pH. Negative correlation was observed between copepods with nitrate phosphate and free carbon dioxide. Mushtaq *et al.*[78] while reporting on variations in the physico-chemical properties of Dal lake highlighted the deterioration of water quality in the lake due to anthropogenic activity in the lake and urbanization. The lake was considered as eutrophic as evidenced by its shallow depth (1-4.5 m), low transparency (1-2.8 m), besides other nutrients such as ortho-phosphate phosphorus (0-170 μg L^{-1}), total phosphorus (0-540 μg L^{-1}) and nitrate nitrogen (50-1430 μg L^{-1}) concentration in the lake. Further, Parveen *et al.*[79] while studied the physico-chemical characteristics of Dal lake and recorded low values of transparency (0.72-1.6 m), nitrate nitrogen (365.1-607.1 μg L^{-1}) values as compared to previous works.

Shah *et al.*[80] while studying the spatial and temporal variations of nitrogen and phosphorus in Wular lake reported higher values of nitrogen in winter and lower values in summer. They further are of the opinion that higher values of phosphorus in summer are due to high internal loading enhanced by warm water conditions. Bhat and Pandit[81] while studying the surface water quality assessment of Wular Lake, reported the cations and anions followed the dominance pattern as Ca_2+>Mg_2+>, Na+>K+ and Cl->$SO4^{2-}$>SiO_2, respectively. They further reported that the lake water is in good condition as per water quality index and can be used for diverse uses, but at the same time, increased values alarm us about future consequences. Hassan *et al.*[82] are of the view that low dissolved oxygen concentrations were observed in the LULC class which has the highest percentage of agricultural land (47.04%, $r = 0.688$, $p<0.05$) followed by horticultural l and (19.10%, $r = 0.554$, $p<0.01$) in the catchment of Wular lake. Shah *et al.*[83] while working on Hokersar wetland concluded that that the rigorous biotic intrusion coupled with anthropogenic activities along the drainage basin were the contributory factors for deteriorating conditions of the wetland that leads to cultural eutrophication. They further opined that the wetland restoration has a potential for reducing nutrient discharges coming from the immediate catchment as the higher values of both the forms of nitrogen and phosphorus were very high at sites which were nearer to the inlet of the wetland.

CONCLUSION

This study discovered that rural lakes in general and urban lakes in particular are strongly influenced by the anthropogenic pressures from the respective catchments. Sound management policies should be adopted to prevent them from further degradation and deterioration. In general, water quality of these lakes is degrading due to excessive inputs of major plant nutrients i.e., nitrogen (N) in general and phosphorus (P) in particular posing a threat to the biotic setup by eutrophication in these systems indirectly affecting the human populations as well.

SIGNIFICANCE STATEMENT

This case study will help the researchers to uncover the critical areas like, the primary causes of water quality degradation, unplanned agricultural activities in the immediate catchment, importance of sewage treatment plants for lakes and wetlands, that many researchers were not able to explore till date. Thus a new theory of P control besides

construction of siltation beds along the inlets, reduction of soil erosion, establishment of sewage treatment plants and overall reduction of point and diffuse sources of pollution to the lakes should be espoused to prevent them from entering into the dystrophic state may be arrived at.

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