150 Years of Lake Research in India : Bibliography and Critical Review

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ABSTRACT

Many lakes in India are in lime light in recent years because of the problems they are facing. The number of such lakes, and the number of problems of these lakes are increasing. In order to overcome the various problems of lakes, systematic and scientific investigations are required. Although, studies on lakes in India have a history of more than a century now, most of the research is limited to the bio-limnological aspects. Other aspects, particularly the hydrological aspects, have not been adequately addressed to. However, for proper, efficient and integrated management of any lake ecosystem, in terms of its quantitative and qualitative regime, a complete understanding of the various hydrological and ecological processes of the lakes and their interaction with the catchments is essential. At present the limnologists and hydrologists are working in isolation and not much coordinated work has been done in the area of lake research. Moreover, lake hydrology can still be considered to be in a budding phase in India. There are hardly any studies related to the dynamic behaviour of the lakes. The present paper reviews the history and status of lake related research in India with particular emphasis on hydrological aspects. It is the first known attempt at reviewing the lake hydrology research in India. Trends in the lake research in India have been described along with the various issues and challenges. Specific suggestions for directing the future research activities have been made. A detailed bibliography of the various important works on Indian lakes has been provided.

INTRODUCTION

The increasing demand for fresh water and concern for protection of the environment has given rise to concerns for conservation and management of lakes. Lakes are not only prime sources of freshwater, but they also act as catalysts in the development of a region by serving variety of social, economic, ecological and cultural purposes. It is said that there are about three million lakes on the earth and about 95% of the Earth's fresh liquid water is contained in lakes. Besides the natural lakes, hundreds and thousands of man made lakes have also been created all over the world to cater the civilian needs. No assessment of the total lake water resources of India has been reported so far. A national inventory of wetlands, entitled "The All India wetland Survey", initiated by the Govt. of India as long back as the 1960's, could only be able to give a broad assessment of the wetland areas in the country in 1984 (Ghosh, 1992). There are hundreds of lakes of varying socio-economic significance in India, both natural and artificial. Natural lakes are mostly concentrated in Himalayas and the manmade lakes in the arid and semi-arid regions.

The utility and popularity of lakes often prove detrimental for their own health. Unscientific and over exploitation of lake waters for developmental activities and otherwise, and increasing biotic interference in their catchments, degrade them both qualitatively as well as quantitatively, leading to a number of problems. Problems like pollution, sedimentation, eutrophication etc. are commonly observed in most lakes. Although, lakes are bound to have natural death, but the processes of eutrophication and sedimentation hasten their extinction. In order to overcome the various problems of lakes, systematic and scientific investigations are required. Lake is not only a component of the hydrologic cycle, but it is an ecosystem in itself. As such, the hydrological and ecological behaviour of the lake ecosystems depend on complex interaction of many physical, dynamic and bio-chemical processes occurring within the lakes as well as their catchments. The physico-biochemical characteristics of lake waters and, the various physical and dynamic processes together represent the a-biotic backdrop against which the biotic components (fauna and flora) interact. A scientific knowledge of the various processes and their interactions is essential for efficient, economic and environment friendly management of lakes. Hence, lake related studies have assumed great significance in recent times.

Although lake studies in India started long ago, there are hardly any comprehensive reviews of the status of lake related research in India. Gopal (1973) is reported to have reviewed the ecological studies of wetlands of India. Sinha (1977) reviewed the various works related to origin of salinity in saline lakes of Rajasthan. Zutshi (1989) reviewed the various works pertaining to the ecological research on Kashmir lakes. Vyas et al. (1989) reviewed the various biological studies carried out on lakes of Udaipur. Ghosh (1992) gave a brief account of some of the biological and ecological studies on Indian lakes. Khobragade (1996) reviewed the status of research on lakes of Rajasthan. All these review works had limited dimensions in terms of scope and objectives. The present paper, on the other hand, attempts to give a more comprehensive and updated review of the status of lake related studies in India with an emphasis on hydrological aspects. An attempt has also been made to provide a comprehensive bibliography. It is also the first ever known attempt to review the hydrological investigations on Indian lakes. It should be noted that in the present paper work carried out upto 2004 only have been reviewed and reported. Work carried out thereafter would be included in future review.

LAKE HYDROLOGY

The matter of precise definition of a lake is yet to receive adequate attention and a unique definition of a lake does not exist. There are a few reported attempts at defining a lake. Zumberge and Ayers (1964), for example, defined lake as "an inland basin filled or partially filled by a water body whose surface dimensions are sufficiently large to sustain waves capable of producing a barren wave swept shore". In the absence of a universally accepted definition, and because of the inherent complexity in understanding as well as practical utilization of the existing definitions such as that of Zumberge and Ayers, the terms lake, pond, tank, reservoir, impoundment etc are synonymously being

used for various forms of inland water bodies, more so in India. Moreover, there are a number of local terms such as *tal, talab, talao, talaiyya, sarowar, jheel, beel, samand, sagar* etc. which are in use in different parts of India. As such, it is very difficult to decipher from literature, whether a referred water body is a natural lake, a reservoir, a pond or a tank. Although, there are technical differences between these terms (Khobragade, 1992; Khobragade, 1996), for the purpose of this paper, all these water bodies have been considered in the category of lakes, since exact technical information about most of them is not available to the authors. However, very large and big modern multipurpose dams have been excluded from the review, except at a few places where their reference was necessary. This means that other small size manmade reservoirs and reservoirs of all sizes of ancient origin, have been considered. Coastal water bodies having interaction with the sea waters, such as estuaries, lagoons etc, referred to sometimes as coastal lakes, have been excluded. Similarly, wetlands such as swamps, marshes, bogs etc have not been considered as lakes.

Lake hydrology can be defined as *"that branch of hydrology which studies the various physical and dynamic processes occurring within the lake and their catchments, including the interrelationships between the two, for their proper conservation, restoration and management, for the welfare of the human beings and other biological species (Khobragade, 2004)"*. Thus, the subject matter of lake hydrology, involves the study of various hydrologic processes occurring within the lakes, interrelationships of a lakes and their catchments, and the response of the lakes to various forms of energy inputs. Some of the major components of lake hydrology as a scientific discipline are: morphometric and bathymetric studies, hydro-meteorological studies, lake evaporation studies, lake-groundwater interaction studies, lake-river interaction studies, water balance/ water availability studies, lake catchment studies, thermal regime, energy balance of lakes, sedimentation studies, pollution, eutrophication and water quality studies, hydrodynamic studies, modelling studies and management/restoration related studies.

LAKE RESEARCH IN INDIA: *HISTORY AND STATUS*

General

In the world's context, true scientific beginning of lake studies is probably not slightly more than one and a quarter century old. It can be traced back to the paper published by Forel in the year 1869 describing the bottom fauna of Lake Geneva (Khobragade, 1997). India, too, has a history of lake research of well over a century now. Studies on Kumaun lakes were reported as early as in the late nineteenth century. Initial studies in India were mostly on the geological origin of the Kumaun lakes. Strachy (1851) was probably the first to describe the origin of the Kumaun lakes. Among the other initial works on origin of Kumaun lakes was Blanford (1877), Ball (1878), Theobald (1880), Oldham (1880), Middlicott (1881), Middlemiss (1890) and Holland (1895). Several theories related to origin of the Kumaun lakes were put forward by these investigators, based either on the

glacial origin or landlside origin. The theories proposed, failed to satisfy many. The issue continued to puzzle the geologists and work on this aspect was further taken up again in the second half of the twentieth century (Thomas, 1952; Mathur, 1955; Kharkwal, 1971; Pande, 1974; Hukku et a.; 1974; Pal and Merth, 1975 etc). Most of this work was credited to the Geological Survey of India. Besides, the work on Kumaun lakes, the issue of origin of salinity of saline lakes in Rajasthan was also looked into. Earliest attempts to explain salinity was by A. O. Hume in 1967-68 (Hooland & Christe, 1909). Subsequent works include Holland and Christie (1909), Godbole (1952), Pramanik and Ramakrishna (1954), Khandelawal (1975) and many more. The issue still remains unresolved. Sinha (1977) has provided an excellent review of the various works related to the origin of salinity. More recent studies on this aspect are by Ramesh et al (1993) and Yadav (1995).

However, these studies only concentrated on the origin and geological aspects and did not study the behaviour of the lake ecosystem. The first reference to lake behaviour is made by Mukerji (1921) who reported the biotic succession in Dal lake. Mukerji (1925, 1926, 1934) also studied the ecology of the vegetation in Dal lake. Mukerji (1932) is also credited with the first reported bathymtric survey on an Indian lake. It would not be an exaggeration to call him the 'Father of Indian Limnology' for his pioneering efforts. Another important initial study is that of Hutchinson (1933) who made a reference to the limnological aspects of the high altitude lakes of Ladakh. The details of these earlier works are not available with the authors. The work initiated by Mukerji and Hutchinson proved to be a great inspiration for subsequent research on the high altitude Himalayan lakes and a number of studies covering diversified aspects of ecology for Kashmir lakes have followed since then. A plethora of literature and data have been generated, thanks to the hard work and sustained efforts of D. P. Zutshi, S. Kant, V. Kaul, M. A. Khan, C. L. Trisal, K. K. Vass and others. In South India, studies on water bodies were initiated by Ganapati, who first undertook studies on ecological aspects of a garden pond in Madras in 1940 and 1943, and latter undertook regular investigations on a number of water bodies in the then Madras State. Ganapati carried out other pioneering studies on tropical lakes in India (Ganapati et al. 1952; Ganapati, 1955; Ganapati, 1956; Ganapati, 1960a ; Ganapati, 1960b; Ganapati, 1973 etc) and appears to have laid the foundation for subsequent lake research on tropical lakes in India. Ganapati's initiation was continued by Sreenivasan (1963, 1964, 1965, 1966, 1970 etc) and others subsequently.

Status of research related to certain important aspects of lakes is reviewed in the following section.

HYDROLOGICAL ASPECTS

Knowledge of hydrology of tropical and subtropical lakes is in general relatively scarce, compared to the magnitude of the knowledge being generated on their temperate counterparts. The light thrown by the fascinating research on temperate lakes has generated curiosity in understanding the hydrological regime of the tropical/subtropical

lakes. It is because, unlike the temperate zone, tropical lakes and reservoirs are characterized by highly seasonal rainfall, limited annual temperature cycle, absence of freeze-thaw cycle, higher mean annual temperature and radiation, higher productivity etc. Understanding of hydrology is also otherwise an essential requirement for efficient management of these lakes. For example, knowledge of the precise estimates of the water available in lakes, at different points of time, is required to plan the various uses of the lake water for various demands. This needs understanding of the various hydrological aspects such as hydro-meteorology, evaporation, ground-water lake interaction, river–lake interaction, runoff from lake catchment, water level fluctuations in lakes etc. This is also necessary for understanding the various other ecological processes such as eutrophication, pollution etc. However, despite its significance, hydrological studies have not received adequate attention in India. Till the early 90's, only few and sporadic studies were reported (for eg. Basak, 1989; Khan et al. 1990; James and Padmini, 1992 etc). Realizing the need of the hour, the National Institute of Hydrology, Roorkee took up studies related to hydrological aspects of lakes in India. Pioneering work was carried out by Bhishm Kumar et al. (1999a) who studied comprehensive hydrology of Nainital lake including hydro-meteorology, water balance, sedimentation, water quality, eutrophication etc. Some studies on other lakes such as Mansar, Sagar, Dal, Surinsar, Barapani, tanks of Karnataka, Bhopal lake etc. have been carried out by the Institute. Work on Pichhola lake is under progress. Khan et al. (1990) mentioned that CAJRI, Jodhpur has taken up detailed hydrological investigations on Sardarsamand reservoir in Pali (Rajasthan) as a representative study for arid zone. NGRI, Hyderabad is also known to have undertaken work on Hussainsagar lake of Hyderabad. Thus, a growing interest is being observed since the 1990's in the area of lake hydrology. Brief review of the various reported studies is presented here.

Basak (1989) studied the various aspects of hydrology of Pookot Lake in Kerala including meteorology, water quality, sedimentation, catchment characteristics etc., based on the data generated during 1985-87 and suggested scientific management and conservation measures for the lake. The measures included among others, declaring the catchment as protected area. Hydrological investigations for Pookot Lake have also been reported by James and Padmini (1992). Khan et al (1990) carried out hydrological investigations on Sardarsamand reservoir in Pali, Rajasthan using 11 years of water level and meteorological data (1977-88). They observed that most of the inflow to the reservoir occurred in response to a few high magnitude rainfall events and ranged from 0.1 -10% depending upon its magnitude, while the annual runoff ranged from 1.2 to 6.8%. Bhishmkumar et al., (1999a) undertook detailed hydrological investigations of Lake Nainital. The study included water balance, sedimentation rates and patterns, water quality and pollution, hydrodynamics, lake-spring interaction and identification of recharge zones. Other components included geomorphology of the catchment, hydro-meteorology, effect of sedimentation on water balance and trophic status of the lake. It was observed that the lake receives 16% as input from direct precipitation. The net sub-surface inflow

through springs has been estimated as 39% of the total input. Analysis of the 100 years of rainfall data indicates a falling trend for the lake area, although this is not a cause of a concern for near future. Increasing sedimentation and water quality deterioration has been identified as the most significant problems for the lake. Specific recommendations for improving the status of the lake have been suggested. Nachiappan et al. (2000), apart from other hydrological characteristics, reported the residence time for Nainital lake as 1.99 yrs, 1.77 yrs and 1.92 yrs by isotope mass balance, chloride mass balance and conventional water balance methods respectively. Nayak (2000) undertook investigations on Sagar lake and estimated inflows to the lake using GIS and SCS model. Sharma (2003) studied the inflow regime of two reservoirs; Himayatsagar and Osmansagr in Hyderabad using 36 years of rainfall data (1961-96). He observed that with the current rate of bio-interference, the lakes will not receive any inflow by the next 30-50 yrs. His remarkable observations point out at the dying nature of the lakes owing to increasing human interference. He has also suggested remedial measures for lake restoration. Complete water balance have been reported for Nainital lake (Bhishmkumar, 1999a), Sagar lake (Singh and Thakural, 1999) and Kailana-Takhat Sagar lakes in Jodhpur (Suthar, 2003). Rainfall characteristics of lakes have been studied for lakes of Bombay (Mukherjee,1984) and lakes of Madras (Jayanthi and Das,1982). Other studies involving hydrological characteristics of lakes include preliminary investigations for Loktak lake in Manipur (Palaniappan et al., 1994).

Lake-ground water interaction studies have in general remained the most neglected aspects of the water balance studies the world over, India being no exception. This is because of the complexity of the interaction and the type of geo-hydrological information required which is generally not available. However, its only since the last decade or so that this aspect is being explored, particularly using isotope techniques. Some studies have been carried out in India also. Bhar (1996a), for example, conducted studies on contribution of tanks to ground water recharge in Jabalpur region of M. P., for the period of 1989-1993 using conventional method. He observed that about 0.514 mcum and 0.596 mcum of ground water is recharged by the tanks, in pre and post monsoon periods respectively. Goyal et al. (2002) evaluated the ground water contribution in Mansar lake in Jammu and Kashmir for the period Oct. 99- Sept. 2000 using the water balance approach. A net annual recharge of 149 mm was observed for the study period. Nachiappan et. al. (1999, 2000 & 2002) have carried out elaborate studies for Nainital lake using isotope techniques. They have estimated the sub-surface inflow to the lake using the water balance method wherein the subsurface outflow was estimated using indirect means. The results were verified by environmental isotope and chloride mass balance methods. Results show that ground water contributes about 50% of total annual inflow to Nainital lake. The subsurface outflow being about 55% of the total annual outflow from the lake.

Although, precise estimates of evaporation rates are needed for various research

and management purposes, not many studies have been reported on this aspect. Goyal and Sikka (1987) estimated the rates of evaporation from Bhadra reservoir in Karnataka using mass transfer and Penman method. They observed that mass transfer method underestimates the evaporation rates while estimates by Penman method are more reliable. Singh et al. (1995) studied the correlation between evaporation and different meteorological parameters for Hissar region in Haryana using the data of 1980-1993. Highest correlation was observed with air temperature, followed by wind. Lowest correlation was observed with sunshine hours. However, in a similar study for a higher altitude (Ooty region in T.N), relatively low correlation was observed by Sharma (1995). Most of the other reported studies deal with evaluation of various models of evaporation for their suitability to some locations in India. Sarma (1973) compared estimates of reservoir evaporation obtained from Rowhers method with the observed pan values and described the anomalies between the two. Venkataramn and Krishnamurthy (1973) compared few methods of estimating mean daily shallow lake evaporation and reported that Penman method gives rational estimates and that Kohler's coaxial graphical techniques using climatically derived estimates of radiation are also fair. Pande (1995) carried out evaporation studies for Bargi reservoir in Jabalpur district. Evaporation estimates obtained from four models viz. Morton, Penman, Kohler and Van Bavel were compared with those obtained from pan. Kohler model was found to provide better estimates for monthly as well as on annual basis. Similar observations were also recorded for an earlier study on Navil Thirth reservoir in Belgaum (Pande et al., 1994). In a study on a high altitude Nainital lake, Khobragade et al. (2003) compared 12 commonly used models of lake evaporation for estimating lake evaporation. The results indicate that there is a high degree of error for different models. In particular, the various models underestimate the peak rates by a high degree. ANNs are increasingly being used all over the world to model the various hydrological processes since the last one decade, although they have not been adequately evaluated for lake evaporation studies. Khobragade et al. (2004a) have recently evaluated the suitability of ANN in predicting the evaporation from a tropical lake; Lake Pichhola in Udaipur. They have developed an ANN model to estimate lake evaporation. An ANN model with 3 neurons and 91 epochs have been selected as the best architecture for the model. The performance of the model has been tested vis-a-vis Penman Model, Brutsaert Model, Thornthwaite Model, Stephans-Stewart Model and Jansen-Haise Model. The results of ANN are far more superior than the other models. It is observed that in all the reported comparative studies on evaporation, pan evaporation based estimates of lake evaporation have invariably been used as actual lake evaporation. Probably this is the only possible way in the absence of precise energy balance estimates. However, assuming lake evaporation to be some fraction of the available pan evaporation, may be grossly erroneous, particularly if the estimates are made for monthly or shorter periods, and if the pan coefficients are not locally available. Ramasastri (1987) suggested seasonal coefficients for India which have been used by Pande et al. (1994, 1995) and Khobragade et al. (2003, 2004a). The latitude has been used as a criteria by Ramasastri (1987) to demarcate the seasonal

variation in pan coefficients. His coefficients are based on subjective analysis of the trends and patterns of pan evaporation data of India and available information on observed pan coefficients of some countries, and not on any field investigations. Local pan coefficients have to be determined based on energy balance of lakes and pans. Although, energy balance method is supposed to give the most accurate estimates of lake evaporation, not a single study on energy balance of any of the lakes in India has been reported so far. Besides estimation of lake and reservoir evaporation, some investigations on evaporation control from water bodies have also been reported. Mistry (1981) carried out field experiments on Aji Lake in Gujrat for evaporation control studies using cetyl-stearyl alcohol. He observed that spraying of the chemical can provide partial control of evaporation. However, the percentage of water saved decreases with increase in wind velocity. Various parameters involved in the application of the chemical have been analyzed along with the economic aspects. Earlier, Kumaraswamy (1973) conducted studies on efficacy of straight chain alcohol in preventing evaporation loss in arid climate in India (at Buderi) for 6 years and evaluated their practical feasibility. The efficacy of spraying alcohol was found to decrease with an increase in temperature. Percentage savings for the tropical climate was about 20% as against 50-60% in the U. S. and other temperate climates. In a relatively recent study, Vedagiri et al. (1989) conducted studies on three reservoirs of Madras using cetyl alcohol and observed substantial reduction in evaporation losses. However, they observed that wind breaks the chemical layer and reexposes the water surface to atmosphere. They have also analyzed the economic aspects. Other references on evaporation control studies include Ramdas (1968), CBI&P (1978), CWC (1988), Chaube and Dhagat (2000) etc. The various reported studies are inadequate to assess the performance of the various suggested chemicals for saving evaporation losses. Various parameters such as variation in surface area and volume etc have not been considered. Since, lake evaporation is highest during th e peak summer during which the wind also is generally high, there is a question mark over the effectiveness of thee methods. Moreover there are no reported studies on the effect of the various chemicals on the ecology of the lakes in the long run.

Studies related to thermal regime and hydrodynamics are rare in India. Nassar (1977) reported that Balsamand lake in Jodhpur exhibits a temporary thermal stratification during day time which is broken during night. However, no such phenomenon was observed by Jakher et al. (1981). Khatri (1985) studied the thermal regime of Idukki reservoir in Kerala and observed that during monsoon season the temperature increased with depth while in pre and post monsoon reverse trend is seen. Susheel (1989) has reported the heat balance of Ranisagar lake in Jodhpur. Belsare (1990) observed a temporal thermal stratification in Upper Bhopal lake every day at 14 hrs while homothermal condition is reached at 2 to 6 hrs. Contrary to the observations of Belsare (1990), Das (1991) observed that the lake mixes continuously at irregular intervals, causing the well defined overturns to remain absent. This is not surprising for a low elevation tropical lake as the effect of wind can easily reach upto the bottom, causing continuous mixing. Week

thermal stratification has been observed in Pichhola and Fatehsagar lakes of Udaipur (Jheel Sanrakshan Samitee Rep., 1996).. Saravanakumar et al (2001) studied the dynamic aspects of lake Nainital involving a detailed analysis of the water temperature, EC and DO. The lake water was observed to be stratified during summer months up to beginning of winter (March/April to October/November) and remains well mixed during the rest of the period. The two sub-basins of the lake were observed to behave differently due to the presence of the ridge. The lake has been classified thermally as warm monomictic lake. Thermal regime of the Nainital lake has also been reported earlier by Sharma and Pant (1979b). Rai et al. (1998, 2001, 2002) investigated the thermal regime of Mansar and Surinsar lake and observed that the lakes undergo mixing during Jan.–Feb. and remain stratified during summer and rainy season. Based on the temprature of July they have observed that the epilimnion extends upto 3 m depth, the thermocline from 3 to 9 m depth and hypolimnion below 9 m depth. Various reported studies indicate that definite mixing and stratification behaviour is observed in the high altitude sub-tropical lakes of Himalayas. When the water stratifies in summer, the hypolimnion water often becomes anoxic on account of the sediment oxygen demand, causing death of fish. When the water overturns in winter, these dead fishes are brought to the surface. This has been observed in the lake Nainital. As far as tropical lakes are concerned, from the few reported studies, no specific thermal behavior or pattern is observed. However, it appears that some of the shallow tropical lakes do undergo stratification (may be on a daily basis), although such stratification is week and temporary and easily broken by the wind. More detailed studies are awaited on this aspect. No studies on diurnal variations in the thermal regimes have been reported. Similarly no temperature modelling studies have been reported.

Thus, from the review of the reported studies, it is aptly clear that lake hydrology studies in India are gaining momentum only after 1990's. It is still in the budding phase. Most of the areas are not adequately explored. Areas such as energy balance, temperature modelling etc. are totally untouched, for both tropical as well as subtropical lakes. Off late, the National Institute of Hydrology has taken a leading role in Lake Hydrology research in India and various hydrological aspects are now being systematically studied for some lakes.

MORPHOMETRIC AND BATHYMETRIC STUDIES

Morphometric data are of fundamental importance in many limnological and hydrological studies. As a matter of fact they are the starting points for many investigations. Unfortunately, bathymetric maps are not available, except for a few lakes. The first reported bathymetric survey in India is that of Mukerji (1934). Only a handful of other studies have been reported in this respect. Reference to the morphometric features of lakes of Nainital has been made by Singhal and Singh (1978). Morphology and morphometric studies have also been reported by Rawat (1987) for Nainital lake and by Khanka and Jalal (1984, 1985) for Nainital and Bhimtal lakes. Khanka (1991) has described the

morphometric features including the bathymetry of various lakes of Kumaun Himalaya such as Lake Nainital, Bhimtal, Nakuchiatal, Puntal and Sattal etc. Vass and Zutshi (1979) carried out morphometric studies for Dal lake. Singh et al.(1987) have reported the morphometric features of Renuka lake in Himachal Pradesh. Hashmi et al. (1993) carried out extensive bathymetric survey of Nainital lake. They observed that the lake basin is divided into two sub-basins by an approximately 100 m transverse underwater ridge, 7 to 10 m below the surface. They further observed that a number small but rapidly growing deltas along the shores indicating accelerated pace of sediment input. Rai et al. (1999) carried out detailed bathymetric survey of lake Mansar in J&K. They have described the various morphometric features of the lake including the lake bottom profile. Rao et al. (1989) studied the morphometry and bathymetry of four Udaipur lakes viz. Pichhola, Rangsagar , Swaropsagar and Fatehsagar. They have analyzed the various morphometric features to understand the biological, chemical and trophic features of the lakes.

SEDIMENTATION STUDIES

Sedimentation is one of the serious problems of many lakes causing reduction in lake capacity and useful life of the lake. As such, the knowledge of sedimentation process is very crucial for control and management of lake sedimentation. Sediment analyses is also important for understanding the ecological behaviour of lakes. In India regular monitoring of sedimentation is done only for few selected big dams. Reference to siltation problem in lakes is, however, made in various works (eg. Singh et .al. 1987; Zutshi, 1987; James & Padmini, 1992; Khanka, 1991; Sohal, 2000; Wolstencroft etc). The Khajjar lake in H.P. is more or less filled up by the process of sedimentation. The area of Dal lake has been reported to have shrunk from 23.4 sq. km to 13.82 sq. km. in 118 yrs and with this rate, Dal lake is expected to be converted into a marshy land or swamp in 70-80 yrs. (Zutshi, 1987). The depth of Renuka lake has reduced considerably from 25 meters at the time of formation to a depth of 13 meters, due to siltation (Singh et al., 1987). The water spread area of Sukhna lake in Chandigarh has reduced from 2.28 sq. km. to 1.52 sq. km, while the capacity has reduced from 10.74 MCM to 4.2 MCM (Sohal, 2000). The depth of Nainital has reduced from 28 meters in 1922 to a depth of 24.2 meters due to sediment accumulation (Valdiya, 1988). However, despite the references to the siltation problem, sedimentation studies have been reported only for some Himalayan lakes such as Nainital and Dal based on the bathymetry. Very few studies have been reported on other lakes. Purohit et al.(1991) estimated sedimentation in Pichhola and Fatehsagar lakes of Udaipur based on bathymetry. Reduction in capacity of Lake Pichhola is observed to be 0.93% per year while that of Fatehsagar is 1.16% per year. The estimated useful life of the lakes is less than a century. A number of studies are now being regularly undertaken at the National Institute of Hydrology, Roorkee using the isotopes. Bhishm Kumar et al. (1999b) estimated the useful life of Naintal lake using Pb-210 and Cs-137 dating methods. Useful life of the lake was estimated to be 2200 yrs which was much higher than the results obtained by earlier investigators. Similar results have also been

reported by Sarvanakumar et al. (1999). Earlier Hukku et al. and others had predicted a life of about 300-350 yrs for the lake. Bhishmkumar (2000a) studied the rates and patterns of sedimentation and useful lives of Dal and Nagin lakes of J&K using the radioisotopes. The average rate of sedimentation in Dal lake was found to be 0.52+0.04 cm/yr since 1964 and 0.22+0.03 cm/yr since 1987. Similarly the rate of sedimentation for Nagin lake was found to be 0.41+0.05 cm/yr since 1964 and 0.34+0.03 since 1987. Based on the rates of sedimentation since 1986-87, the useful life of Dal lake has been estimates as 364+50 years and that of Nagin lake as 379+33 years. This is in contrast to the useful life reported by Zutshi (1987). It was also found that organic matter contributes to about 25-30% in lake sedimentation process of the Dal lake. 10% of this comes from the inflowing streams while the rest is internally produced by the underwater weeds. Rai et al. (2000a, 2001) studied the sedimentation in Mansar lake using radioisotopes. Rate of sedimentation was found to vary from 0.14 to 0.37 by Cs-137 dating techniques and from 0.24 cm/yr to 0.34 cm/yr by the Pb-210 technique at different sampling locations in the lake. The mean rate of sedimentation for the whole lake is 0.23+0.031 cm/yr. The predicted useful life of the lake is 9110+790 years. Bhishmkumar (2003) studied the rates and patterns of sedimentation and useful lives of three Kumaun lakes viz. Bhimtal, Nakuchiatal and Sattal using CS-137 dating technique. The average rates of sedimentation for lake Bhimtal, Nakuchiatal and Sattal are estimated to be 1.44 + 0.18 cm/y, 0.74 +0.04 cm/y and 0.84+0.05 cm/y respectively. The useful life of the three lakes have been estimated as 661+94 yrs, 3164+281 yrs and 1357+ 126 yrs respectively. Among other reported studies, Choudhary and Nayak (2003) estimated soil erosion in the catchment of Sagar lake using USLE model in GIS platform. The soil loss from the catchment has been estimated to be 17840 t/yr. Based on this estimation, the rate of silt deposition in the lake has been calculated as 1.15 cm/yr. Thus, from the various reported studies and references made at places, it appears that the lakes in India are constantly shrinking. While estimating the sedimentation rates in the subtropical lakes, probably the aspect of summer stratification should also be taken into account. Bhar (1996b) suggested a simple methodology based on Stoke's law to estimate the sedimentation in stratified lakes if the temperature-depth profiles and sieve analysis data are available. The methodology was applied to the three lakes of Kumaun viz, Bhimatal, Khurpatal and Sattal. It was observed that settling time of a sand particle and a silt particle are almost the same for stratified and homothermal lake conditions. However, in case of a clay particle, the settling time is more than that of sand and silt for both stratified and homothermal conditions.

Analysis of the sediments for their chemical composition has also been reported in some studies. Analysis of the chemical composition of lake Nainital sediments has been reported by Gupta and Pant (1983) and Pande and Das (1980). Seenayya (1985) studied the effect of bio-geo-chemical factors on the release and exchange of essential nutrients between water profile and sediments of Hussainsagar and Himayatsagar lakes of Hyderabad. Jain (1995) observed very high concentration of heavy metals in the sediments

of Lower Bhopal Lake. Kumar and Kalsotra (2001) analyzed the geochemistry of the sediments of the Choubari Tal in Garhwal Himalayas and studied their interaction with the glacial melt waters. Sreenivasa Rao and Rammohana Rao (2001) analyzed the sediments of Kolleru lake in A.P. for heavy metals. Patra (2002) studied the chemical composition and mineralogy of Nainital lake sediments. The water chemistry is observed to be dominated by Ca, Mg and HCO_3^- which indicates carbonate lithology source. Vasudevan et al. (2003) studied the bi-organics of the sediments of Veli-Akkulam lake in Kerala. Ansari and Sunil Kumar (2003) studied the effect of nitrate input on the phosphorus exchange across the sediment water interface of Bhopal lake and observed a decreasing trend in the release of TP and SRP with increased concentration of nitrate. Although, sediments may play a significant role in heat budget of a lake, no studies have been reported on the contribution of sediments to the heat balance of any lake.

WATER QUALITY AND POLLUTION STUDIES

Lake waters are used for variety of purposes. Standards have been set for suitability of water for such uses. Water quality and eutrophication studies determine the suitability of lake water for various purposes and hence are one of the most essential aspects for lake management. There are a number of point and non point sources contributing to the deterioration in quality and trophic status, and a systematic studies of cause and effect phenomenon is required to understand the relative contribution of these sources in the overall degradation so that proper management solutions can be suggested. Unfortunately water quality research in India has remained stagnant up to the point of determination of water quality parameters and there are only a few studies leading to subsequent analysis. Studies on general limnological aspects covering the physico-chemical characteristics of the lake waters and their seasonal variation have been one of the most dominating aspect of lake research in India, ever since lake studies began in India. It continues to do even today. This is evident from some of the most recent studies. As a matter of fact for many of the water bodies, this remains the only aspect that has been studied so far.

After the early works of Mukerji and Ganapati, hundreds of studies have appeared on limnological aspects of different lakes of India. It is impossible to discuss all of them. Reference to only a few of them is made here. Dos et al. (1973) studied the water quality of some man made lakes of South India and evaluated their suitability for various uses. Pant et al. (1981) discussed the pollution problems of lake Nainital. Joshi et al (1981) carried out limnological investigation on Sattal lake in Kumaun Himalaya. Rajasthan Pollution Prevention and Control Board (1986) studied the environmental status of some important lakes of Rajasthan viz. Pichhola, Fatehsagar, Mansagar, Ramgarh, Keoladeo, Gaibsagar, Pushkar and Nakhi based on the analysis of the various physcico-chemical characteristics of the lake water and suggested various remedial measures to improve their environmental status. Trivedy (1988) studied five water bodies of south western Maharashtra for water quality status, flora and fauna, ecosystem functioning, impact of

pollution on water quality and future changes expected. The study revealed that the people who use the water of the lake are suffering from many diseases. The study further revealed that urbanization, industrialization and tourism were responsible for the deterioration of the water bodies. Krupanidhi and Bhushan (1988) have studied the ground water contribution to water quality degradation of the Udaisagar lake in Udaipur. Belsare (1990) et al. studied the seasonal variations in the physico-chemical characteristics of Bhopal lakes. Agrawal et al. (1990) evaluated the effect of addition of phosphate and nitrate on the primary productivity of Sagar lake by adding the nutrients separately as well as in combination. The phosphate enrichment alone did not increase the productivity. However, when the phosphate was combined with nitrate, a sudden enrichment in the productivity was observed. Sharma and Durve (1990) studied the water clarity of 26 water bodies in Rajasthan including temple tanks, medium and small reservoirs and lakes. Temple tanks reported lowest water clarity values while large reservoirs reported maximum clarity. Based on the results, they have developed a regional classification system for water bodies of Rajasthan. Kumar et al. (1992) carried out water quality studies on Nakuchiatal lake in Nainital and observed that the lake is in oligotrophic condition. Khatavkar and Trivedi (1993) have undertaken detailed investigations on the water quality and pollution of four manmade water bodies of Maharashtra. Das and Singh (1995) studied the water chemistry of lake Pichhola. It was observed that the chemical composition of the lake water is dominated by Na^+ and HCO_3^-. Silicate rock weathering as well as contributions from alkaline/saline soils are observed to be the major mechanisms controlling the water chemistry of the lake. The high phosphate content was attributed to the mining activity and also to the flow of municipal and domestic waste. Omkar et al. (1995) carried out detailed monthly monitoring of water quality parameters of Surinsar Lake in Jammu over a period of Sep., 94 to March, 1995 and evaluated its suitability for irrigation purpose based on USDA and Doneen's classification. The results showed that the water is suitable for irrigation and drinking. Sharma et al. (1997) studied the water quality of Mansar and Surinsar Lakes of Jammu and observed that water is suitable for drinking as well as irrigation purposes. Similar observations for Mansar Lake have been reported by Rai et al. (1997, 2000). Rai et al (1997) further observed that calciun, magnesium and sodium are dominant cations while bicarbonate is the dominant anion. Bhishm Kumar and Nachiappan (2000b) have reported the detailed analysis of the water quality of Nainital lake including the analysis of accuracy of measurements/analysis. The variations in the concentrations of the ions and their possible sources have been discussed. Dhote et al. (2001) studied the effect of immersion of idols on the water quality of Bhopal lakes. The studies indicate considerable degradation of water quality in post immersion period compared to pre idol immersion. Patil and Tijare (2001) evaluated the water quality of Gadchiroli lake and found that the water is unsafe for human consumption and only suitable for irrigation. Batcha (2002) analyzed the seasonal variation in dissolved oxygen of surface and bottom water of Vemband lake in Kerala and found that the south-west monsoon and the river inflows has a profound

effect on the distribution of D.O. Sudha Rani et al (2003) studied the toxicity of Hussain Sagar lake waters to fish. Kundangar and Abunaker (2001) studied the effect of dredging on the physico-chemical characteristics and bio-diversity of Dal lake and observed that although the physico-chemical characteristics changed after dredging, no significant change was observed in phytoplankton and zooplankton. Garg and Garg (2001) studied the water quality deterioration of Bhopal lakes and suggested some policy measures to cure the degradation. Garg and Garg (2003) observed the response of hydro-biological parameters to addition of nitrogen in three lakes of Bhopal.

Some studies on heavy and toxic metals in lake waters and sediments have also been reported. Mohan et al. (1989) studied the presence of trace metals (Zn, Cu, Pb and Cd) in four water bodies of Jodhpur viz. Balsamand, Fatehsagar, Gulabsagar and Kailana lake. The water of Balsamand, Fatehsagar and Gulabsagar, is found unsuitable for drinking owing to the high concentrations of trace metals. Prasad (1993) studied the metal pollution in Hussainsagar and Banjara lakes of Hyderabad. They have analyzed the possible mechanisms of metal detoxification and metal tolerance, and the role of metal binding complexes in the above manifestations with particular reference to aqatic algae. Jain (1995) analyzed the presence of certain heavy metals in Lower Lake of Bhopal. Very high concentration of heavy metals was observed in sediments. Zink concentration ranged from 0.02 ppm to 0.082 ppm in surface waters, 0.071 to 0.163 ppm in bottom water and 300 to 50 ppm in sediments. Maxium concentration was observed during summer. Copper concentration ranged from 0.014 to 0.089 ppm in surface water, 0.015 to 0.18 ppm in bottom water and 42 to 90 ppm in sediment. Cadmium concentration was relatively less. Domestic effluent and washing from chemical laboratory of a nearby science college were identified as the main sources of heavy metals. More recently, Baptiste and Altaf (2002) studied the heavy metals in some fresh water culture ponds of Chennai and observed the mercury levels to be very high. Mohan and Sharma (2002) studied trace metals in Lakhotia lake and Hemawas dam of Pali, Rajasthan and found that Pb, Cd and Ni concentrations to be high. Sudha Rani and Reddy (2003) studied the heavy metals in Hussain Sagar Lake in Hyderabad and observed that the concentration of Fe, Zn and Co was very high.

BIOLOGICAL AND EUTROPHICATION STUDIES

Most fascinating aspect of the lake related research in India is the database on biological aspects of tropical lakes. There are hundreds of studies on the biological aspects of the tropical and sub-tropical lakes covering wide range of water bodies ranging from a small ancient village pond to very large multipurpose manmade modern dams. Kashmir lakes, Kumaun lakes, Bhopal lakes, Sagar lake, Hyderabad lakes and Udaipur lakes are in particular extensively studied for their biological aspects thanks to the contribution of the various universities such as Kashmir Univ., Shrinagar; Osmania Univ., Hyderabad; Sagar Univ., Sagar; Barquat Ullah Univ., Bhopal and Sukhadia University, Udaipur etc. These studies cover a wide spectrum of subjects encompassing the

phytoplanktons, zoopalnktons, macrophytes, birds, fishes, productivity, energy transfer etc. To review and give an account of the biological studies is beyond the scope of this paper. Only some selected bibliography has been provided.

Studies have also been reported on eutrophication. Pant et al. (1980) studied the impact of human activities on eutrophication in Nainital lake. Sudan et al. (1984) conducted eutrophication studies for Lake Pichhola in Udaipur including its impact on the social and economic life. It was observed that the parts of city where the lake water is supplied has a higher incidence of water borne diseases. They have also suggested various measures to check the process of eutrophication. Rao and Durve (1989) studied the cultural eutrophication in Rangsagar lake in Udaipur and observed that the lake is highly polluted and eutrophic as revealed through planktonic community succession and limnochemical characterisitcs. Bhismkumar and Nachiappan (2000b) have studied the trophic status of the lake Nainital based on Carlson Index and found that the lake is in hypertrophic condition. Misra et al. (2001) assessed the trophic status of Bhopal lake using Nyagaard Index and concluded that the lakes were in advanced stage of eutrophy. Reddy et al.(2002) reported the studies conducted by NEERI on eutrophication of Hussain sagar lake and reported that the lake is in hypereutrophic condition. Rai et al. (2002) evaluated the trophic status of the Mansar and Surinsar lakes in Jammu based on the DO and planktonic forms and concluded that the lake is in eutrophic condition due to increased anthorpogenic activities. Khobragade (2004c) carried out assessment of trophic status of lake Pichhola based on various physico-chemical indices including the Carlson index. The lake is observed to be in hypertrophic status. Some of the other studies on eutrophication include Chaudhari et al. (2001), Mohan (1987c), Nirmal Kumar (1993) etc. Most of the reported eutrophication studies use biological indicators of trophic status such as algae or fish. Not many studies have been reported based on the data of chlorophyll and productivity. No attempt to model the process of eutrophicaton has been reported. Although a number of lakes have been reported to be in eutrophic to hypertrophic condition, hardly any studies on eutrophication control have been reported. Pani and Misra (2003) conducted studies on artificial aeration of Lower Bhopal Lake as a means of control of eutrophication and observed that method could be effectively used for improving the lake. Seshavatharam (1989) is known to have explored the possibility of control of eutrophication through bio-manipulation. The details are not available.

OTHER IMPORTANT STUDIES

Pant and Sharma (1978) studied the causes of fish mortality in Nainital lake. Das (1981) studied the ecological characteristics of high altitude lakes of Kumaun viz. Nainital, Bhimtal, Naukuchiatal, Sattal and Khurpatal etc. Various aspects such as history, geology, origin, catchment areas, physiography, mapping of nallahs causing pollution etc. have been described. Special biological indicators of pollution in Nainital lake have been reported. Causes and remedies for mass mortality of fish observed during winter were elucidated. Singh and Singh (1985) have analyzed limnological characteristics of some

Himalayan lakes with regard to fisheries potential. Some strategies have been suggested for development of fisheries based on this analysis. Zutshi (1985a) discussed a comparative limnology of nine lake ecosystems of Himalaya including their ecological problems. The degradation of these lake ecosystems, according to him, are due to unregulated tourist flow, development of tourist infra structure and opening of the terrestrial ecosystem, flow of human, animal, agricultural and industrial wastes into the lake waters, conversion of lakes into hydroelectric dams, siltation, invasion of exotic weeds and encroachment of the lake catchment area. Zutshi (1985b) studied the impact of human settlements on the ecology of three rural lakes of Kashmir viz. Khanpur, Trigam and Tilwansar to the west of Srinagar. The lakes were observed to show progressive signs of eutrophication. Highly erodible nature of soils and low rate of water renewal, being the major causes of accumulation of nutrients. Anonymous (1986) has described the cultural significance of Rewalsar lake in H.P. Batcha and Domodaran (1987) studied the impact of Idukki hydro electric project on the salinity regime of Vemband lake in Kerala. Anonymous (1987) reported effect of drought on fish catch from Kolleru Lake. Gundroo (1989a) has analyzed the various restoration and development plans for Dal lake. Gundroo (1989b) has also analyzed the environmental problems of Wular lake in Jammu and Kashmir along with their causes and given some preliminary suggestions for the restoration of the lake. Rao (1990) suggested some remedial measures to restore the Ooty lake. Khobragade (1992) prepared an inventory of some important lakes of India describing their physical features and environmental status. Unni (1993) reviewed the limnology of various ponds, lakes and reservoirs of M.P. and described their physico-chemical and ecological characteristics at length. Pandit (1993) has described the various features of the Dal Lake ecosystem based on the works of the various investigators on aspects of morphometry, physico-chemical characteristics of water and sediments, biological features, nutrient dynamics, energy flow and trophic status and suggested various measures for conservation of the lake. Singh and Sharma (1999) have described geo-environmental aspects of Mansar and Surinsar lakes of Jammu and Kashmir. Goyal and Srinivasulu (2001) prepared an inventory of water bodies in the Jammu and Kashmir using satellite data and SOI maps. Various aspects such as elevation, water spread area, perimeter of the water body have been estimated and reported. Thakural et al (2002) have described the hydro-geological characteristics of Sagar lake including hydro-meteorology, siltation and water quality aspects. Chari and Abbasi (2002) suggested strategies for conservation of Oussudu lake through the study of morphologic and hydrologic characteristics of the lake catchment. Abbasi (2003) studied the impact of land use changes on the palnktonik community of the Oussudu lake.

TRENDS, ISSUES AND CHALLENGES

A journey through the course of the lake research in India brings out that after the initial attempts at understanding the origin, geology and salinity of some lakes, lake research first concentrated on the biological aspects such as the fauna and flora. The

spectrum of lake studies slowly expanded thereafter and analysis of the physico-chemical characteristics of the lakes and their interaction with the biotic components gained momentum and even today, remains one of the most significant aspects of lake studies in India, as evident from some of the most recent works. Lake studies in India have always had a definite bio-limnological bias. This is understandably so, because most of the studies are credited to the biologists. As such, mostly the bio-chemical, eutrophication and pollution aspects of the lakes are reported. One significant observation is that although, many of the lakes in India are reported to be threatened environmentally, there are hardly any field investigations on lake restoration techniques. Similarly no systematic investigations have been reported on the long term trends in the quality as well as availability of water particularly in lakes of arid and semi-arid environments. Although its quite commonly quoted that the lake status is degrading on account of human interference in the catchment, no systematic quantification of the effect of human interference on hydrological regimes of lakes have been reported. Till recently, even the hydrological aspects of lakes were hardly addressed to. Only few scattered studies were reported on these aspects but compared to the total volume of lake studies, their number was very less. Its only in the 1990's that systematic hydrological investigations began. However, with a growing concern for conservation and proper management of lakes, the significance of lake hydrology is now being felt, as purely limnological or ecological approach is not going to suffice the need. As rightly pointed out by Ghosh (1992), "studies carried out so far mainly dealt with ecological, environmental and limnological aspects of the lakes. However, these are to be linked with the hydrological aspect of lakes along with other components, if lake based water resources developments are truly to be achieved". Systematic hydrological studies for some lakes are now being carried out, particularly by the National Institute of Hydrology, Roorkee since the last decade.

It is also noticed that lake research has concentrated in certain regions in India. In general, the natural lakes have received more attention than the artificial lakes. In the natural lakes, studies on lakes of Himalayas dominate and natural lakes elsewhere in India have not attracted the similar attention of investigators. Lakes of Kahmir Himalaya are by far the most extensively studied lakes in India. Dal Lake in Kashmir appears to be the most extensively studied lake of India, covering wide spectrum of subject matter. Number of studies have also been reported on lakes of Kumaun Himalaya (Uttaranchal). Studies on lake Nainital, in particular are numerous. Of the low altitude tropical lakes, studies have concentrated on some specific regions. Thus, lakes of Udaipur, Hyderabad, Mysore, Bhopal, Sagar etc have been relatively well studied. As far as other lakes are concerned, only sporadic and preliminary studies have been reported. In many cases, the various studies carried out on different lakes are scattered at different sources, often not easily accessible and there are only a few attempts to bring the various findings together for eg. Jheel Sanrakshan Samitee report (1996) etc.

The progress and quality of research depends upon the quality of data. Unfortunately the data availability scenario in India is not very encouraging. On-lake data required for

water balance, energy balance and mechanistic modelling studies are almost not available. Long term data collection programme needs to be planned for atleast some of the representative lakes. Depth-area-capacity curves, which are backbone of the many hydrological investigations, are not available for most lakes. Where they are available, they are very old. A good amount of water quality data have however been generated through many studies. Although, such data are very significant for further research on water quality and pollution aspects, the quality of data reported in many cases is very poor, as it does not indicate the other meta-data such as period of sampling (month or season) or year of data collection, sampling locations, methodology, supplementary data etc. For example DO data has not been supplemented with the required water temperature data in many cases. In water quality studies, samples collected at different places and different times give different results. It is desirable to standardize methodologies and procedures. Systematic data books may be prepared atleast for some lakes.

There are hundreds of lakes in India. Although eco-hydrological behaviour of each lake varies, it is not possible to practically study all the lakes. It is therefore necessary to group the various lakes into certain eco-hydrological classes so that results of studies on a lake of one group may be generalized for other similar lakes in that group. Classification systems need to be developed for the water bodies of India for specific purposes.

Modern techniques like remote sensing, GIS and isotope techniques etc. are finding increasing applicability in lake research the world over. Conventional methods in identification of recharge zones of lakes, and precise estimation of different components of water balance equations such as evaporation and sub-surface inflow and outflow, are not properly equipped. Isotope methods have contributed significantly to study and estimate these parameters with fair accuracy. Similarly, in situations where long term record of sediment data do not exist, as for most lakes in India, isotope techniques are the only way of estimating sedimentation rates. These techniques are also useful in finding out the sediment deposition patterns and in predicting the lake bed configuration and monitoring of suspended sediment concentration (Bhishm Kumar and Sinha, 1994). Similarly, remote sensing and GIS are proving as very important tools in studying various aspects such as erosion and sedimentation, non-point source pollution, catchment morphology, lake evaporation and catchment evapo-transpiration, eutrophication, mapping of land use changes in catchment, thermal studies, bathymetry etc. At present, only limited applications of these techniques have been reported in India. There is a need to popularize and encourage the use of these methods.

Lake research is a multidisciplinary subject involving various other scientific disciplines such as geology, physics, fluid mechanics, biology, environmental science, chemistry and hydrology etc. Even the lake hydrology part includes various frontiers of hydrology. For comprehensive understanding of the lake ecosystem and its behaviour, various above aspects need to be studied and interrelated. In India, a number of scientific and academic institutes, both governmental as well as non-governmental, are dealing with different aspects of lake research, but in isolation. Hence there is a need for a

coordinating agency to assimilate and integrate the various research findings and, to develop and standardize the methodologies for the Indian conditions etc. There is a need for a national consortium on lakes such as "National Lake Research and Development Authority".

CONCLUDING REMARKS

Many lakes in India are in lime light in recent years because of the problems they are facing. The number of such lakes, and the number of problems of these lakes are increasing. In many cases the problems are further aggravated by the improper or inadequate management techniques. So, the major goal of lake research in India should be the development of technical know-how to understand and overcome these problems. Present research perspective and the data availability, however, are practical constraints in this direction. Lake research in India also appears to lack clear-cut objectives and vision. Many studies appear to accomplish only academic interests. As such a long term strategy is needed to properly plan the research in lake hydrology in India. Keeping this overall background in mind, future research activities on lake hydrology in India need to address to the followings:

1. Generation and collection of systematic on-site hydrological, meteorological, ecological and other related data and its systematic storage and management. Creation of data banks for lakes.
2. Categorization of various lakes into definite eco-hydrological groups and select representative lake from each group for extensive research to develop generic methods applicable to other similar lakes.
3. Shift in research perspective from present ecological approach to an "Integrated Eco-Hydrological Approach" with definite vision, long term strategy, clear cut objectives and problem solving mode.
4. Standardization of methods particularly for water quality, eutrophication and pollution studies.
5. Assessment of the various major problems of the lakes in general along with specific problems for some individual lakes and systematic research efforts to understand their nature, causes, consequences and, to develop economically feasible and environment friendly technologies/methodologies and decision support systems, suitable to Indian conditions, for the restoration and management of lakes.
6. Increased use of advanced techniques such as isotope techniques, remote sensing and GIS etc
7. Coordination among the various lake related research organizations all over the country through creation of a 'National Consortium on Lakes'. Besides, it is also essential to transfer and spread the technical know-how to various field users and agencies through field interactions, conferences/seminars, training workshops etc. It is equally important to generate public awareness in lake conservation otherwise all the research efforts would be futile.

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